REVISIONS AND CORRECTIONS

AREA Proceedings, Volume 42 (1941)

Changes in the text for correction of typographical errors, and to take account of revisions, deletions and additions requested by committees in presenting their reports.

For revisions of matter submitted for adoption, see "Discussions."

Page 48, see Discussion, page 805 for revisions submitted by committee.

Page 49, see note above.

Page 102, under sub-head "Internal Treatment", sixth line, first word should be "sludge" instead of "scale".

Page 106, see Discussion, page 822 for revised list of committees.

Page 176, illustration on lower half of page is Fig. 5.

Page 237, under sub-head "Accelerated Weathering Tests", delete the words "called weatherometers" in the first line.

Page 276, under sub-section (d), add the factor "$9L$" to the denominator immediately under the factor "$10P$" in the numerator.

Page 356, in eighth line of the text, italic letter L under the radical should be lower case; following line should read: "l = length of stringer in span, in inches".

Page 358, under sub-head "Welding", sixth line, "n^s" should be "n_s^2".

Page 362, under Section (9), seventh line, delete the word "very".

Page 363, Assignment 3 should read: Non-Ballast Type Metal Floor for Steel Bridges.

Page 561, under sub-section 5. (a), the first word should be "Settling".

Page 574, second line, change "½-in." to "¾-in.".

Page 610, under sub-head "Loss of Bolt Tension", first line, change "1939" to "1938".

Page 634, under sub-head "Unloading", delete the words following the word "base" in the second line.

Page 635, fourth line, change "double-track" to "multiple-track".

Page 636, twelfth line, change "new" to "newly laid". In second line from the bottom of the page, change "chord and point" to "chord end point".

Page 637, see Discussion, page 844 for correction in table.

Page 658, first line of text should read "Subcommittee 4".

Page 1 (in Monograph section), in second line of sub-title, seventh word should be "before" instead of "by".

PROCEEDINGS

OF THE

FORTY-SECOND ANNUAL CONVENTION

OF THE

American Railway Engineering Association

HELD AT THE

PALMER HOUSE, CHICAGO, ILLINOIS

March 11, 12 and 13, 1941

VOLUME 42

CHICAGO

A

BOARD OF DIRECTION

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W. H. PENFIELD, Chief Engineer, Chicago, Milwaukee, St. Paul & Pacific Railroad, Chicago

Secretary

W. S. LACHER, 59 East Van Buren Street, Chicago

Assistant Secretary

FRANK MCNELLIS, 59 East Van Buren Street, Chicago

* Deceased, January 2, 1941.

† Mr. Smith was elected by the Board of Direction on November 15, 1940, to fill the vacancy caused by Mr. Faries' death on September 8.

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American Railway Engineering Association

CONSTITUTION

Revised to June 7, 1940

Article I

NAME, OBJECT AND LOCATION

1. Name

The name of this Association shall be the AMERICAN RAILWAY ENGINEERING ASSOCIATION.

2. Object

The object of the Association shall be the advancement of knowledge pertaining to the scientific and economic location, construction, operation and maintenance of railways.

3. Means to be Used

The means to be used for this purpose shall be:

(a) The investigation of matters pertaining to the object of the Association through Standing and Special Committees.

(b) Meetings for discussion of reports and papers.

(c) The publication of papers, reports and discussions.

4. Conclusions

The conclusions reached shall be recommendatory.

5. Location

The office of the Association shall be located in Chicago, Illinois.

Article II

MEMBERSHIP

1. Classes

The membership of this Association shall be divided into five classes: Members, Life Members, Honorary Members, Associates and Junior Members.

2. Qualifications

A. GENERAL

(a) An applicant to be eligible for membership in any class other than that of Junior Member shall be not less than twenty-five (25) years of age.

(b) To be eligible for election to or retention of membership as a Member or an Associate, a person shall not be engaged directly and primarily in the sale to railways of appliances, supplies, patents or patented services.

B. MEMBER

A Member shall be:

(a) An Engineer or Officer in the service or on the retired list of a railway corporation who has had not less than five (5) years' of experience in the location, construction, operation or maintenance of railways.

Graduation in engineering from a school of recognized standing shall be considered as equivalent to three (3) years of active practice, and the satisfactory completion of each year of work in such school, without graduation, shall be considered as equivalent to one-half year of active practice.

(b) A Professor of Engineering in a university or college of recognized standing.

(c) An Engineer or Member of a public board or commission who in the discharge of his regular duties deals with railway problems.

(d) An Engineering Editor of a magazine which deals primarily with railway matters.

C. Life Member

A Life Member shall be a Member who has paid dues for thirty-five (35) years, or who has been retired under a recognized retirement practice and has paid dues for not less than twenty-five (25) years.

D. Honorary Member

(a) An Honorary Member shall be a person of acknowledged eminence in railway engineering or management.

(b) The number of Honorary Members shall be limited to ten (10).

E. Associate

An Associate shall be:

(a) An Engineer of a railway which is essentially an adjunct of an industry or which is used primarily to transport the products and materials of an industry to and from a railway which is a common carrier.

(b) A person qualified by training and experience to co-operate with Members in the object of this Association but who is not qualified to become a Member.

F. Junior Member

(a) A Junior Member shall be not less than twenty-one (21) years of age and shall be an engineering employee of a railway corporation who has had not less than three (3) years of experience in the location, construction, operation or maintenance of railways.

Graduation in engineering from a school of recognized standing shall be considered as equivalent to three (3) years of active practice, and the satisfactory completion of each year of work in such school without graduation, shall be considered as equivalent to one-half year of active practice.

(b) His membership in this Association shall terminate at the end of the calendar year in which he becomes thirty (30) years of age.

(c) He may make application for membership other than as a Junior Member at any time when he becomes eligible to do so.

3. Transfers

The Board of Direction shall transfer from one class of membership to another, or may remove from membership any person whose qualifications so change as to warrant such action.

4. Rights

(a) Members and Life Members shall have all the rights and privileges of the Association.

(b) Honorary Members shall have all the rights and privileges of the Association except those of holding elective office, provided, however, that Members or Life Members who are elected Honorary Members shall retain all the rights and privileges of the Association.

(c) Associates and Junior Members shall have all the rights and privileges of the Association, except those of voting and holding elective office.

Article III

Admission, Resignation, Expulsion and Reinstatement

1. Charter Membership

The Charter Membership of this Association consists of all persons elected to membership before March 15th, 1900.

2. Application for Membership

(a) A person desirous of membership in this Association shall make application upon the form provided by the Board of Direction. In the event that Junior Membership is desired, the application shall so state.

(b) The applicant shall give the names of at least three Members of this Association to whom personally known. Each of such Members shall be requested by the Secretary of the Association to certify to a personal knowledge of the applicant with an opinion of the applicant's fitness or otherwise for membership.

(c) If an applicant is not personally known to three Members of this Association, the names of at least three well known persons engaged in railway or allied professional work to whom personally known shall be given instead. Each of such persons shall be requested by the Secretary of the Association to certify to a personal knowledge of the applicant with an opinion of the applicant's fitness or otherwise for membership.

(d) No further action shall be taken upon the application until replies have been received from at least three of the persons named by the applicant as references.

3. Election to Membership

(a) Upon completion of the application in accordance with Section 2 of this Article the Board of Direction through its Membership Committee shall consider the application and make such investigation as it may consider desirable or necessary.

(b) Upon completion of such consideration and investigation, each member of the Board of Direction shall be supplied with all the information obtained, together with the recommendation of the Membership Committee as to the class of membership, if any, to which the applicant is eligible and the admission of the applicant shall be canvassed by letter ballot among the members of the Board of Direction.

(c) In the event that an application has been made under the provisions of Section 2, Paragraphs (a) and (b) of this Article, a two-thirds affirmative vote of the entire Board of Direction shall be required for election.

(d) In the event that an application has been made under the provisions of Section 2, Paragraphs (a) and (c) of this Article, a unanimous affirmative vote of the entire Board of Direction shall be required for election.

4. Subscription to the Constitution

A person elected to membership in this Association shall subscribe to its Constitution on the form prescribed by the Board of Direction. If this provision has not been complied with within six months of notice of election the election shall be considered null and void.

5. Honorary Member

A proposal for Honorary Membership shall be endorsed by ten or more Members of the Association and a copy furnished each member of the Board of Direction. The nominee shall be declared an Honorary Member upon receiving a unanimous vote of the entire Board of Direction.

6. Resignation

The Board of Direction shall accept the resignation, tendered in writing, of any person holding membership in the Association whose obligations to the Association have been fully met.

7. Expulsion

Charges may be preferred in writing by ten or more Members against a person holding membership in the Association. The person complained of shall be served with a copy of such charges and shall be given an opportunity to answer them to the Board of Direction. After such opportunity has been given, the Board of Direction shall take final action. A two-thirds affirmative vote of the entire Board of Direction shall be required for expulsion.

8. Reinstatement

(a) A person having been a Member, an Associate or a Junior Member of this Association and having resigned such membership while in good standing may be reinstated by a two-thirds affirmative vote of the entire Board of Direction.

(b) A person having been a Member, an Associate or a Junior Member of this Association and having forfeited membership under the provisions of Article IV, Section 3, may, upon such conditions as may be fixed by the Board, be reinstated by a two-thirds affirmative vote of the entire Board of Direction.

Article IV

Dues

1. Entrance Fee

(a) An entrance fee of ten dollars ($10.00) shall be payable to the Association with each application for membership other than Junior Membership. This sum shall be returned to an applicant not elected.

(b) No entrance fee shall be payable to the Association on account of Junior Membership.

2. Annual Dues

(a) The annual dues for each Member and each Associate shall be ten dollars ($10.00).

(b) The annual dues for each Junior Member shall be five dollars ($5.00).

(c) Life Members and Honorary Members shall be exempt from the payment of dues.

3. Arrears

A person whose dues are not paid before April 1st of the current year shall be notified by the Secretary. If the dues are still unpaid on July 1st further notice shall be given and a delinquent Member shall lose the right to vote. If the dues remain unpaid October 1st the person shall be notified on the form prescribed by the Board of Direction, and shall no longer receive the publications of the Association. If the dues are not paid by December 31st, the person shall forfeit membership without further action or notice, except as provided for in Section 4 of this Article.

4. Remission of Dues

The Board of Direction may extend the time of payment of dues, and may remit the dues of any Member, Associate or Junior Member who, for good reason, is unable to pay them.

Article V

Officers

1. Officers

(a) The officers of the Association shall be a President, two Vice-Presidents, nine Directors, a Secretary and a Treasurer.

(b) The President, the Vice-Presidents and the Directors, together with the five latest living Past-Presidents continuing to be Members, shall constitute the Board of Direction, in which the government of the Association shall be vested, and shall act as Trustees and have the custody of all property belonging to the Association. The President, the Vice-Presidents and the Directors shall be Members.

(c) The Secretary and the Treasurer shall be appointed by the Board of Direction.

2. Term of Office

The term of office of the President shall be one year, of the Vice-Presidents two years and of the Directors three years. The term of each shall begin at the close of the Annual Convention at which elected and continue until a successor is qualified. All other officers and employees shall hold office or position during the pleasure of the Board of Direction.

3. Officers Elected Annually

(a) There shall be elected at each Annual Convention a President, one Vice-President and three Directors.

(b) The candidates for President and for Vice-President shall be selected from the members or past members of the Board of Direction.

4. Conditions of Re-election of Officers

A President shall be ineligible for re-election. Vice-Presidents and Directors shall not be eligible for re-election to the same office until at least one full term has elapsed after the end of their respective terms.

5. Vacancies in Offices

(a) When a vacancy occurs in the office of President the duties shall be performed by the senior Vice-President.

(b) When a vacancy occurs in the office of either Vice-President the Board of Direction shall select a Vice-President from among the Directors. A Vice-Presidency shall not be considered vacant when one of the Vice-Presidents is filling a vacancy in the Presidency.

(c) A vacancy in the office of Director shall be filled by the Board of Direction.

(d) An incumbent in any office for an unexpired term shall be eligible for re-election to the office held; provided however, that anyone appointed to fill a vacancy as Director within six months after the term commences shall be considered as coming within the provisions of Article V, Section 4.

6. Vacation of Office

(a) When an elected officer ceases to be a Member of the Association, as provided in Article II, the office shall be vacated.

(b) In case of the disability of or neglect in the performance of duty by an officer, the Board of Direction, by a two-thirds affirmative vote of the entire Board, shall have the power to declare the office vacant.

Article VI

Nomination and Election of Officers

1. Nominating Committee

(a) There shall be a Nominating Committee composed of the five latest living Past-Presidents of the Association, who are Members, and five Members who are not officers.

(b) The five Members who are not officers shall be elected annually for a term of one year, when the officers of the Association are elected.

(c) The senior Past-President who is a member of the Committee shall be the Chairman of the Committee. In the absence of the senior Past-President from a meeting of the Committee the Past-President next in seniority present shall act as Chairman.

2. Method of Nominating

(a) Prior to December 1st of each year the Chairman shall call a meeting of the Committee at a convenient place, at which nominees for the various elective offices shall be selected as follows:

Office to be Filled	*Number of Candidates to be named by the Nominating Committee.*	*Number of Candidates to be elected at the Annual Election of Officers.*
President	1	1
Vice-President	1	1
Directors	9	3
Nominating Committee	10	5

(b) The Chairman of the Nominating Committee shall send the names of the nominees to the President and Secretary not later than December 15th of the same year, and the Secretary shall report them to the members of the Association on a printed slip not later than January 1st following.

(c) At any time between January 1st and February 1st any ten or more Members may send to the Secretary additional nominations for any elective office for the ensuing year signed by such Members.

(d) If any person nominated shall be found by the Board of Direction to be ineligible for the office for which nominated, or should a nominee decline such nomination, the name shall be withdrawn. The Board of Direction may fill any vacancies that may occur in the list of nominees up to the time the ballots are sent out.

3. Ballots Issued

Not less than thirty days prior to each Annual Convention, the Secretary shall issue a ballot to each voting member of record in good standing, listing the several candidates to be voted upon. When there is more than one candidate for any office, the names shall be arranged on the ballot in the order that shall be determined by lot by the Nominating Committee. The ballot shall be accompanied by a statement giving for each candidate, his record of membership and activities in this Association.

4. Substitution of Names

Members may erase names from the printed ballot list and may substitute the name or names of any other person or persons eligible for any office, but the number of names voted for each office on the ballot must not exceed the number to be elected at that time to such office.

5. Ballots

(a) Ballots shall be placed in an envelope, sealed and endorsed with the name of the voter, and mailed to or deposited with the Secretary at any time previous to the closure of the polls.

(b) A voter may withdraw a ballot, and cast another, at any time before the polls close.

(c) Ballots not endorsed or from persons not qualified to vote shall not be counted.

(d) The ballots and envelopes shall be preserved for not less than ten days after the vote is canvassed.

6. Closure of Polls

The polls shall be closed at twelve o'clock noon on the second day of the Annual Convention, and the ballots shall be counted by tellers appointed by the Presiding Officer.

7. Election

(a) The persons who shall receive the highest number of votes for the offices for which they are candidates shall be declared elected.

(b) In case of a tie between two or more candidates for the same office, the Members present at the Annual Convention shall elect the officer by ballot from the candidates so tied.

(c) The Presiding Officer shall announce at the convention the names of the officers elected in accordance with this Article.

Article VII

Management

1. President

The President shall have general supervision of the affairs of the Association, shall preside at meetings of the Association and of the Board of Direction, and shall be ex-officio a member of all committees, except the Nominating Committee.

2. Vice-Presidents

The Vice-Presidents, in order of seniority, shall preside at meetings in the absence of the President and shall discharge the duties in case of a vacancy in the office.

3. Treasurer

The Treasurer shall receive all monies, deposit the same in the name of the Association, receipt to the Secretary therefor and invest all funds not needed for current disbursements as shall be ordered by the Board of Direction. The Treasurer shall pay all bills, when properly certified and audited by the Finance Committee, and make such reports as may be called for by the Board of Direction.

4. Secretary

The Secretary, shall be under the direction of the President and Board of Direction, the Executive Officer of the Association and shall attend the meetings of the Association and of the Board of Direction, prepare the business therefor, and duly record the proceedings thereof. The Secretary shall see that the monies due the Association are collected and without loss transferred to the custody of the Treasurer, and shall personally certify to the accuracy of all bills or vouchers on which money is to be paid. The Secretary is to conduct the correspondence of the Association, keep proper record thereof, and perform such other duties as the Board of Direction may prescribe.

5. Auditing of Accounts

The accounts of the Treasurer and of the Secretary shall be audited annually by an approved accountant under the direction of the Finance Committee of the Board of Direction.

6. Board of Direction

(a) The Board of Direction shall manage the affairs of the Association, and shall have full power to control and regulate all matters not otherwise provided in the Constitution.

(b) The Board of Direction shall meet within thirty days after each Annual Convention, and at such other times as the President may direct. Special meetings shall be called on request, in writing, of five members of the Board of Direction.

(c) Seven members of the Board of Direction shall constitute a quorum.

(d) At the first meeting of the Board of Direction after the Annual Convention, the following committees, each consisting of not less than three members, shall be appointed by the President from the Board of Direction and they shall report to and perform their duties under the supervision of the Board of Direction.

Finance
Publication
Outline of Work of Committees
Personnel of Committees
Membership
Manual

7. Duties of the Committees of the Board of Direction

(a) Finance Committee

The Finance Committee shall have immediate supervision of the accounts and financial affairs of the Association; shall approve all bills before payment, and shall make recommendations to the Board of Direction as to the investment of monies and other financial matters. The Finance Committee shall not have the power to incur debts or other obligations binding the Association, nor authorize the payment of money other than the amounts necessary to meet ordinary current expenses of the Association, except by authority of the Board of Direction.

(b) Publication Committee

The Publication Committee shall have general supervision of the publications of the Association. The Publication Committee shall not have the power to incur debts or other obligations binding the Association, nor authorize the payment of money except by authority of the Board of Direction.

(c) Committee on Outline of Work of Committees

The Committee on Outline of Work of Committees shall prepare and present to the Board of Direction a report of the subjects to be investigated, considered and reported upon by the standing and special committees of the Association during the ensuing year.

(d) Committee on Personnel of Committees

The Committee on Personnel of Committees shall prepare and present to the Board of Direction a list of chairman, vice-chairmen and members of the standing and special committees of the Association for the ensuing year.

(e) Membership Committee

The Membership Committee shall make investigation of applicants for membership and shall make recommendations to the Board of Direction with reference thereto.

(f) Manual Committee

The Manual Committee shall study and recommend to the Board of Direction as to the manner in which the material adopted for addition or deletion from the Manual shall be handled.

8. Standing Committees

The Board of Direction may appoint standing committees to investigate, consider and report upon questions pertaining to railway location, construction, operation and maintenance.

9. Special Committees

The Board of Direction may appoint special committees to examine into and report upon any subject connected with the objects of this Association.

10. Discussion by Non-Members

The Board of Direction may invite discussions of reports from persons not members of the Association.

11. Sanction of Act of Board of Direction

An act of the Board of Direction which shall have received the expressed or implied sanction of the membership at the next annual convention of the Association shall be deemed to be the act of the Association.

Article VIII

Meetings

1. Annual Convention

(a) The Annual Convention of the Association shall be held in the City of Chicago, Illinois. The convention shall open on a Tuesday in the month of March to be determined by the President.

(b) The Secretary shall notify all members of the Association of the time and place of the Annual Convention at least thirty (30) days in advance thereof.

(c) The order of business at the Annual Convention of the Association shall be:

Reading of the Minutes of the last meeting
Address of the President
Reports of the Secretary and the Treasurer
Reports of Committees
Unfinished Business
New Business
Installation of Officers
Adjournment

(d) This order of business may be changed by a majority vote of Members present.

(e) The proceedings shall be governed by "Robert's Rules of Order" except as otherwise herein provided.

(f) Discussions shall be limited to members and to those others invited by the Presiding Officer to speak.

2. Special Meetings

Special meetings of the Association may be called by the Board of Direction and special meetings shall be so called by the Board of Direction upon written request of thirty Members. The request shall state the purpose of such meeting.

The call for such special meeting shall be issued not less than ten (10) days in advance and shall state the purpose and place of the meeting. No other business shall be taken up at such meeting.

3. Quorum

Twenty-five (25) Members shall constitute a quorum at all meetings of the Association.

Article IX

AMENDMENT

1. Amendment

Proposed Amendment of this Constitution shall be made in writing, shall be signed by not less than ten Members and shall be acted upon in the following manner:

The amendment shall be presented to the Secretary, who shall send a copy to each member of the Board of Direction as soon as received. If a majority of the entire Board of Direction so votes the matter shall be submitted to the Association by letter-ballot.

The Board of Direction shall canvass the ballots which have been received within sixty days after the date of issue of the letter-ballot and if two-thirds (⅔) of the votes so received are in the affirmative the amendment shall be declared adopted and shall become immediately effective.

The result shall be announced at the next Annual Convention.

GENERAL INFORMATION

(Revised to March, 1941.)

GENERAL RULES FOR THE PREPARATION, PUBLICATION AND CONSIDERATION OF COMMITTEE REPORTS

(A) Appointment of Committees and Outline of Work

Standing Committees

1. The following are Standing Committees:

1. Roadway and Ballast.
3. Ties.
4. Rail.
5. Track.
6. Buildings.
7. Wood Bridges and Trestles.
8. Masonry.
9. Highways.
10. Signals and Interlocking.
11. Records and Accounts.
13. Water Service, Fire Protection and Sanitation.
14. Yards and Terminals.
15. Iron and Steel Structures.
16. Economics of Railway Location and Operation.
17. Wood Preservation.
18. Electricity.
20. Uniform General Contract Forms.
22. Economics of Railway Labor.
24. Cooperative Relations with Universities.
25. Waterways and Harbors.
26. Standardization.
27. Maintenance of Way Work Equipment.
28. Clearances.

Special Committees

2. Special Committees will be appointed from time to time, as may be deemed expedient, in the manner prescribed by Article VII, Section 9, of the Constitution.

The following are Special Committees:

Waterproofing of Railway Structures.
Impact.

Personnel of Committees

3. The personnel of all committees will continue from year to year, except when changes are announced by the Board of Direction. It is desirable that ten percent of the membership of each committee be changed each year.

Members of committees who do not attend meetings of committees during the year or render service by correspondence will be relieved and the vacancies filled by the Board at the succeeding annual convention.

Outline of Work

4. As soon as practicable after the reports of committees for the current year have been filed with the secretary, the Board of Direction will assign to the committees, subjects which in its judgment should preferably be considered during the succeeding year, provided, however, that such assignments may be subject to revision until the close of the Annual Convention. *Such assignments should not be deviated from except in extreme cases and then not until approved by the Committee on Outline of Work.*

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* Committee 12—Rules and Organization and the Special Committee on Stresses in Railroad Track have been discontinued by action of the Board of Direction. The Committee on Research Administration will supervise investigations on track stresses.

(B) Preparation of Committee Reports

General

5. The objectives of the Association are advanced through the work of the committees in two ways—(1) the development of useful information pertinent to their assignments to be presented to the Association "as information", and (2) the formulation of recommended practices to be submitted for adoption and publication in the Manual.

(a) Whether the report on any particular assignment should take the form of "information" or a "recommended practice", depends largely on the nature of the assignment. Some assignments will be fulfilled completely by the presentation of information; others call for information in support of appended recommendations that are submitted for adoption. In still other cases, the primary objective is a comprehensive statement of recommended practices, but the development of these recommended practices may entail investigation or research work, the results of which are of such importance as to warrant their presentation as information prior to the submission of the recommendations. In some cases, also, it may be advisable to submit as information matter in the form of recommended practice, with a view to inviting suggestions and criticisms that may serve as the basis for revisions prior to the resubmission of the matter for adoption a year later.

Planning the Work

6. In pursuing the work on any assignment, the first step is necessarily one of fact finding, including (a) a study of available literature on the subject, particularly reports of previous investigations, (b) a compilation of current practice, especially recent changes in practice, and (c) resort to original tests or experimentation, after a canvass of all other sources of information indicates that research work is necessary.

Collection of Data

(a) Committees are privileged to obtain data or information in any proper way. If desired, the secretary will issue circulars of inquiry, which should be brief and concise. The questions asked should be specific and pertinent, and not of such general or involved character as to preclude the possibility of obtaining satisfactory and prompt responses. They should specify to whom answers are to be sent, and should be in such form that copies can be retained by persons replying either by typewriter or blueprint.

(b) Requests for appropriations for the conduct of research work should be sent to the secretary with a supporting statement setting forth: (a) the nature of the information sought; (b) how the railroads are adversely affected by the lack of this information; (c) the estimated cost of the investigation; (d) the estimated time to complete the work; (e) the basis for assuming that the investigation will produce the data desired; and, (f) an estimate of the savings to be realized or other advantages to accrue from the successful completion of the investigations. A request for funds to continue or complete an investigation shall include a statement of the results obtained to date.

Reports

7. Committees should pursue their investigations on all assignments but are expected to present progress or final reports for publication only on those assignments regarding which pertinent information has been developed.

(a) Committees are privileged to present the results of any special study or investigation they may be engaged upon in connection with their assignments that may be considered of sufficient importance to warrant presentation.

(b) Reports of information, supplementing previous reports of progress, may include a brief review of matter previously presented, but should avoid extended repetition of such matter.

(c) Matter offered for adoption and publication in the Manual should be submitted in full, regardless of its publication in previous years unless the matter being offered appeared in identical form not more than one year before being submitted for adoption.

(d) Illustrations accompanying reports should, when possible, be prepared so that they can be reproduced on one page. The use of inserts should be avoided.

(e) One of the most important duties of each committee is to examine its own subject-matter in the Manual each year and submit such revisions of or supplements to the Manual as are deemed necessary to keep it up to date. New matter for publication in the Manual and revisions thereof must be submitted in the form and manner specified in the General Rules for Publication of the Manual.

Form of Reports

8. Committee reports shall be prepared in accordance with the Instructions published in the annual pamphlet of committee assignments and personnel.

(C) Publication of Reports

Dates for Filing and Publication of Reports

9. For the convenience of those attending the convention, the reports of committees to be presented at any session of the annual convention will be published, so far as possible, in the same bulletin. To carry out this plan requires a careful scheduling of the filing of reports and the publication of bulletins, and the arrangement of the convention program. It is of utmost importance that chairmen file complete reports of their committees on or before the dates specified on the schedule furnished them.

Written Discussions

10. Written discussions of published reports will be transmitted to the chairman of the interested committee who will read or present them by title or in abstract at the convention. Written discussions will be published in the Proceedings as a part of the discussion of the committee reports.

Verbal Discussions

11. Each speaker's remarks will be submitted to him in writing before publication in the Proceedings, for the correction of diction and errors of reporting, but not for the elimination of remarks.

(D) Consideration of Committee Reports

Sequence

12. The sequence in which committee reports will be considered by the convention will be determined by the Board of Direction.

Method

13. Reports offered as information will be presented by title or by a brief outline of the contents. Comments or criticisms may be offered from the floor upon invitation from the presiding officer.

14. Matter submitted for adoption and publication in the Manual may receive consideration by one of the following procedures:

(a) Reading by title.
(b) Reading, discussing and acting upon each conclusion separately.
(c) By majority vote, discussion will be had on each item. Clauses not objected to when read will be considered as voted upon and adopted.

Action on Reports

15. No formal action is to be taken by the convention on matter submitted as information, whether in the form of a progress or final report.

Action on matter submitted for adoption and publication in the Manual will be one of the following:

(a) Adoption as a whole as presented.
(b) Affirmative action on the amendment of a part or parts of the matter presented, followed by adoption as a whole, as amended.
(c) Adoption of a part, complete in itself, and referring of remainder back to the committee.
(d) Recommittal with or without instructions.

Note.—An amendment which affects underlying principles, if adopted, shall of itself constitute a recommittal of such part of the report as the committee considers affected.

The Chair will decline to entertain amendments which in his opinion are primarily a matter of editing.

(E) Publication of Abstracts by Technical Journals

The following rules will govern the releasing of matter for publication in technical journals:

Committee reports, requiring action by the Association at the annual convention, will not be released until after presentation to the convention; special articles, contributed by members and others, on which no action by the Association is necessary, are to be released for publication by the technical journals after issuance in the bulletin; provided, application therefor is made in writing and proper credit be given the Association, authors or committees presenting such material.

GENERAL RULES FOR PUBLICATION OF THE MANUAL

Title

1. The title of the volume will be "Manual of the American Railway Engineering Association."

2. The Board of Direction shall have the authority to withhold from publication any matter which it shall consider as not desirable to publish, or as not being in proper shape, or as not having received proper study and consideration.

Contents

3. The matter adopted by the Association for publication in the Manual shall be considered Recommended Practice, but shall not be binding on the members. Recommended Practice, as defined by the Board of Direction (May 20, 1936) is a material, device, plan, specification or practice recommended to the railways for use as required, either exactly as presented or with such modifications as may be necessary or desirable to meet the needs of individual railways, but in either event, with a view to promoting efficiency or economy, or both, in the location, construction, operation or maintenance of railways.

Requisites for Adoption

4. The Manual will include only such matter as has been made the subject of a special study by a standing or special committee and embodied in a committee report, published not less than thirty days prior to the Annual Convention, and submitted by the committee to the Annual Convention, and which, after due consideration and dis-

cussion, shall have been voted on and formally adopted by the Association. Subjects which, in the opinion of the Board of Direction shall be reviewed by the Association of American Railroads, may be referred to that association before being published in the Manual.

5. All conclusions included in the Manual must be in concise and proper shape for publication, as the Manual will consist only of a summary record of the definitions, specifications and principles of practice adopted by the Association, with a brief reference to the published Proceedings of the Association for the context of the committee report and subsequent discussion and the final action of the Association.

Revision

6. Any matter published in the Manual may be amended or withdrawn by vote at any subsequent Annual Convention, provided such changes are proposed in time for publication not less than thirty days prior to the Annual Convention, and in the following manner: (a) upon recommendation of the committee in charge of the subject; (b) upon recommendation of the Board of Direction; (c) upon request of five members, made to the Board of Direction.

7. Revisions of or additions to the Manual authorized by action at each convention will be published annually in the form of loose-leaf sheets which will be made available to all holders of the Manual. These supplemental sheets will be accompanied by instructions for insertion of the new sheets and the withdrawal of sheets that have been superseded, as well as those that have been withdrawn by action of the Association.

Report of Committee 26—Standardization

F. L. Nicholson, *Chairman,*
J. E. Armstrong
F. L. C. Bond
A. E. Botts
John Foley
W. H. Penfield
W. G. Arn
L. H. Laffoley
H. M. Church
J. F. Leonard
J. G. Brennan
H. G. Morgan
C. A. Knowles
W. T. Dorrance
B. W. DeGeer
C. H. Mottier
R. A. Van Ness
H. M. Stout
H. R. Duncan*
H. F. Brown
W. G. Nusz
G. M. O'Rourke
G. P. Palmer
G. R. Westcott
Dr. A. N. Talbot
A. R. Wilson
J. A. Lahmer
J. B. Hunley

Committee

* Appointed to succeed C. F. Ford, chairman of Committee 17—Wood Preservation, who died on June 9, 1940.

To the American Railway Engineering Association:

Your committee reports on the following assignments:

1. What AREA recommended practices should be advocated for general use on railways?

Your committee submitted to the membership at the 1940 convention a tabulation of recommended practices and urged their adoption insofar as possible by the railroads represented in the Association. Such use, it is believed, will result in economies in construction and maintenance and most satisfactory performance.

The committee makes no additional recommendations at this time.

2. What AREA recommended practices should be sponsored as subjects for national standardization?

The recommended practices as adopted and printed in the Manual are largely for the benefit of the railroad industry, and with possibly few exceptions are not subjects to be sponsored for national standardization through the American Standards Association or like organizations.

The committee has no recommendations to make at this time.

3. Maintain contact with standardization bodies and keep the Association informed on important matters developed by such contact.

The interests of this Association are cared for by duly appointed representatives to these national organizations. The committee furnished to the members in its report at the 1940 convention, a list of members representing this Association on the committees of the American Standards Association and on the committees of the American Society for Testing Materials.

The changes during the year in representation on committees of the American Standards Association are as follows:

ASA Projects:

B1 —Screw Threads, Standardization and Unification of,
Committee 4—Rail (C. & M. Section)†
C. B. Bronson appointed representative to replace J. V. Neubert, deceased

† As this representation is sponsored by the AAR, the AREA committees are designated as representing the Construction and Maintenance Section.

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A

B18—Bolt, Nut and Rivet Proportions
    Committee 4—Rail (C. & M. Section)
        C. B. Bronson appointed representative to replace J. V. Neubert, deceased; R. T. Scholes appointed alternate to succeed J. B. Myers
    Committee 15—Iron and Steel Structures (C. & M. Section)
        O. E. Selby appointed to replace P. G. Lang, Jr., deceased

The representation of the AAR on Standards Council of the American Standards Association has been changed as follows:

Principals

A. R. Wilson (Engineering Division), term extended to December 31, 1942

Alternates

A. L. Sorensen (Purchases and Stores Division) replaces C. B. Tobey
J. D. Rogers (Operating—Transportation Division) appointed

The Canadian Engineering Standards Association, through Mr. W. R. McCaffrey, its secretary, reports the publication during the year of new standards or revisions of existing standards, as follows:

A5 —1940—Portland Cement (3rd Edition)
A57—1940—High Early Strength Portland Cement (included in A5—1940)
B12—1939—Galvanized Steel Wire Strand (2nd Edition)
B53—1939—Code for Identification of Piping Systems
C14—1939—Reinforced Concrete Poles (2nd Edition)

The following standards have been the subject of discussion by appropriate committees during the past year and such progress has been made that it is anticipated revised standards will be published during the year, as follows:

A1 —1928—Steel Railway Bridges (Revision)
A16—1930—Steel Structures for Buildings (Revision)
    (New edition will be S16—1940)
A23—1929—Concrete and Reinforced Concrete (Revision)
S59 —Metallic Arc Welding (Bridges and Buildings)

The American Society for Testing Materials, through Mr. C. L. Warwick, secretary, reports the following changes:

Committee A5 on Iron and Steel
    AREA Committee 13—Water Service, Fire Protection and Sanitation
        Ray McBrian appointed to replace J. J. Laudig as representative; W. L. Curtiss appointed alternate

Committee C9 on Concrete and Concrete Aggregates
    AREA Committee 8—Masonry
        C. P. Marsh appointed representative to succeed W. K. Hatt

Committee D7 on Timber
    AREA Committee 17—Wood Preservation
        Add Dr. Hermann von Schrenk, to correct error of omission in last report to the Association

Committee C4 on Clay Pipe
    AREA Committee 1—Roadway and Ballast
        Add W. C. Swartout, appointed

The report of Committee A1 on Steel presented at the 1940 annual meeting included five new tentative specifications—one on factory-made wrought carbon-steel and carbon-molybdenum-steel welding fittings, and four covering carbon and alloy-steel forgings, respectively, for general industrial and railroad use. An addition was made in the carbon-steel specifications for general industrial use providing a grade for use in bridges with a minimum tensile strength of 66,000 lb. per sq. in., and a yield point of 33,000 lb. per sq. in.

Committee C1 on Cement recommended new specifications for Portland cement comprising five types. These include one for use in general construction, another for high early strength, one for use when a low heat of hydration is required, one for use when high sulfate resistance is required, and one for use when special properties of the three latter types are not required. It is expected that the new tentative standard will replace the present Standard Specifications for Portland Cement (C9—38) and for High Early Strength Portland Cement (C74—39).

This report is submitted as information.

THE COMMITTEE ON STANDARDIZATION,
F. L. NICHOLSON, *Chairman*.

Report of Committee 18—Electricity

H. F. Brown, *Chairman,*	W. L. Morse	D. B. Thompson, *Vice-Chairman,*
D. J. Brumley	R. J. Needham	W. M. Vandersluis
D. M. Burckett	S. R. Negley	R. P. Winton
F. W. Gardiner	A. E. Owen	
Paul Lebenbaum	H. W. Pinkerton	*Committee*

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Developments in the application of electricity to railway service.

Progress report, presented as information below.

2. The principal current activities of the Electrical Section, Engineering Division, AAR, by synopsis, supplemented with list and reference by number of adopted specifications, designs and principles of practice.

Progress report, presented as information .... page 29.

The Committee on Electricity,
D. B. Thompson, *Vice-Chairman.*

Report on Assignment 1

Developments in the Application of Electricity to Railway Service

During the past year there have been very few new developments. There has, however, been a widening of the usefulness of previous development, thereby providing the railroads with several more ways in which electricity can be made to serve them.

For electrified roads using direct current, the ignition rectifier is proving an efficient and desirable conversion unit.

The recently developed air-blast circuit breaker and other makes of breakers in which the arc is interrupted in air (thus obviating the use of any insulating oil) should be of interest on railroads where heavy alternating currents must be handled.

Plate type rectifiers for quiet and efficient battery charging are being favorably received. They are available in portable and stationary types for charging batteries on shop and baggage trucks, and on passenger cars. In addition, small units have been developed for mounting underneath passenger cars.

The a.c. transformer type welder is finding broad fields of usefulness in railroad shops for many classes of work.

Lowered cost of lamps and accessories, plus lengthened lamp life, has increased the advantages of fluorescent and high intensity mercury vapor lighting. Improved illumination with lower power consumption makes it well suited for use in offices, stations, shops and passenger cars. Lamps for 64-volt d.c. operation are now available, and improved inverters are furthering the use of 110-volt a.c. units on passenger cars.

For greater passenger comfort, electrically refrigerated drinking water coolers are now available in several different types for installation on passenger cars.

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Floodlighting, which has long been used in railroad yards, is now being applied to highway grade crossings in an effort to further reduce accidents.

The severe weather that was experienced in many localities last winter has shown the need for a more extensive use of tubular type track switch heaters. They have been remarkably successful in keeping important interlockings free from trouble due to frozen switch points.

In the field of switching engines, the Diesel-electric switching locomotive has demonstrated its merits from the standpoint of both economy and availability.

Where fine dust or pollen is objectionable, the electrostatic air cleaner is efficient and may prove a desirable adjunct to air conditioning systems in offices and restaurants.

The use of rubber either in the form of molded material or rubber coating of metal, is being promoted in connection with the insulation of third rails and running rails for the purpose of preventing electrolytic action as well as to provide voltage protection. There seems to be a considerable field and a demand for this form of rubber insulation and future studies and developments will result in a more general use.

Report on Assignment 2

The Principal Current Activities of the Electrical Section, Engineering Division

The reports of the committees of the Electrical Section, Engineering Division, have been published in Bulletin 419, September–October, 1940, and are therefore merely summarized here.

Power Supply.—In general, the assignments to this committee cover the relative economy and advantages of Diesel-electric power and purchased power; electrical power supply design for air conditioning and battery charging service; consolidation of metering, and form of contract for the purchase of electrical energy for other than traction purposes, as well as to study the feasibility of a standard electric power supply for electric traction.

Electrolysis.—The purpose of this committee is to report on the various practices of electrified railroads in preventing leakage of stray currents through the foundations and guys of catenary supported structures; to report on the electrolytic corrosion of insulation hardware; to study the methods used on various railroads and other utilities for handling their electrolysis problems in regard to organization, period of surveys and equipment used; to report on the methods of protection applied to foreign cables and other similar structures where they enter the railroad right-of-way.

Electric Heating and Welding.—The committee report covers the use of thermal pliers for producing low-voltage high-amperage current from standard a.c. distribution circuits. They find their principal use in localized heating, such as sweating terminal lugs and copper tubing joints. The committee also reports on the comparative advantages and disadvantages of a.c. 60-cycle and 180-cycle, and d.c. rectifiers, motor generators and other equipment and methods of control used in welding. There is also a report on recent developments in snow melting equipment and its installation, as well as a report on the prevention of the formation of sleet on transmission wires.

Application of Motors.—This is a report of a joint committee comprised of representatives of the Electrical sections of the Mechanical and Engineering divisions. It covers the inspection and maintenance of motors, as well as repair shop practice; a report on alternating-current commercial electric motor characteristics; motor control for various types of equipment and the design of motor supply circuits.

Clearances for Third-Rail and Overhead Working Conductors.—This committee has prepared a clearance diagram, entitled Clearance Lines for Pantograph, Catenary Construction and Adjacent Permanent Way Structures. The diagram presented last year as information was presented in revised form at the annual meeting of the Electrical Section on October 29, 1940, and, in accordance with action taken, will be submitted to the Member Roads for letter ballot approval.

Track and Third-Rail Bonds.—This is a progress report presented as information only, and includes a study of detail bond design with the view of developing specifications for welded bonds; information concerning rail joint clearance and its effect on rail bond design, including experience with various types of bonds; and a report on various methods of welding, using gas or electricity, or by brazing, types of electrodes and their chemical composition, best suited to each method.

Illumination.—The committee report touches on fluorescent lighting for offices, drafting rooms, etc., and also on the availability and types of drying lamps which were discussed last year under the caption "Heating Lamps".

High Tension Cables.—The report contains information concerning the selection, handling and maintenance of high tension cables.

Application of Corrosion-Resisting Materials to Railroad Electrical Construction.—The report of this committee covers a continuation of the study of corrosion-resisting materials as installed at Lambert Point on the Norfolk & Western Railway, with a view of obtaining qualitative and quantitative data on the service life of various metals.

In conclusion, attention is directed to the interest shown by the various committees in the effort being made to avoid duplication in the work of different sections of the AAR concerned with the use of electricity. The committees have collaborated with various committees of other sections for the purpose of avoiding such duplication as well as obtaining valuable suggestions from other sections interested in the same subject.

Report of Committee 10—Signals and Interlocking

H. G. Morgan, *Chairman*,
F. H. Bagley
G. H. Dryden
W. J. Eck
W. H. Elliott
P. M. Gault
W. N. Hartman
C. R. Hodgdon
J. C. Mock
R. D. Moore
F. W. Pfleging
W. M. Post
A. H. Rudd
J. E. Saunders
H. H. Orr, *Vice-Chairman*,
H. L. Stanton
E. G. Stradling
G. K. Thomas
C. H. Tillett
W. M. Vandersluis
F. B. Wiegand
Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Developments in railway signaling.

No report; no developments worthy of mention have taken place since the annual meeting in 1940.

2. The principal current activities of the Signal Section, AAR, by synopsis, supplemented with list and reference, by number, of adopted specifications, designs and principles of practice.

Progress report—presented as information.

The Committee on Signals and Interlocking,
H. G. Morgan, *Chairman*.

Report on Assignment 2

The Principal Current Activities of the Signal Section, AAR, by Synopsis

Supplemented With List and References by Number of Adopted Specifications, Designs and Principles of Signaling Practice

W. M. Post (chairman, subcommittee), G. H. Dryden, W. J. Eck, J. C. Mock, W. N. Hartman, C. H. Tillett.

Current Activities of the Signal Section, AAR, Since November 1939

There are now available 23 of a series of 24 pamphlets on American Railway Signaling Principles and Practices, prepared for the education of signal men and others desiring to study this subject.

The work performed during the fiscal year of 1939 and reported at the 1940 Annual Meeting covers the following subjects:

1. Costs involved in stopping trains—progress report.
2. Costs (other than fuel and water) involved in stopping trains.
3. Additions and revisions to Chapter III—Principles and Economic Phase of Signaling.
4. Economy in signaling construction and maintenance costs by using 78-ft. rails instead of 39-ft. rails.

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5. Economy of slide detector fences.

6. Train operation by signal indication.

7. Economic value of car retarders—progress report.

8. Economic value of electrically lighted lamps.

9. Mechanical facing point locks for spring switches—progress report.

10. Protection of traffic against slides and rock falls.

11. Switch, frog and crossing layout plans—collaborating with AREA Committee 5.

12. Summary of automatic train control and automatic cab signals in the United States as of January 1, 1940.

13. Applications to the Interstate Commerce Commission for modification of signals, etc.

14. Hearings before the Interstate Commerce Commission.

15. Activities of radio communication for railroad purposes—cooperative report.

16. Interstate Commerce Commission rules, standards and instructions for installation, inspection, maintenance and repair of automatic block signal systems, interlocking, centralized traffic control systems, automatic cab signal systems continuously controlled, dragging equipment and slide detectors and other similar protective devices; other similar appliances, methods, and systems.

17. Devices and methods to control automatic signals or special signals for the protection of traffic against high water at vulnerable points and fires at bridges and trestles.

18. Possibility of hazard or false operation resulting from the use of rail fissure detector cars and recommended protective measures.

19. Protection against lightning—progress report.

20. Development of proposed inductive coordination measures involving railroad power lines and power equipment—progress report.

21. Tables showing capacity available in various types of storage and primary batteries at solution temperatures ranging from zero degree to 100 deg. F.

22. Electric insulating materials in general—cooperative report.

23. General classification for signal interruptions.

24. Illumination of crossings.

25. Corrective measures to minimize or eliminate phantom indications of flashing light signals.

26. Modifications of the National Electrical Safety Code to avoid confliction with recognized signal practice.

27. Noteworthy changes in signal practices.

Revised Specifications Submitted to Letter Ballot

	Old No.	*New No.*
Channel Pins	23–39	23–40
Installation of Made Ground for Protection Against Abnormal Potentials	60–39	60–40
Electric-Pneumatic Interlocking	6733	67–40
Signal Glasses (exclusive of kerosene hand lantern globes).......	69–39	69–40
Multiple-Conductor Rubber-Insulated Cable with Weather-Resistant or Flame-Retarding Braid Covering	89–39	89–40
Multiple-Conductor, Rubber-Insulated, Submarine Cable, Lead Sheathed and Round Steel Armored	90–39	90–40
Single and Multiple-Conductor, Rubber-Insulated Lead Sheathed Cable	91–39	91–40

	Old No.	New No.
Zero-Degree Fahrenheit Lubricating Oil, Summer Grade	102–39	102–40
Forty-Five Degrees Below Zero Fahrenheit Lubricating Oil, Winter Grade	103–39	103–40
Single-Conductor, Rubber-Insulated Wire and Cable with Flame-Retarding, Moisture-Resistant Braid Covering or Weather-Resistant Braid Covering	111–39	111–40
Paint and Painting	120–39	120–40
Circuit Controller for Drawbridges	130–39	130–40
Track Circuit Rail Bonding	135–39	135–40
Single and Multiple-Conductor, Rubber-Insulated, Lead-Covered Parkway Cable Armored with Flat Steel or Zinc Tape	145–39	145–40
Car Retarder System	147–35	147–40
Electro-Pneumatic Switch Operating Mechanism	152–39	152–40
Railroad Highway Grade Crossing Signs	155–39	155–40
Reflector Unit	156–39	156–40
Single and Multiple-Conductor, Rubber-Insulated, Non-Metallic Sheath Cable	161–39	161–40
Tractive Armature Direct-Current Polarized Relay	165–39	165–40
Copper-Covered Steel Line Wire with or without Weather-Resistant Covering	167–39	167–40
Copper Alloy Line Wire with or without Weather-Resistant Covering	168–39	168–40
Hard-Drawn Copper Line Wire with or without Weather-Resistant Covering	169–39	169–40
Interlocking at Drawbridges for the Protection of Train Movements	175–38	175–40
Weather-Resistant Braid Covering for Insulated Wire and Cable	182–39	182–40
Enameled Round Copper Magnet Wire	193–40	......
Copper-Bearing Steel Line Wire with or without Weather-Resistant Covering	196–40	.....*

* (Old title Specification for Galvanized Copper Bearing Steel Line Wire.)

Revised Drawings Submitted to Letter Ballot

Pipe Adjusting Screws (details and assembly)	1002	1002B
Forged Cranks (details)	1007	1007B
Screw and Solid Jaws (details)	1016B	1016C
Jaws—Tang End and Adjustable Link (details and assembly)	1019B	1019C
Multiple Unit Terminal Block	1054A	1054B
Ball Studs (details and assemblies)	1254A	1271A
Ball Socket Screw Jaw	1254A	1272A
Switch Circuit Controller Lug	1255C	1255D
Switch Circuit Controller Rods	1256A	1256B
Plunger Switch Lock—Rectangular Plunger	1425C	1425D
Plunger Switch Lock-Details—Rectangular Plunger	1426C	1426D
Highway Crossing Gate and Slow Track Sign Lamp Hangers	1496	1496B
Method of Applying Compensation	1536	1536B
Highway Crossing Signal Assembly—Wig-Wag Type	1651B	1651C
Highway Crossing Signal Assembly—Wig-Wag Type	1652B	1652C
Highway Crossing Signal Assembly—Flashing Light Type	1653B	1653C

	Old No.	*New No.*
Highway Crossing Signal Assembly—Flashing Light Type.......	1654B	1654C
Highway Crossing Flashing Light Signal Assembly—Cantilever Type	1686A	1686B
Highway Crossing Sign—50-Deg. Reflector Type	1691A	1691B

Revised Requisites Submitted to Letter Ballot

Automatic Block Signaling Circuits
Automatic Block Signaling Systems (Old title Requisites for Automatic Block Signal System)
Centralized Traffic Control. (Old title Requisites for Centralized Traffic Control System)
Highway Grade Crossing Signals
Interlocking (Consolidation of old Requisites for Interlocking System, and Requirements for the Protection of Traffic at Movable Bridges)
Mechanically Locking the Levers of Interlocking Machines
Minimizing the Effect of Foreign Current on Direct-Current Track Circuits
Track Welding or Heat Treating in Track Circuit Territory

Revised Instructions Submitted to Letter Ballot

Alternating-Current Relays (Old title Instructions for Inspecting, Testing and Maintaining Alternating-Current Relays)
Alternating-Current Track Circuits (Old title Instructions for Maintenance and Operation of Alternating-Current Track Circuits)
Car Retarder Systems (Old title Instructions for Maintaining and Testing Car Retarder Systems)
Copper-Oxide Caustic Soda Primary Cells (Old title Instructions for Installation and Maintenance of Copper-Oxide Caustic Soda Primary Cells)
Direct-Current Track Circuits (Old title Instructions for Maintenance and Operation of Direct-Current Track Circuits)
Electric Lamps (Old title Instructions for Maintaining and Testing Electric Lamps)
Insulated Rail Joints (Old title Instructions for Inspecting, Testing and Maintaining Insulated Rail Joints)
Insulation Resistance (Old title Measurement of Insulation Resistance)
Interlocking (Consolidation of old Instructions for Maintaining and Testing Interlocking Plants; Signal Maintenance; and Inspecting and Testing Mechanical Locking of an Interlocking Machine)
Light and Motor Semaphore Signals (Consolidation of old Instructions for Maintaining and Testing Motor Semaphore Signals, and Maintaining and Testing Light Signals)
Rectifiers and Motor-Generators (Old title Instructions for Maintaining and Operating Rectifiers)
Resistance of Made Grounds (Old title A.R.A. Sig. Sec. 1377B—Methods of Measuring Ground Resistance)
Spring Switches (Old title Instructions for Maintaining, Inspecting and Testing Spring Switches)
Storage Batteries (Consolidation of old Instructions for Installation, Maintenance and Operation of Nickel, Iron, Alkaline Storage Batteries, and Installation, Maintenance and Operation of Lead Acid Type Storage Batteries)
Switch Circuit Controllers (Old title Instructions for Inspecting, Testing and Maintaining Switch Circuit Controllers)

Tractive Armature Direct-Current Relays (Old title Instructions for Inspecting, Testing and Maintaining Direct-Current Relays)
Wire and Cable (Old title Instructions for Handling Insulated Wires and Cables)

Revised Miscellaneous Matter Submitted to Letter Ballot

Definition for Technical Terms Used in Signaling
Form of Agreement for Interlocking Plant
Joint Signal Facilities—Construction Cost Detail
Performance Report—Automatic Highway Grade Crossing Protection—A.A.R. Sig. Sec. 7054
Stringing Tensions for New Suspension Strand with Various Sizes of Cables (Old title Recommended Sags for Messenger Wire)

New Specifications Submitted to Letter Ballot

	No.
Air Depolarized Carbon Caustic Soda Primary Cell	172–40
Fusible Asphaltic Base Sealing Compound for Protecting Wire Entrances, Outlets, Sleeves, Potheads, etc., Against the Entrance of Moisture	184–40
Cold Application Compound for Closing Wire Entrances and Openings	188–40
Tantalum Rectifiers and Valves	189–40
Flashing Light Signal Lamp Unit	190–40
Flame-Retarding, Moisture-Resistant Braid Covering for Insulated Wire and Cable	191–40
Single-Conductor, Asbestos Varnished-Cambric Insulated Signal Wire with Flame-Retarding Braid Covering	192–40
Cotton-Covered Round Copper Magnet Wire	194–40
Silk-Covered Round Copper Magnet Wire	195–40
Metal Plating	......
Various Types of Steel	......

New Drawings Submitted to Letter Ballot

Electric Hand Lantern	1346A
Porcelain Covers (Air Depolarized Primary Battery)	1417A
Base for Five-Inch Mast	1447A
Base for Five-Inch Mast	1448A
Crossing Gate Arm	1491A
Electric Hand Lantern Lens	1609A

New Requisites Submitted to Letter Ballot

A.C. and D.C. Coded Signal Systems
Fence for the Protection of Traffic Against Slides and Rock Falls

New Instructions Submitted to Letter Ballot

Automatic Block Signaling Systems
Electric Locks for Interlocking Machines

Specifications Submitted to Letter Ballot for Removal from the Manual

	No.
Galvanizing for Iron or Steel	......
Weatherproof Covering for Line Wire	163–39

Drawings Submitted to Letter Ballot for Removal from the Manual

	No.
Method of Laying Single and Sewer Pipe Duct	1331
Duct Reducers, Mandrels, Duct Plugs and Dowel Pins	1332
Manhole Frame (Ten Inches High) and Cover	1333
Cable Hanger Sockets, Sewer Steps and Manhole Clevis	1334
Vitrified Clay Duct	1335
Method of Laying Single and Multiple Duct	1336
Concrete Manhole	1337
Brick Manhole	1338
Manhole Frame (Four Inches High) and Cover	1339
Adjustable Resistance (for Testing)	1422A

Requisites Submitted to Letter Ballot for Removal from the Manual

Protection by Signal in Emergencies
Switch Indicators

Instructions Submitted to Letter Ballot for Removal from the Manual

Maintaining and Handling Dry Cells
Installation and Operation of Switchboard

Miscellaneous Matter Submitted to Letter Ballot for Removal from the Manual

Table of Wires Required for Stranded and Flexible Conductors

Report of Committee 20—Uniform General Contract Forms

W. G. Nusz, *Chairman*,
E. H. Barnhart
Clark Dillenbeck
W. D. Faucette
J. P. Hanley
B. Herman
N. D. Hyde
F. R. Layng
S. L. Mapes
A. A. Miller
O. K. Morgan
F. L. Nicholson
J. S. Lillie, *Vice-Chairman*,
C. B. Niehaus
H. A. Palmer
W. M. Post
W. R. Swatosh
E. L. Taylor

Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

At the request of the Electrical Section of the Engineering Division, a subcommittee of Committee 20 has been collaborating with Committee 1—Power Supply of the Electrical Section in a comparison of the Form of Agreement for the Purchase of Electrical Energy for Other than Traction Purposes (Manual page 20–101) with a tentative form drawn up by the Committee on Power Supply, but it was deemed desirable to continue the study before proposing any revision of the form now in the Manual.

2. Form of agreement for commercial signs on railway property.

A tentative form of this agreement was submitted at the last convention of the Association. All suggestions received have been considered and the committee now presents a form of agreement for adoption as recommended practice.............. page 39

3. Form of lease for air-right development.

No report. The committee has given this a great deal of study over the last two years but is unable at this time to present a form of lease.

4. Form of agreement for wire or cable line crossings, collaborating with Committee 3—Overhead Transmission Line and Catenary Construction, Electrical Section, Engineering Division, AAR.

The committee has nothing to report on this assignment at the present time. Suggestions received from the Rural Electrification Authority for revisions of the form adopted by the Association on March 12, 1940, are being considered.

5. Form of agreement for unloading liquefied petroleum and other gases.

This contract was prepared at the request of the Association of American Railroads to provide protection for handling these commodities. A form of agreement is submitted for adoption as recommended practice...................................... page 41

The Committee on Uniform General Contract Forms,
W. G. Nusz, *Chairman*.

James C. Irwin

Committee 20 cannot close its transactions for the year without recording with the deepest regret the death of Past-President James C. Irwin, at Newtonville, Mass., March 20, 1940.

Those who have had the opportunity of serving on Committee 20 during the past quarter of a century were endeared to Mr. Irwin and have lost in his passing a friend

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and counselor whose achievements were many and whose position and work were a living example to be followed by the members of the Association.

James Clark Irwin was born on September 23, 1868, at Cheyney, Delaware County, Pa., the son of William Henry and Catherine (Browning) Irwin. He attended the Protestant Episcopal Academy at Philadelphia and was graduated from the University of Pennsylvania in 1890 with the degree of Bachelor of Science and, in 1891, received the degree of Civil Engineer from the same university.

He is survived by his wife; three sons, James C., Robert M., and John, and one daughter, Katharine. Another son, William H., died in 1923, following military service in the World War.

In 1892, Mr. Irwin entered railroad service with the New York Central System and was continually in the service of this railroad and its affiliated lines until his retirement, during which period he held the positions of assistant transitman, assistant superintendent of signals, division engineer, signal engineer, assistant to general superintendent, engineering assistant on staff of vice-president, resident engineer and superintendent of construction, office engineer, chief engineer (Rutland Railroad) and valuation engineer (Boston & Albany Railroad), holding the last named position until his retirement on October 1, 1938.

Mr. Irwin was a member of the American Society of Civil Engineers; the American Standards Association; the Signal Section, Engineering Division, AAR; and the American Railway Engineering Association, in addition to other important organizations. He held many responsible positions in these societies and as a member of the AREA he served on the Committee on Uniform General Contract Forms (1909–1940), as vice-chairman (1910–1913), inclusive, and 1923–1926, inclusive, and as chairman from 1927 to 1931, inclusive; on Committee 26—Standardization (1927–1930) and as chairman from 1931 to 1935, inclusive; on Committee 12—Rules and Organization, as vice-chairman (1939–1940); as director of the Association from March, 1932 to March, 1935; vice-president from March, 1935 to March, 1937; and as president in 1937–1938, as well as chairman, General Committee, Engineering Division.

In addition to the engineering societies of which he was a member, Mr. Irwin was identified with many other organizations and for 15 years he was active in St. John's Church (Episcopal), Newtonville, Mass., as vestryman, junior warden or senior warden.

Mr. Irwin's energy, interest, personality, ability and kindly disposition won for him a host of friends who could not fail but be impressed with his high standards of life, his earnestness and sincerity in all that he undertook and his careful consideration and gentleness toward all. He gave unselfishly and unstintingly of his time and experience to Committee 20 and to the entire Association; nothing was too difficult for him to do, and no work that he undertook was too laborious for him not to give it scrupulous attention. His many associates, both in a social and professional way, will testify that they were bettered and profited by all their contacts with Mr. Irwin, and the membership of Committee 20, as well as his other friends and associates, will continue to miss him keenly. By his death, the committee and the Association lost a true friend and a valuable member.

W. D. Faucette, *Chairman,*
F. L. Nicholson,
J. S. Lillie.
Committee on Memoir

Report on Assignment 2

Form of Agreement for Commercial Signs on Railway Property

O. K. Morgan (chairman, subcommittee), E. H. Barnhart, J. P. Hanley, N. D. Hyde, S. L. Mapes, A. A. Miller, C. B. Niehaus, H. A. Palmer, E. L. Taylor.

Your committee prepared a form of agreement and submitted it to the Association in Bulletin 413, page 48, November, 1939, for information and discussion. Minor changes have since been made and the agreement is now submitted for approval of the Association and printing in the Manual.

FORM OF AGREEMENT FOR COMMERCIAL SIGNS ON RAILWAY PROPERTY

1940

THIS AGREEMENT, made this .... day of ...., 19...., by and between ...., a corporation organized and existing under the laws of the State of ...., hereinafter called the Railway Company, and ...., hereinafter called the Licensee:

WITNESSETH:

The Licensee desires to construct, maintain and use a commercial sign upon the property of the Railway Company situated at .... and substantially as shown on the plan and in the specifications hereto attached, designated as .... dated .... and made a part hereof:

It is mutually agreed as follows:

1. License

The Railway Company gives permission to the Licensee to construct, maintain and use a .... sign upon the property of the Railway Company, in accordance with said plan and the specifications forming a part hereof, and subject to the requirements of the Railway Company.

2. Display Copy

The permission herein given is upon the express condition that any sign erected and advertising displayed thereon during the term of this agreement shall be in substance, form, kind and character satisfactory to and approved by the .... of the Railway Company, and upon any breach of this condition by said Licensee, such license shall terminate at once.

3. Permits and Taxes

Prior to the erection of said sign the Licensee shall, at its sole cost and expense, procure all necessary consents and permits from all public authorities having jurisdiction, and shall pay all license fees and taxes, or increase of taxes, assessed against or imposed on or by reason of said sign, and at all times during the continuance hereof, shall comply with all rules, regulations and requirements of said authorities and of the National Board of Fire Underwriters relative thereto.

4. Cost and Maintenance

The Licensee shall at its sole cost and expense, in a manner satisfactory to the .... of the Railway Company, construct and maintain said sign and keep the land and buildings appurtenant thereto in a cleanly condition, free of litter and refuse matter occasioned by said sign, at all times during the continuance of this agreement.

5. Changes of Structures

The Licensee further covenants and agrees that if and in case the location of the sign should in the opinion of the Chief Engineer of the Railway Company require the strengthening of any building, roof, sidewall or appurtenance thereto, or increase the load so as to require additional support, or to cut through any roof for the attachment of said sign or its supports, the same shall be done and said alterations thereafter maintained during the term of this agreement by the Licensee at its sole cost and expense, and to the satisfaction of the Chief Engineer of the Railway Company.

6. Removal

Upon notice of termination of the license, the Licensee shall at once and at its sole cost and expense remove said sign and restore, if requested by the .... of the Railway Company, the Railway Company's property to its former condition; and if the Licensee within .... days shall fail so to do, said sign shall forthwith become the property of the Railway Company, and all right, title and interest therein of the Licensee shall terminate, or the Railway Company may, at its option, remove said sign and restore the Railway Company's property to its former condition at the sole cost and expense of the Licensee, which cost and expense the Licensee covenants and agrees to pay upon demand.

7. Rentals

The Licensee shall pay as rental therefor .... Dollars ($............) per annum, in advance, for each year and at the same rate for any part of a year unexpired at the termination of this license.

8. Liability

The Licensee shall not in any way or at any time interfere with the safe passage of the Railway Company's trains; and shall indemnify and save harmless the Railway Company from any and all damage, loss or injury, including injury resulting in the death of any person whomsoever, suits, claims, liabilities, recoveries, or demands resulting directly or indirectly from the installation, maintenance, use or existence of said sign, whether caused by the negligence of the Railway Company or otherwise.

9. Risk

The Licensee assumes all risk of loss or damage to its property on the premises of the Railway Company, however caused, and hereby releases the Railway Company from all liability on account of such loss or damage.

10. Term

This agreement shall continue in force for .... years, and thereafter from year to year until terminated by either party giving to the other .... days' notice in writing at the last known address, of its intention so to do and upon the expiration of the time mentioned in such notice this agreement shall terminate.

11. Assignment

This agreement shall not be assigned or in any manner transferred without the written consent of the .... of the Railway Company.

Until terminated as herein provided, this agreement shall inure to the benefit of and be binding upon the legal representatives and successors of the parties respectively.

In Witness Whereof, the parties hereto have executed this agreement in ...., the day and year first above written.

.... Company

Attest .... By ....
Secretary

.... Licensee

Witness .... By ....

Report on Assignment 5

Form of Agreement for Unloading Liquefied Petroleum and Other Gases

W. R. Swatosh (chairman, subcommittee), W. D. Faucette. F. R. Layng, J. S. Lillie, A. A. Miller, F. L. Nicholson, W. M. Post.

Your committee submits the following form, which was prepared at the request of the Association of American Railroads and has received the approval of its Law Department and the endorsement of the General Committee of the Engineering Division. The matter of protecting the railroads appears to be urgent and this agreement is submitted for adoption and printing in the Manual.

FORM OF AGREEMENT FOR UNLOADING LIQUEFIED PETROLEUM AND OTHER GASES

(Using Railway Facilities)

1940

THIS AGREEMENT, made this .... day of ...., 19...., by and between ...., a corporation, organized and existing under the laws of the State of ...., hereinafter called the Railway Company, and ...., hereinafter called the Industry:

Witnesseth:

Whereas, the Industry desires to unload ....
(Liquefied petroleum gas, chlorine gas, etc.)
from an industry track located on the premises of the Railway Company at or near .... Station, County of ...., State of ...., described as follows:
....
....
....
...., and

WHEREAS, the Railway Company desires to license and permit the Industry to use certain unloading facilities along the Industry track belonging to the Railway Company, the facilities to be operated by the employees of the Industry.

NOW, THEREFORE, in consideration of the payment to the Railway Company of .... Dollars ($..............), the receipt of which is hereby acknowledged, and the covenants herein contained, it is mutually agreed:

1. Grant

That the Railway Company hereby grants the right and permission to the Industry to use its facilities, located along the industry track for the purpose of unloading .... without charge to the Industry, except
(liquefied petroleum gas, chlorine gas, etc.)
as herein provided, the unloading facilities to be operated by the employees of the Industry.

2. Ownership of Facilities

It is understood that the title to and the sole ownership of all of the facilities shall remain in the Railway Company and that the Industry does not acquire any interest therein.

3. Use by Others

The permission herein granted to the Industry is not for the exclusive use of the above described unloading facilities; it being understood and agreed that such facilities may be used also by other patrons of the Railway Company. It is understood and agreed further that the Industry shall not use the unloading facilities for the benefit of any other person, firm or corporation, without the written consent of the Railway Company.

4. Permits and Licenses

The Industry shall obtain, at its expense, any and all authority, license and permission from municipal and governmental authorities that may be necessary for it to unload or handle the commodity herein specified.

5. AAR Circulars and Instructions

It is understood and agreed that in using the facilities, the Industry shall fully comply with and be governed by Circular 17A or 17B, dated May 1, 1939, and Circular 17C, dated October 10, 1940, of the Association of American Railroads, respectively, and amendments to or reissues thereof, or such other circulars and instructions as may be issued from time to time by either the AAR or the Bureau of Explosives, and that the unloading shall also be under the jurisdiction of and subject to the instructions of the .... of the Railway Company.

6. Clearances

The Industry shall not place or permit any obstructions over the Industry Track less than .... feet above the top of the rail nor alongside of the said track less than .... feet from the center of the track.

7. Liability

The Industry agrees that it will protect, indemnify, and forever hold harmless the Railway Company from any and all claims, liabilities and expenses which the Railway Company shall incur by reason of any real or alleged injury (including injury resulting in death) to any person or persons whomsoever, (including the employees of the parties

hereto), and from all loss, claims, liabilities and expenses by reason of any real or alleged damage to or destruction of property (including the property of the parties hereto), arising out of, or in any way attributable to the use of said unloading facilities by the Industry, or the unloading of .... or the removal
(liquefied petroleum gas, chlorine gas, etc.)
of the same from the premises of the Railway Company by the Industry, regardless of whether or not such injury or damage is caused by the negligence of the Railway Company, its agents or employees.

8. Assignment

The Industry shall not assign this contract nor any rights thereunder without the written consent of the Railway Company.

9. Duration and Cancellation

This agreement shall be in effect after .... 19.... and continue in effect until terminated by .... days' written notice from either party to the other. Such notice shall be sufficiently given and delivered if deposited in the United States mail, enclosed in an envelope, properly stamped and addressed to the Railway or to the Industry, as the case may be. All notices or other communications from one party to the other with respect to this contract shall be addressed, as the case may be, to the .... Railway Company, ... (Street and Number) ....(City) ....(State) or the ....(Industry), ...(Street and Number) ....(City) ....(State), unless and until notice in writing of a change of address shall have been given by one party to the other, in which event the new address shall be used.

As hereinbefore provided, this agreement shall inure to the benefit of and be binding upon the parties hereto, their heirs, executors, administrators, successors and assigns.

In Witness Whereof, the parties hereto have executed this agreement in ...., the day and year first above written.

....
Railway Company

By ....

....
Industry

Witness:

....
Witness:

Report of Committee 16—Economics of Railway Location and Operation

H. M. Stout, *Chairman,*
E. G. Allen
E. Y. Allen
B. T. Anderson
J. A. Anderson
S. E. Armstrong
T. B. Ballantyne
J. W. Barriger, III
C. H. Blackman
V. T. Boughton
J. C. Bradley
C. W. Breed
Richard Brooke
J. L. Campbell
S. B. Clement
L. E. Dale
Miss Olive W. Dennis
J. H. Dyer
H. H. Edgerton
J. A. Erskine
E. K. Eugene
J. M. Farrin
R. P. Forsberg
G. W. Hand
J. L. Haugh
C. H. R. Howe
E. A. Humphreys
W. B. Irwin
E. E. Kimball
E. E. King
A. W. Laird
Fred Lavis
R. S. Marshall
F. H. McGuigan, Jr.
L. G. Morphy
F. N. Nye
J. A. Parant
H. R. Peterson
J. W. Porter
J. F. Pringle
C. P. Richmond
L. S. Rose
M. F. Mannion, *Vice-Chairman,*
E. H. Roth
F. A. Russell
H. F. Schryver
B. J. Schwendt
O. E. Selby
H. M. Shepard
H. A. Shinkle
L. K. Sillcox
H. W. Snyder
C. B. Stanton
R. R. Strother
J. E. Teal
H. M. Tremaine
W. D. Wiggins
H. W. Williams
S. L. Wonson
J. A. Wood
J. S. Worley

Committee

To the American Railway Engineering Association:

Your committee submits its report on the following subjects:

1. Revision of Manual.

A new study of "the cost of stopping and starting trains", preliminary to recommendation of the revision of the material now in the Manual, section 21, pages 2–5, has been begun. In this the collaboration of the Signal Section, Engineering Division, AAR, has been secured. No report.

2. Methods for obtaining a more intensive use of existing railway facilities.

Progress report, directed to the intensification of use of railway facilities resulting from the operation of the port control organization recently set up. Submitted as information.. .... page 45

3. Methods or formulas for the solution of special problems relating to more economical and efficient railway operation.

Progress report; supplementary discussion of the sub-topic (k) Economic relation between track structure and traffic to be handled. Submitted as information.... page 48

4. Effect of volume of traffic on railway operating expenses, collaborating with Committee 22—Economics of Railway Labor.

Progress report. This year there is presented a method for determining the effect of volume of traffic on transportation expenses. Submitted as information......... page 50

5. Effect of inland waterway transportation on the economics of railway operation, collaborating with AAR Committee on Waterway Projects and with Committee 25—Waterways and Harbors.

No report.

Bulletin 420, November, 1940.

6. Effect of high speed on railway operating expenses.

Progress report. Analysis of increase in power requirements and the resulting increases in costs due to increases in speed in hauling a given volume of traffic. Submitted as information.......... page 56

7. Effect of rail lubrication on train operation, collaborating with Committee 5—Track.

No report.

8. Economics of railway location and operation as affected by railway electrification, collaborating with Electrical Section, Engineering Division, AAR.

Progress report—submitted as information.......... page 68

9. Effects of speeds in excess of 75 miles per hour on the economics of railway location.

No report.

10. Effect of highway transportation on the economics of railway operation.

No report.

11. Train resistance of freight trains under various conditions of loading and speed.

Progress report. Introductory to the work on this assignment a résumé of some of the more important work which has been done in the establishment of general resistance formulas—submitted as information.......... page 69

12. Development of modern power units and the effects on the economics of railway location and operation.

No report.

13. The general course of the cost of railway transportation and operation over the past 100 years, the principal determining elements and the economic significance.

No report.

14. The advantage derived from stiffness of track in improving economics of train operation.

No report.

The Committee on Economics of Railway Location and Operation,

H. M. Stout, *Chairman.*

Report on Assignment 2

Methods for Obtaining a More Intensive Use of Existing Railway Facilities

L. E. Dale (chairman, subcommittee), E. Y. Allen, B. T. Anderson, C. H. Blackman, C. W. Breed, J. H. Dyer, W. B. Irwin, H. F. Schryver, B. J. Schwendt, H. A. Shinkle, J. A. Wood.

Previous studies and reports made by this subcommittee have discussed the accomplishment of the desired objective by means of pooling, coordinating terminals and consolidating railroads. The present report describes a plan made effective by the Association of American Railroads which has been designed to insure the maximum use of railroad facilities and equipment at the Atlantic and Gulf ports through cooperative efforts of individual railroads, shippers and receivers of freight and the steamship companies and so avoid a repetition of congestion and delay to traffic such as occurred during the World War.

An unprecedented rate of increase in railroad traffic, starting the middle of August 1939, when weekly revenue carloadings totalled 660,000, reaching 800,000 cars by the middle of September and a peak of about 860,000 cars in October (this increase being coincident with the start of the European War), directed attention to the necessity for effective action to prevent any recurrence of rail traffic congestion such as was experienced at the end of 1917. At that time in the territory north of the Ohio and Potomac rivers and east of the Mississippi river and Chicago 62,247 carloads of freight were delayed short of their ultimate destination, in addition to which there were held by the lines at and west of St. Louis, 31,421 carloads; at and west of Chicago, 24,836 carloads; at and south of the Ohio river gateways 14,061 carloads; and at and south of the Potomac river gateways 15,545 carloads. Most of this freight was for destinations within a line drawn from Portland, Me., through Albany, N.Y., and Rochester, Harrisburg, Pa., and Baltimore, Md. Delivery could not be made because of large accumulations of cars already at terminals awaiting delivery.

The significance of these figures is that this use of railroad equipment for storage purposes, due to inability to release cars at destination, was a major cause contributing to congestion, and that congestion can be prevented by avoiding such misuse of railroad equipment.

Because of the probability that a substantial increased movement of export freight would take place, the AAR, through its Car Service Division, placed in effect early in November 1939, a plan for preventing serious congestion at Atlantic and Gulf ports. Under that plan, a manager in charge of port traffic was appointed to direct a system for controlling the movement of rail traffic to these ports to the extent necessary to prevent accumulation of more traffic than can be promptly unloaded.

During the first ten months that the plan has been in effect it has been necessary to exercise control over the movement of freight in only one instance, i.e., bulk grain and soy beans for handling through the public elevator at New Orleans, La., due to limited storage space. In the month of December 1939, over 250 cars were handled by permit, and additional grain was accepted as rapidly as ships were available to transport the grain from the port.

There have been two instances where cars accumulated more rapidly than the facilities available appeared able to dispose of them currently, and each of these situations was quickly resolved through cooperative action of the several interests directly concerned.

Under the plan now in operation no restriction is contemplated on the movement by rail of any freight, export or domestic, to Atlantic and Gulf ports so long as facilities are available to transfer such freight promptly to ships or into warehouses, thus avoiding the use of freight cars for storage purposes.

The plan placed in effect by the Car Service Division is comparatively simple. Under it a manager of port traffic is located at New York. He has complete authority with respect to the supervision of any control placed on traffic moving to or through any port. At each of the principal Atlantic and Gulf ports, local committees consisting of representatives of the port and of the railroads entering these ports have been created. Each of these committees keeps closely in touch with the situation. Written detailed reports are made at regular intervals to the manager of port traffic, advising him as to the number of loaded cars received daily, the number unloaded, the number held for unloading and other pertinent information pertaining to the situation at that port.

The manager in charge of port traffic has thus far devoted his attention largely to keeping in close touch with the situation at the various ports along the Atlantic and Gulf coasts in order to make sure that no congestion develops and to bringing about increased cooperation on the part of shippers, exporters, steamship operators and port authorities in utilizing to the maximum the facilities already available. Should a sudden increase in freight traffic develop, or other circumstances arise, the manager of port traffic has authority under the plan to require that before any freight for export is loaded on freight cars for shipment that formal assurances be given that the shipment will be promptly unloaded at destination so that the cars will be promptly released and returned to active service.

Because of the heavy movement of export freight through the Port of New York special attention has been given this area. A daily report is received by the secretary of the General Managers' Association (which includes all roads operating within the New York area) showing the following information:

(a) Car float freight for New York station delivery.
(b) Car float freight for Brooklyn terminal delivery.
(c) Freight for New Jersey terminal delivery.
(d) Freight interchanged by car float.
(e) Freight interchanged by rail.
(f) Tidewater coal situation.
(g) Company fuel situation.
(h) Grain—received, on hand, in cars, elevators and boats.
(i) Cars released and on hand in the several Brooklyn terminal companies.
(j) Lighterage freight unloaded and on hand.
(k) Carload freight in storage on covered piers, open piers and ground.
(l) Carload storage space available but not used.
(m) Cars held outside the terminal district awaiting movement to it.
(n) Number of lighters held at steamship piers in excess of 48 hours awaiting unloading.

This information is given the manager of port traffic by the secretary of the General Managers' Association each day, together with supplemental information at intervals showing the detail of railroad lighters delayed by steamship companies and cars on hand over 15 days for unloading, so that the manager of port traffic has currently a picture of the port operations before him. His point of contact with the railroads at New York is the secretary of the General Managers' Association, with whom any question pertaining to operating conditions in the New York district is handled.

The Maritime Association of the Port of New York, through its Traffic Advisory committee, is the point of contact for the manager of port traffic with the steamship people. Conferences are held regularly between this committee and the Lighterage committee of the General Managers' Association, for the discussion of mutual problems pertaining to the handling of lighterage freight in the New York district. Illustrative of the effectiveness of the work done is the fact that prior to November 15 the average number of lighters delayed over 48 hours awaiting unloading to ships was over 150 daily. During December 1939, this average was 104; during January 1940, it was 105; March, 88; and May, 75. The volume of traffic handled increased during this period.

Records show that the volume of business handled through the Port of New York during the first six months of 1940 has approximated two-thirds of the volume handled daily during the peak of the World War movement. The volume handled on peak days has approached that of 1918. During the month of August the tons of export freight handled through the North Atlantic ports exceeded that handled August 1918, and the volume at the Port of New York practically equalled that handled in August 1918. This traffic has been handled without congestion and with satisfaction.

Report on Assignment 3

Methods or Formulas for the Solution of Special Problems Relating to More Economical and Efficient Railway Operation

C. H. R. Howe (chairman, subcommittee), J. L. Campbell, J. A. Erskine, J. M. Farrin, H. R. Peterson, E. H. Roth, H. F. Schryver, H. A. Shinkle, J. A. Wood.

Economic Relation Between Track Structures and Traffic to Be Handled

Your subcommittee desires to supplement its reports on this subject, published in Volumes 40 and 41 of the Proceedings, with a graphical illustration (Chart IX) showing the economical limitations of rail weights which may be used with various traffic densities. The basic data used in preparing the chart are shown in the accompanying Tables F and G.

The investment values given in Table G are assumed, as they would vary in any given case. The costs of labor shown are actual, being derived from the average man-hours spent by each group of railways for the year 1936, as reported to the Interstate Commerce Commission. However, as the labor hours published by the commission are given per equated mile, it is essential that a conversion be made into hours per main track mile, in terms of which calculations are customarily made. The conversions are shown in Table F. The conversion into money was accomplished by using a flat rate of 40 cents per hour. The basic labor costs and the respective average traffic densities, are those shown in Tables A and C of the report of this subcommittee beginning on page 130 of Vol. 40 of the Proceedings.

It will be noted on the chart that the intersection of the horizontal line, representing the cost to own and maintain, and the vertical line, designating the average traffic density of any particular group, is taken as the point of origin for increased cost as traffic density increases. It will be noted also that the slope of the line indicating the rate of cost increase is determined by the cost to the lighter weight rail group of handling the traffic density of the next higher heavier weight rail group.

In the application of this mathematical procedure the interest rate on the investment will remain the same, but the replacement costs will increase approximately in direct proportion to the increase in traffic density. The increases in labor costs are obtained through the use of the formula evolved on page 134, Vol. 40 of the Proceedings, namely, $1.00 + (0.3865 \times \text{percent traffic density increase})$.

Take for example the 112-lb. rail costs for handling a traffic density of 5,248,898 g.t.m. per mile and determine the costs of handling the 11,309,126 g.t.m. traffic of the 131-lb. rail group on the lighter rail.

Interest remaining the same	\$1,290
Replacement cost increasing in the ratio $\frac{11{,}309{,}126}{5{,}248{,}898} = 2.16 \times 0.05\% = 0.108$	
Investment \$25,800 $\times$ 0.108 =	\$2,786
Increased labor cost, $1 + (0.386 \times 1.16) = 1.448$; \$614 $\times$ 1.448 =	\$ 889
Total cost for 131-lb. track traffic on 112-lb. track	\$4,965

CHART No. IX

TRAFFIC DENSITIES REQUIRED TO JUSTIFY INCREASED RAIL WEIGHT

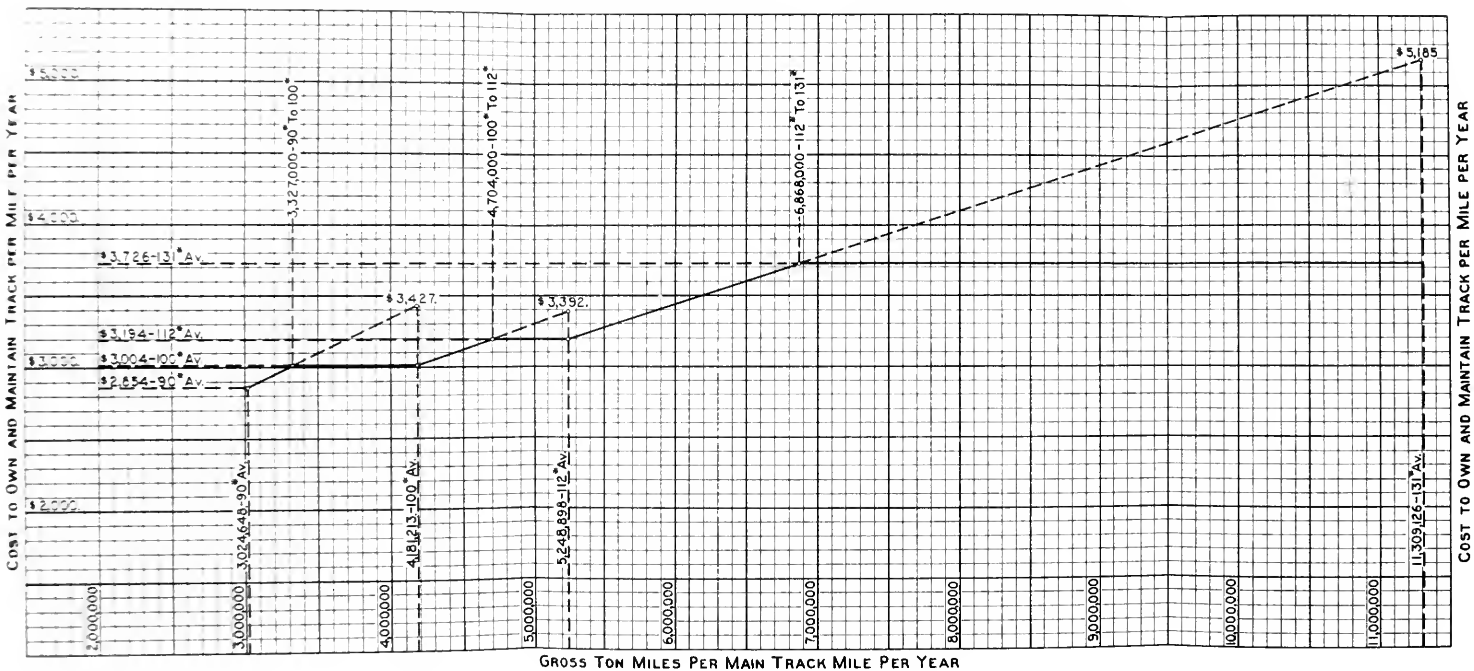


Table F

Track Class	Miles 1st Main Track	Equated Miles Track	Conversion Factor	G. T. Miles per Equated Mile per Year	G. T. Miles per Main-Track Mile per Year	Section Man-Hours per Equated Mile per Year	Section Man-Hours per Main-Track Mile per Year	Annual Labor Cost at 40c per Hour
90 lb.	16,479	18,526	1.12	2,700,579	3,024,648	1,125	1,260	$504
100 lb.	44,630	54,554	1.22	3,427,224	4,181,213	1,136	1,386	554
112 lb.	113,423	141,993	1.25	4,199,118	5,248,898	1,229	1,536	614
131 lb.	55,721	86,874	1.56	7,296,210	11,382,088	1,564	2,440	976

Table G

Track Class	Investment	Interest 5 percent	Replacement Cost 5 percent	Labor	Total	Replacement Cost With Denser Traffic percent Variable	Increased Labor Cost	Total Cost
90 lb.	$23,500	$1,175	$1,175	$504	$2,854	0.071% $1,622	$578	$3,375
100 lb.	24,500	1,225	1,225	554	3,004	0.062% 1,544	608	3,377
112 lb.	25,800	1,290	1,290	614	3,194	0.107% 2,786	889	4,965
131 lb.	27,500	1,375	1,375	976	3,726	-----	-----	-----

It is the opinion of this committee that any railway preparing a similar chart, substituting its local factoral values, will find it provides a simple solution of many rail weight problems.

This report is submitted as information.

Report on Assignment 4

Effect of Volume of Traffic on Railway Operating Expenses

J. F. Pringle (chairman, subcommittee), C. H. Blackman, Richard Brooke, S. B. Clement, C. H. R. Howe, J. A. Parant, B. J. Schwendt, H. A. Shinkle, J. A. Wood, J. S. Worley.

In previous reports the committee has shown by analysis of mass statistical data the effect of volume of traffic, measured by gross ton-miles, on operating expenses as a whole.

While this method of approach is of considerable interest, your committee is of the opinion that a method whereby estimates can be made with a reasonable degree of accuracy of the effect of traffic volume on each of the general expense accounts under the peculiar conditions that pertain on any particular road will be of practical value.

Railway accounting divides operating expenses into six general accounts. The following shows these and their relative importance on Class I American and Canadian railways:

General account	*Approximate percentage of total operating expense*
1. Maintenance of way and structures	16
2. Maintenance of equipment	26
3. Traffic expense	4
4. Transportation	49
5. Miscellaneous operations	1
6. General	4
Total	100

The Association has adopted a prior report of the committee offering a method whereby the effect of traffic density as expressed in gross ton-miles on maintenance of way and structures expense can be determined.

The effect of volume of traffic on maintenance of equipment expenses has been studied and a report made thereon by the Mechanical Division of the AAR.

Your committee this year submits as information a method for determining the effect of volume of traffic on transportation expenses.

It is recognized that certain primary accounts of this group of expenses bear a direct relationship to traffic density while others are more or less independent and vary only to a minor extent even with large variation in traffic volume.

Volume of railway traffic is measured by units chosen to reflect the resulting revenue and expense items and no one of these units can be used to the exclusion of others in a study of the effect of volume on transportation expense.

The common measure of volume of railway traffic is gross revenue but this in itself cannot be used as a measure of transportation expense and the first step in determining the effect of volume is the establishing of the relationship between revenue and certain units which can be used to measure transportation expense as expressed in the various primary accounts.

Railway revenues, for the purpose of this study, may be divided as between—

(1) freight revenue, including switching
(2) passenger revenue, including mail and express
(3) all other

For the Class I railways of the United States and Canada, group 1 (freight) represents approximately 82 percent, group 2 (passenger) 14 percent and group 3 (all other) 4 percent. If, therefore, the study is confined to the effect of variations in freight and passenger revenues any error due to neglect of other revenue will be negligible.

The relationship between freight and passenger revenue shows considerable variation on different railways and as this relationship has considerable effect on operating expenses, it must be determined for the particular property under consideration.

Having divided the gross revenue as indicated above, the next step is to relate revenue to the transportation units which cause expense. These units are:

For freight service
(1) Net ton-miles
(2) Gross ton-miles
(3) Freight train-miles
(4) Freight train car-miles

For passenger service
(1) Passenger train-miles
(2) Passenger train car-miles

Table 1, with notes, affords a convenient method of relating revenue and transportation units.

Having determined the transportation units for the selected test period and estimate period, it is necessary to relate the primary accounts of the transportation group of expenses to the units so determined. Certain of these primary accounts combine both freight and passenger expense, and the expense due to each must be separated.

For convenience, the primary accounts may be grouped as shown in the accompanying table.

Grouping of Primary Accounts

Group	*Designation*	*Approximate percentage of total transportation expense*	*Accounts included*
1	Supervision	4.6	371, 372
2	Station service	18.7	373, 376
3	Yard service	17.6	377, 378, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389
4	Train and locomotive operation	52.6	392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402
5	Signal and crossing protection	1.5	379, 404, 405, 406
6	Casualties	1.8	415, 416, 417, 418, 419, 420
7	Miscellaneous operations	2.7	374, 375, 403, 407, 408, 409
8	General expense	0.4	410, 414
9	Joint facilities, debit and credit	0.1	390, 391, 412, 413
		100.0	

The percentage which each group bears to the total will vary with conditions on individual roads, and must be determined for that road. The percentages shown are only used to show generally the relative importance of each group.

TABLE 1

SELECTED TEST PERIOD AND ESTIMATED EARNINGS AND OPERATING UNITS

	Selected Test Period	*Estimate*
Freight revenue		
Passenger revenue		
Other revenue		
Total revenue		
Net ton-miles		
Gross ton-miles		
Freight train-miles		
Freight train car-miles		
Passenger train-miles		
Passenger train car-miles		

Notes:
1. In estimating net ton-miles based on freight revenue allowance must be made for any probable change in freight rates, or nature of tonnage to be handled.
2. In estimating gross ton-miles based upon net ton-miles allowance must be made for any change in nature of tonnage handled which might affect average car loading or relationship between empty and loaded car movement.
3. In estimating freight train-miles based upon gross ton-miles, allowance must be made for reserve capacity of trains already operating and for any possible increase in locomotive capacity. Fixed or scheduled freight train service which must be operated to meet service requirements will often be found to have a reserve capacity and minor increases in traffic can be handled without increase in mileage.
4. In estimating freight train car-miles based on net ton-miles allowance must be made for any probable change in nature of tonnage handled which would result in a change in average car loading or in the relationship between empty and loaded car movement.
5. Passenger train-miles are dependent on policy as well as volume of traffic. In estimating passenger train-miles the policy of the company in respect to increasing or decreasing passenger service must be given consideration. In general, passenger train mileage will not vary with minor fluctuations in passenger earnings. Consideration must be given also to any probable change in passenger rates.
6. Passenger train car-miles may be assumed to vary with the passenger traffic but the extent depends upon the amount of change in traffic expected, and the reserve capacity of the cars already operating. Coach car-miles may be assumed to vary directly; luxury cars, i.e. parlor and sleepers, to a much smaller extent.

The following indicates for each group the method to be followed in determining their probable variation with traffic volume. Necessary correction must be made for changes in wages and material prices.

Group 1. Supervision. This group includes Accounts 371, Superintendence, and 372, Despatching Trains. These accounts are not affected by changes in relationship between passenger and freight traffic, and only to a slight degree by changes in volume. It may be assumed that these expenses will vary 10 percent of the variation in traffic volume as expressed in gross revenue.

Group 2. Station Service. This group includes Accounts 373, Station Employees, and Account 376, Station Supplies and Expenses. Those portions of Accounts 373 and 376 due to the expense of operating large freight offices and sheds, vary almost directly with the volume of freight traffic while that portion due to expense of operating stations with less than a total staff of four men, and passenger stations, will show very little variation with ordinary changes in traffic. For these reasons it is necessary to divide the expense as between variable expense, which is the expense incurred at larger freight stations, and fixed

TABLE 2

YARD SERVICE

Primary Acct. No.	Name of Account	Selected Test Period Expense			Percent Variable with Volume		Estimated Expense		
		Frt.	*Passgr.*	*Total*	*Frt.*	*Passgr.*	*Frt.*	*Passgr.*	*Total*
377	Yardmasters and yard clerks	------	------	------	25	25	------	------	------
378	Yard conductors and brakemen	------	------	------	60	60	------	------	------
380	Yard enginemen	------	------	------	60	60	------	------	------
381	Yard motormen	------	------	------	60	60	------	------	------
382	Fuel for yard locomotives	------	------	------	60	60	------	------	------
383	Yard switching power produced	------	------	------	60	60	------	------	------
384	Yard switching power purchased	------	------	------	60	60	------	------	------
385	Water for yard locomotives	------	------	------	60	60	------	------	------
386	Lubricants for yard locomotives	------	------	------	60	60	------	------	------
387	Other supplies, yard locomotives	------	------	------	60	60	------	------	------
388	Enginehouse expenses, yard	------	------	------	40	40	------	------	------
389	Yard supplies and expenses	------	------	------	25	25	------	------	------
	Total	------	------	------	------	------	------	------	------

Note: (1) The most convenient unit of volume is car miles, freight or passenger as the case may be.

(2) Account 377. The extent to which this account will vary with volume will differ in accordance with conditions on each road. The amount represented by the expense of yardmasters and clerks in minor yards and by general yardmasters and chief clerks at larger yards, will not vary except under unusual fluctuations, but the amount represented by assistant yardmasters, checkers and clerks at large yards will vary closely with volume. 25 percent may be used as a trial figure.

(3) Accounts 378, 380, 381, 382, 383, 384, 385, 386, 387. These accounts represent the direct cost of yard switching, and vary directly with the number of yard engines worked. The extent of their variation with volume is dependent upon:

(a) Number of engines engaged in smaller yard where variation in volume does not permit or necessitate decreases or increases in power

(b) Number of engines engaged in passenger switching

(c) Reserve capacity in larger yards.

Before an accurate estimate can be formed, it is necessary to take above into consideration and they will be found to vary on each road. 60 percent may be used as a trial.

(4) Account 388. This account is subject to the same conditions as mentioned in Note 3 and also to reserve roundhouse capacity. 40 percent may be used as a trial.

(5) Account 389. May be taken to vary to same extent as 377.

TABLE 3

TRAIN AND LOCOMOTIVE OPERATION

Primary Acct. No.	Name of Account	Amount Frt.	Amount Passgr.	Selected Test Period Units Frt.	Selected Test Period Units Passgr	Unit Cost Frt.	Unit Cost Passgr.	Units Frt	Units Passgr.	Estimate Unit Cost Frt.	Estimate Unit Cost Passgr.	Amount Frt.	Amount Passgr.
392	Train enginemen	----	----	TM	TM	----	----	----	----	TM	TM	----	----
393	Train motormen	----	----	TM	TM	----	----	----	----	TM	TM	----	----
401	Trainmen	----	----	TM	TM	----	----	----	----	TM	TM	----	----
394	Fuel for train locos.	----	----	GTM	TM	----	----	----	----	GTM	TM	----	----
395	Train power produced	----	----	GTM	TM	----	----	----	----	GTM	TM	----	----
396	Train power purchased	----	----	GTM	TM	----	----	----	----	GTM	TM	----	----
397	Water for train locos.	----	----	GTM	TM	----	----	----	----	GTM	TM	----	----
398	Lubricants for train locos.	----	----	TM	TM	----	----	----	----	TM	TM	----	----
399	Other supplies for train locos.	----	----	TM	TM	----	----	----	----	TM	TM	----	----
400	Engine house expenses, train	----	----	TM	TM	----	----	----	----	TM	TM	----	----
402	Train supplies and expenses	----	----	TM	TM	----	----	----	----	TM	TM	----	----

Total train and locomotive operation

Accounts 392, 393, 401)	Freight	It may be assumed that these accounts vary directly with freight train-miles
398, 399, 402)	Passenger	It may be assumed that these accounts vary directly with passenger train-miles
Accounts 394, 395, 396, 397)	Freight	It may be assumed that these accounts vary directly with gross ton-miles
	Passenger	It may be assumed that these accounts vary directly with passenger train-miles but some allowance must be made if there is a material difference in car-miles
Account 400		Variation in this account may be taken as 40 percent of train-miles variation.

expense which is the expense at small stations and passenger stations. Variable expense varies directly with volume as measured in tons of L.C.L. freight handled, or if this figure not obtainable, net ton miles may be used. It may be assumed that the group will vary 50 percent of the variation in traffic volume as measured either in tons of L.C.L. freight handled or net ton miles.

Group 3. Yard Service. This group includes those expenses due to yard switching services. The expenses included in the group are dependent upon the relationship as between passenger and freight service as well as upon volume of each. For convenience Table 2 has been set up and probable variation of each item with traffic volume indicated.

Group 4. Train and Locomotive Operation. This group includes those expenses due to train and locomotive operation both passenger and freight. They are dependent upon the relationship between passenger and freight services as well as upon the volume of each. For convenience Table 3 has been set up and the probable variations of each item with traffic volume indicated.

Group 5. Signal and Crossing Protection. This group of accounts includes expense due to switch and signal tenders, signal and interlocker operation, crossing protection and drawbridge operation. The effect of volume of traffic on these items is slight. It may be taken as 10 percent of the variation in train mileage.

Group 6. Casualties. This group includes such items as clearing wrecks, damage to property, etc. No material error will result if they are assumed to vary 70 percent of the variation in traffic volume as expressed in gross revenue.

Group 7. Miscellaneous Operations. This group includes special expenses and their extent varies on each road. The extent of variation of each primary account in the group must be determined in accordance with the peculiar conditions pertaining on the individual property under consideration.

Group 8. General Expense. This group includes stationery and printing, other expenses and insurance. No material error will result in assuming that these expenses vary 10 percent of variations in gross revenue.

Group 9. Joint Facilities. The extent that this group of expenses will vary with traffic is dependent upon the agreements as to joint facilities that are in effect on the property for which estimate is being made.

TABLE 4

The percentages used in the following table are given to illustrate the method. They must be determined for each particular property as indicated in the report. When once so determined for the conditions pertaining to any property they may be used from time to time as long as there are no major changes in conditions.

Expense Group	*Name*	*Percent Total Transportation Expense*	*Percent Variation with Traffic*	*Percent Variable of Total Transpn. Exp.*
1	Supervision	4.6	10	0.46
2	Station service	18.7	50	9.35
3	Yard service	17.6	58	10.21
4	Train and locomotive operation	52.6	80	42.08
5	Signal and crossing protection	1.5	10	0.15
6	Casualties	1.8	70	1.06
7	Miscellaneous operations	2.7	40	1.08
8	General expenses	0.4	10	0.04
9	Joint facilities, debit and credit	0.1	--	-----
		100.0		64.43

Summary

Having determined in the manner indicated above the extent of variations in each group for the particular property under consideration, a summary may be made as shown in Table 4 and the figures thus obtained may be used to estimate future transportation expenses for any given variation in traffic.

This report is submitted as information with the recommendation that the subject be continued.

Report on Assignment 6

Effect of High Speed on Railway Operating Expenses

M. F. Mannion (chairman, subcommittee), V. T. Boughton, C. W. Breed, J. H. Dyer, A. W. Laird, J. W. Porter, J. F. Pringle, H. F. Schryver, B. J. Schwendt, H. W. Snyder.

Increases in speed require increased fuel and water consumption for steam locomotives. This increased fuel and water consumption is greater for a ten-mile increase in speed from 40 to 50 miles per hour than for an increase from 30 to 40 miles per hour. Also the increased fuel and water consumption is greater for an increase in speed from 50 to 60 miles per hour than for an increase from 40 to 50 miles per hour. In other words, the higher the speed, the larger the increase in fuel and water consumption.

Increases in speed also have a very material effect on power requirements. The power requirements for handling a given volume of traffic increase very rapidly as the maximum speed of the service is increased. This increase in power requirements necessitates additional capital expenditures and increases maintenance of equipment expenses in proportion to the increase in power requirements.

In order to show the effect of high speed on fuel and water consumption and power requirements, Tables 1 and 2 have been compiled for three different types of service, passenger train, coal and ore trains and manifest freight trains, based on data contained in Chapter 16 of the Manual. These tables are a composite summary for six different groups of locomotives based on 37.5, 35.0, 32.5, 30.0, 27.5, and 25.0 horsepower per ton on drivers and give the average weight of train for any maximum speed and the average

TABLE NO. 1

COMPOSITE SUMMARY
PASSENGER OR COAL AND ORE TRAINS

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILINO WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
110	.95 W	78.90	83.30	86.70	91.40	94.55	96.80	99.80	101.75
100	1.70 "	72.28	76.13	79.33	83.32	86.27	88.23	90.93	92.60
90	2.47 "	66.05	69.52	72.10	75.80	78.30	80.03	82.30	83.72
80	3.53 "	59.67	62.63	64.90	68.02	70.12	71.57	73.52	74.75
70	5.25 "	52.67	55.52	57.42	60.12	61.85	63.08	64.70	65.72
60	7.56 "	46.14	48.26	49.92	52.13	53.53	54.51	55.79	56.59
55	9.17 "	42.48	44.52	45.96	47.93	49.19	50.07	51.23	51.95
50	11.17 "	38.77	40.61	41.93	43.69	44.83	45.62	46.65	47.28
45	13.74 "	35.00	36.62	37.79	39.37	40.38	41.08	42.00	42.57
40	17.27 "	31.66	33.05	34.03	35.35	36.19	36.79	37.53	38.02
35	21.70 "	27.77	28.98	29.68	30.99	31.72	32.22	32.88	33.28
30	27.43 "	23.74	24.78	25.52	26.50	27.13	27.58	28.14	28.50
25	34.90 "	19.36	20.27	20.93	21.82	22.39	22.79	23.29	23.63
	H.P. HOURS PER 1000 GROSS-TON MILES (TRAILING)								
110	.95 W	127.26	122.10	118.85	113.85	110.96	109.04	106.62	105.16
100	1.70 "	82.83	79.24	76.98	73.86	71.95	70.67	69.06	68.10
90	2.47 "	62.74	60.19	58.44	56.11	54.69	53.74	52.56	51.85
80	3.53 "	48.72	46.82	45.46	43.76	42.68	41.97	41.08	40.54
70	5.25 "	38.21	36.83	35.84	34.53	33.72	33.17	32.55	32.12
60	7.56 "	30.71	29.62	28.84	27.85	27.27	26.91	26.40	26.09
55	9.17 "	27.43	26.44	25.73	24.94	24.43	24.09	23.66	23.42
50	11.17 "	24.66	23.77	23.17	22.41	22.03	21.74	21.38	21.16
45	13.74 "	22.12	21.31	20.84	20.20	19.82	19.57	19.25	19.06
40	17.27 "	19.71	19.09	18.67	18.15	17.84	17.64	17.38	17.22
35	21.70 "	17.77	17.23	16.86	16.42	16.15	15.97	15.74	15.61
30	27.43 "	16.32	15.84	15.51	15.11	14.88	14.71	14.51	14.39
25	34.90 "	15.56	15.07	14.74	14.34	14.09	13.93	13.72	13.60

W - Weight of Locomotive (Engine & Tender) in Tons

TABLE NO. 2

COMPOSITE SUMMARY
MANIFEST FREIGHT TRAINS

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
70	3.78 W	55.90	58.25	59.88	62.18	63.60	64.59	65.89	66.67
60	5.54 "	48.41	50.37	51.70	53.60	54.76	55.56	56.61	57.26
55	6.75 "	44.52	46.30	47.56	49.24	50.28	51.04	51.98	52.55
50	8.25 "	40.68	42.25	43.37	44.65	45.80	46.44	47.29	47.81
45	10.24 "	36.64	38.05	39.05	40.39	41.24	41.82	42.58	43.04
40	12.87 "	32.83	34.06	34.93	36.06	36.79	37.29	37.94	38.33
35	16.18 "	28.70	29.78	30.54	31.54	32.18	32.61	33.19	33.53

H.P. HOURS PER 1000 GROSS TON-MILES (TRAILING)

70	3.78 W	50.69	49.10	48.02	46.67	45.86	45.32	44.64	44.17
60	5.54 "	40.05	38.77	38.05	37.06	36.46	36.06	35.56	35.27
55	6.75 "	35.62	34.58	33.88	33.02	32.50	32.16	31.72	31.46
50	8.25 "	31.88	31.07	30.35	29.61	29.17	28.88	28.50	28.29
45	10.24 "	28.40	27.63	27.11	26.47	26.08	25.82	25.49	25.31
40	12.87 "	25.40	24.75	24.31	23.78	23.46	23.24	22.97	22.81
35	16.18 "	23.03	22.45	22.07	21.58	21.30	21.09	20.87	20.72

W - Weight of Locomotive (Engine & Tender) in Tons

speed, exclusive of time stopped, for various distances between stops; also the horsepower-hours per 1,000 gross ton-miles trailing weight.

Suppose we wish to determine what the effect would be on coal and water consumption and power requirements if we increased the maximum speed of certain coal trains from 45 miles per hour to 60 miles per hour, the locomotives used in this service being a 2–10–2 type, weight on drivers 175 tons, weight of locomotives 240 tons and weight of locomotive (engine and tender) 420 tons. From Table 1 we find that at the maximum speed of 45 miles per hour, a trailing weight can be hauled equal to 13.74 times the weight of the locomotive, or 13.74 times 420 tons or 5,771 tons. At the maximum speed of 60 miles per hour a trailing weight of only 7.56 times 420 tons or 3,175 tons can be hauled. From this it can be seen that in order to haul any given volume of coal per month, say 100,000 tons, at a maximum speed of 60 miles per hour instead of 45 miles per hour, would require an increase of over 80 percent in the number of locomotives and trains. This increase in the number of trains would also result in the same percentage increase in delays, as delays per train vary directly with the number of trains. Wages of train and engine crews would also be increased as well as equipment repairs.

From Table 1 we can also obtain the number of horsepower-hours required per 1,000 gross ton-miles. For a maximum speed of 45 miles per hour and a distance between stops of 25 miles, the horsepower-hours per 1,000 gross ton-miles are 21.31. For a maximum speed of 60 miles per hour and a distance between stops of 25 miles the horsepower-hours per 1,000 gross ton-miles are 29.62. So it is evident that in order to handle any given number of gross ton-miles at this increased maximum speed will require an increase in coal and water consumption of approximately 40 percent.

A preliminary study of the effect of any other increase in maximum speed on power requirements and fuel and water consumption can be obtained in the same manner as above.

The following exhibit is a more detailed discussion of the factors involved and conditions to be considered if a detailed study of the effects of proposed increased speeds is desired.

A

Exhibit A

In studying the cost of operating high speed trains it is important to begin with an analysis of some of the fundamental factors which determine the feasibility of the service and which also have an effect on the cost.

The tables in the body of the report establish the relation which exists between certain of those factors; for example, the relation between the weight of the train and the weight of the locomotive to obtain any desired speed on various grades for three classes of trains, namely passenger trains, coal and ore trains and manifest freight trains.

The tables also show the relation between the maximum and average speed for trains on level tangent track making frequent stops, and the horsepower-hours required to obtain these average speeds. The average speeds do not include any allowance for the duration of stops because this time is a variable which must be allowed for separately.

The horsepower-hours are based on the boiler output (excluding power for auxiliaries) and therefore are proportional to the fuel and water required to perform the desired service. Thus in the early stages the feasibility of performing any service and the magnitude of some of the items involved can be partially determined from these tables.

In developing the tables for steam locomotives it has been necessary to take account of some of the factors connected with the design and also some of those which have to do with operation. The purpose of this exhibit is to present some explanatory notes regarding those details for reference in case they are desired.

I. Design
- (a) Tracking qualities of locomotives
- (b) Weights of locomotives
- (c) Horsepower capacities
- (d) Types of trains
- (e) Train resistance

II. Operation
- (a) Grades and curves
- (b) Weights of trains
- (c) Frequency of stops
- (d) Slow downs
- (e) Power consumption

I. Design

(a) *Tracking qualities.*—The tracking qualities of a locomotive depend upon the mechanical design and construction and are more or less reflected by the wheel arrangement.

(b) *Weights of locomotives.*—The weights of locomotives depend upon the wheel arrangement and the permissible weight per axle which in turn is fixed by or determines the type of roadbed and track construction that is suitable for their operation.

(c) *Horsepower capacity.*—Theoretically the horsepower capacity of a locomotive depends upon its physical dimensions and allowable weight subject to design experience and skill.

For the purpose of this discussion it is assumed that the weight, tracking qualities and horsepower capacities of typical steam locomotives are as set forth in Table 1601 on page 16–15 of the Manual.

Tables 3 to 13 are divided into six groups based on 37.5, 35.0, 32.5, 30.0, 27.5 and 25.0 horsepower per ton on drivers. These horsepowers are typical of one or more types

TABLE NO. 3

PASSENGER OR COAL AND ORE TRAINS
GROUP I (37.5 HP PER TON ON DRIVERS)

		Ratio of Weights
Typical Locomotives	4 - 4 - 2	
Weight on Drivers	70 Tons	1.00
Weight of Engine	143 "	2.04
Weight of Locomotive (Engine & Tender)	253 "	3.62

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
110	.95 W	78.90	83.30	86.70	91.40	94.55	96.80	99.80	101.75
100	1.51 "	72.60	76.40	79.40	83.50	86.40	88.40	91.00	92.70
90	2.25 "	66.15	69.60	72.20	75.85	78.40	80.10	82.40	83.80
80	3.29 "	59.50	62.50	64.70	68.05	70.15	71.60	73.50	74.80

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

110	.95 W	127.26	122.10	118.85	113.85	110.96	109.04	106.62	105.16
100	1.51 "	88.00	84.40	81.92	78.73	76.70	75.38	73.70	72.70
90	2.25 "	65.21	62.64	60.82	58.40	56.96	55.97	54.77	54.05
80	3.29 "	50.00	48.06	46.63	44.81	43.72	42.99	42.09	41.54

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 4

PASSENGER OR COAL AND ORE TRAINS
GROUP II (35.0 HP PER TON ON DRIVERS)

			Ratio of Weights
Typical Locomotives	4 - 4 - 2	4 - 6 - 4	
Weight on Drivers	70 Tons	105 Tons	1.00
Weight of Engine	128 "	192 "	1.82
Weight of Locomotive (Engine & Tender)	224 "	337 "	3.21

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
100	1.79 W	71.65	75.50	78.60	82.85	85.90	87.90	90.70	92.40
90	2.56 "	65.60	69.05	71.80	75.45	78.00	79.80	82.10	83.55
80	3.61 "	59.40	62.40	64.70	67.80	69.90	71.40	73.40	74.60
70	5.10 "	52.60	55.15	57.00	59.65	61.50	62.75	64.45	65.50
60	7.40 "	45.33	47.50	49.30	51.60	53.10	54.10	55.50	56.35
55	9.00 "	41.56	43.60	45.20	47.32	48.70	49.65	50.90	51.70
50	10.90 "	37.83	39.75	41.15	43.05	44.30	45.15	46.30	47.00
45	13.40 "	33.92	35.65	36.90	38.67	39.80	40.55	41.60	42.25

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

100	1.79 W	79.58	76.09	73.71	70.64	68.73	67.45	65.86	64.90
90	2.56 "	61.16	58.63	56.79	54.54	53.12	52.17	50.99	50.28
80	3.61 "	48.10	46.13	44.82	43.13	42.03	41.31	40.42	39.86
70	5.10 "	38.15	36.78	35.80	34.50	33.65	33.04	32.39	31.96
60	7.40 "	30.69	29.49	28.52	27.63	27.01	26.61	26.10	25.79
55	9.00 "	27.39	26.35	25.40	24.72	24.17	23.81	23.32	23.08
50	10.90 "	24.76	23.82	23.18	22.39	21.91	21.59	21.19	20.95
45	13.40 "	22.36	21.53	20.95	20.23	19.80	19.52	19.16	18.94

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 5

PASSENGER OR COAL AND ORE TRAINS
GROUP III (32.5 HP PER TON ON DRIVERS)

Typical Locomotives	4-6-2	2-8-4	4-8-4	Ratio of Weights
Weight on Drivers	105 Tons	140 Tons	140 Tons	1.00
Weight of Engine	173 "	230 "	230 "	1.65
Weight of Locomotive (Engine & Tender)	302 "	404 "	404 "	2.88

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
100	1.79 W	72.60	76.50	80.00	83.60	86.50	88.40	91.10	92.70
90	2.59 "	66.40	69.90	72.30	76.10	78.50	80.20	82.40	83.80
80	3.70 "	60.10	63.00	65.30	68.20	70.30	71.70	73.65	74.85
70	5.26 "	53.00	55.55	57.45	60.20	61.95	63.15	64.75	65.75
60	7.61 "	45.85	47.95	49.60	51.90	53.30	54.33	55.65	56.46
55	9.22 "	42.05	44.05	45.65	47.65	48.95	49.85	51.05	51.80
50	11.13 "	38.46	40.35	41.70	43.50	44.67	45.48	46.55	47.18
45	13.80 "	34.55	36.22	37.45	39.07	40.13	40.90	41.85	42.42

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

100	1.79 W	80.90	77.24	75.30	72.22	70.41	69.17	67.63	66.70
90	2.59 "	61.84	59.30	57.71	55.38	54.00	53.08	51.93	51.23
80	3.70 "	48.07	46.28	44.94	43.35	42.30	41.61	40.73	40.21
70	5.26 "	38.38	36.97	35.97	34.63	33.83	33.30	32.64	32.25
60	7.61 "	30.57	29.49	28.89	27.70	27.11	26.70	26.21	25.91
55	9.22 "	27.46	26.44	25.74	24.87	24.35	24.00	23.56	23.30
50	11.13 "	24.76	23.86	23.16	22.51	22.07	21.77	21.39	21.17
45	13.80 "	22.15	21.37	20.83	20.16	19.76	19.50	19.16	18.96

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 6

PASSENGER OR COAL AND ORE TRAINS
GROUP IV (30 HP PER TON ON DRIVERS)

Typical Locomotives	4-8-2	2-8-4	2-10-4	Ratio of Weights
Weight on Drivers	140 Tons	140 Tons	175 Tons	1.00
Weight of Engine	210 "	210 "	262 "	1.50
Weight of Locomotive (Engine & Tender)	364 "	364 "	455 "	2.60

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
70	5.38 W	53.35	55.85	57.80	60.50	62.10	63.35	64.90	65.90
60	7.77 "	46.18	48.30	49.90	52.13	53.53	54.50	55.80	56.60
55	9.40 "	42.52	44.50	46.00	48.00	49.20	50.05	51.20	51.90
50	11.50 "	38.71	40.60	41.92	43.70	44.82	45.63	46.65	47.30
45	14.00 "	35.15	36.75	37.92	39.45	40.45	41.15	42.05	42.62
40	17.40 "	31.25	32.70	33.70	35.11	35.96	36.60	37.40	37.90
35	21.70 "	27.35	28.60	29.50	30.72	31.50	32.02	32.73	33.15
30	27.30 "	23.25	24.35	25.13	26.20	26.87	27.35	27.97	28.35
25	34.30 "	18.79	19.75	20.47	21.44	22.08	22.52	23.10	23.45

HP. HRS. PER 1000 GROSS TON MILES (TRAILING)

70	5.38 W	38.11	36.74	35.74	34.45	33.69	33.16	32.61	32.14
60	7.77 "	30.44	29.38	28.60	27.64	27.06	26.68	26.20	25.91
55	9.40 "	27.26	26.29	25.63	24.80	24.31	23.98	23.56	23.31
50	11.50 "	24.44	23.53	22.92	22.23	21.80	21.51	21.15	20.93
45	14.00 "	22.10	21.07	20.81	20.18	19.81	19.56	19.25	19.06
40	17.40 "	19.87	19.22	18.78	18.23	17.90	17.69	17.41	17.25
35	21.70 "	18.07	17.49	17.10	16.62	16.32	16.13	15.89	15.74
30	27.30 "	16.72	16.19	15.83	15.39	15.13	14.95	14.73	14.60
25	34.30 "	16.30	15.73	15.35	14.87	14.59	14.40	14.16	14.02

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 7

PASSENGER OR COAL AND ORE TRAINS
GROUP V (27.5 HP PER TON ON DRIVERS)

Typical Locomotives	2 - 8 - 2	2 - 10 - 2	Ratio of Weights
Weight on Drivers	140 Tons	175 Tons	1.00
Weight of Engine	192 "	240 "	1.37
Weight of Locomotive (Engine & Tender)	336 "	420 "	2.40

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
60	7.58 W	46.37	48.53	50.20	52.35	53.70	54.70	55.90	56.70
55	9.19 "	42.93	44.95	46.30	48.20	49.45	50.30	51.40	52.10
50	11.20 "	39.30	41.07	42.34	44.02	45.10	45.86	46.82	47.42
45	13.80 "	35.60	37.15	38.28	39.75	40.70	41.35	42.22	42.75
40	17.30 "	31.68	33.06	34.05	35.35	36.21	36.80	37.55	38.03
35	21.70 "	27.80	29.02	29.85	31.00	31.73	32.23	32.90	33.29
30	27.50 "	23.75	24.78	25.53	26.54	27.15	27.60	28.15	28.50
25	35.00 "	19.35	20.25	20.93	21.80	22.38	22.78	23.28	23.62

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

		20	25	30	40	50	60	80	100
60	7.58 W	30.96	29.87	29.05	28.09	27.52	27.13	26.65	26.36
55	9.19 "	27.52	26.54	25.93	25.11	24.63	24.29	23.88	23.63
50	11.20 "	24.70	23.85	23.30	22.60	22.19	21.91	21.56	21.35
45	13.80 "	22.03	21.32	20.84	20.25	19.90	19.66	19.36	19.19
40	17.30 "	19.69	19.07	18.65	18.14	17.83	17.62	17.36	17.21
35	21.70 "	17.80	17.26	16.88	16.45	16.18	16.00	15.78	15.64
30	27.50 "	16.29	15.80	15.48	15.08	14.87	14.67	14.47	14.35
25	35.00 "	15.49	15.01	14.68	14.28	14.04	13.83	13.68	13.56

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 8

PASSENGER OR COAL AND ORE TRAINS
GROUP VI (25.0 HP PER TON ON DRIVERS)

Typical Locomotives	2 - 6 ≠ 6 - 4	4 - 6 ≠ 6 - 4	Ratio of Weights
Weight on Drivers	210 Tons	210 Tons	1.00
Weight of Engine	300 "	300 "	1.43
Weight of Locomotive (Engine & Tender)	462 "	462 "	2.20

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
60	7.45 W	46.96	49.00	50.60	52.65	54.00	54.90	56.10	56.85
55	9.04 "	43.35	45.50	46.65	48.50	49.65	50.50	51.60	52.25
50	11.10 "	39.53	41.30	42.55	44.20	45.25	46.00	46.95	47.50
45	13.70 "	35.80	37.33	38.42	39.90	40.80	41.45	42.30	42.80
40	17.10 "	32.06	33.38	34.34	35.60	36.40	36.98	37.65	38.12
35	21.70 "	28.17	29.33	30.15	31.25	31.93	32.41	33.01	33.39
30	27.50 "	24.21	25.20	25.89	26.76	27.38	27.80	28.30	28.65
25	35.40 "	19.90	20.75	21.35	22.16	22.69	23.05	23.50	23.80

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

60	7.45 W	30.91	29.87	28.20	27.64	27.44	26.82	26.50
55	9.04 "	27.52	26.59	25.18	24.71	24.39	24.00	23.76
50	11.10 "	24.63	23.81	22.31	22.20	21.93	21.59	21.39
45	13.70 "	21.94	21.24	20.19	19.84	19.61	19.32	19.14
40	17.10 "	19.56	18.97	18.09	17.80	17.60	17.36	17.21
35	21.70 "	17.44	16.94	16.18	15.94	15.77	15.56	15.44
30	27.50 "	15.95	15.52	14.86	14.64	14.50	14.32	14.21
25	35.40 "	14.93	14.51	13.88	13.66	13.52	13.35	13.24

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 9

MANIFEST FREIGHT TRAINS
GROUP II (35.0 HP PER TON ON DRIVERS)

			Ratio of Weights
Typical Locomotives	4 - 4 - 2	4 - 6 - 4	
Weight on Drivers	70 Tons	105 Tons	1.00
Weight of Engine	128 "	192 "	1.82
Weight of Locomotive (Engine & Tender)	224 "	337 "	3.21

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
70	3.60 W	55.45	57.75	59.20	61.85	63.30	64.35	65.70	66.50
60	5.33 "	47.85	49.85	51.30	53.25	54.45	55.30	56.40	57.10
55	6.55 "	43.83	45.70	47.00	48.80	49.90	50.70	51.75	52.35
50	8.00 "	39.90	41.57	42.77	43.37	45.40	46.10	47.05	47.60
45	9.90 "	35.77	37.30	38.40	39.85	40.80	41.45	42.28	42.80

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

70	3.60 W	51.49	49.86	48.72	47.29	46.43	45.86	45.15	44.72
60	5.33 "	40.43	38.78	38.32	37.27	36.64	36.23	35.68	35.38
55	6.55 "	35.86	34.74	34.00	33.07	32.51	32.14	31.67	31.39
50	8.00 "	32.04	31.71	30.43	29.63	29.14	28.82	28.42	28.17
45	9.90 "	28.84	27.97	27.39	26.66	26.23	25.93	25.57	25.35

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 10

MANIFEST FREIGHT TRAINS
GROUP III (32.5 HP PER TON ON DRIVERS)

				Ratio of Weights
Typical Locomotives	4-6-2	2-8-4	4-8-4	
Weight on Drivers	105 Tons	140 Tons	140 Tons	1.00
Weight of Engine	173 "	230 "	230 "	1.65
Weight of Locomotive (Engine & Tender)	302 "	404 "	404 "	2.88

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
70	3.82 W	55.90	58.40	60.10	62.30	63.70	64.70	65.95	66.71
60	5.60 "	48.00	50.10	51.50	53.40	54.60	55.40	56.50	57.17
55	6.80 "	44.15	45.95	47.25	49.00	50.10	51.00	51.90	52.46
50	8.26 "	40.40	42.00	43.15	44.70	45.67	46.33	47.20	47.75
45	10.31 "	36.23	37.69	38.75	40.13	41.02	41.63	42.45	42.95
40	12.70 "	32.23	33.55	34.48	35.70	36.48	37.03	37.73	38.17
35	15.80 "	28.10	29.25	30.07	31.17	31.90	32.35	33.00	33.38

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

70	3.82 W	50.13	48.45	47.41	46.10	45.32	44.80	44.14	43.47
60	5.60 "	39.81	38.51	37.70	36.69	36.08	35.67	35.16	34.86
55	6.80 "	35.50	34.42	33.71	32.81	32.27	31.92	31.44	31.20
50	8.26 "	31.86	30.95	30.34	29.58	29.13	28.83	28.45	28.22
45	10.31 "	28.39	27.57	27.03	26.35	25.95	25.67	25.33	25.13
40	12.70 "	25.77	25.05	24.56	23.98	23.63	23.39	23.09	22.91
35	15.80 "	23.65	23.00	22.57	22.02	21.70	21.48	21.21	21.05

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 11

MANIFEST FREIGHT TRAINS
GROUP IV (30.0 HP PER TON ON DRIVERS)

Typical Locomotives	4-8-2	2-8-4	2-10-4	Ratio of Weights
Weight on Drivers	140 Tons	140 Tons	175 Tons	1.00
Weight of Engine	210 "	210 "	262 "	1.50
Weight of Locomotive (Engine & Tender)	364 "	364 "	455 "	2.60

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
70	3.90 W	55.95	58.30	60.00	62.20	63.60	64.60	65.90	66.68
60	5.71 "	48.35	50.30	51.70	53.55	54.72	55.50	56.60	57.25
55	6.95 "	44.50	46.30	47.58	49.25	50.30	51.00	51.95	52.55
50	8.51 "	40.58	42.15	43.30	44.80	45.75	46.40	47.25	47.78
45	10.50 "	36.66	38.08	39.06	40.40	41.25	41.80	42.58	43.04
40	13.05 "	32.63	33.88	34.76	35.93	36.69	37.20	37.88	38.27
35	16.30 "	28.53	29.62	30.40	31.42	32.07	32.53	33.10	33.44

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

70	3.90 W	50.01	48.54	47.47	46.13	45.33	44.80	44.12	43.72
60	5.71 "	39.64	38.46	37.66	36.67	36.08	35.68	35.18	34.88
55	6.95 "	35.32	34.29	33.60	32.74	32.22	31.88	31.45	31.19
50	8.51 "	31.50	30.62	30.03	29.29	28.85	28.55	28.13	27.96
45	10.50 "	28.27	27.54	26.99	26.35	25.97	25.71	25.34	25.19
40	13.05 "	25.44	24.77	24.33	23.77	23.44	23.21	22.93	22.77
35	16.30 "	23.17	22.57	22.18	21.68	21.39	21.15	20.95	20.80

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 12

MANIFEST FREIGHT TRAINS
GROUP V (27.5 HP PER TON ON DRIVERS)

Typical Locomotives	2 - 8 - 2	2 - 10 - 2	Ratio of Weights
Weight on Drivers	140 Tons	175 Tons	1.00
Weight of Engine	192 "	240 "	1.37
Weight of Locomotive (Engine & Tender)	336 "	420 "	2.40

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
70	3.79 W	56.30	58.55	60.20	62.35	63.80	64.70	66.00	66.77
60	5.57 "	48.70	50.60	51.70	53.80	54.90	55.70	56.70	57.34
55	6.79 "	44.85	46.60	47.80	49.45	50.47	51.15	52.10	52.65
50	8.29 "	41.07	42.65	43.68	45.10	46.00	46.60	47.40	47.91
45	10.29 "	37.10	38.46	39.41	40.67	41.47	42.03	42.75	43.17
40	12.90 "	33.02	34.21	35.07	36.18	36.87	37.38	38.00	38.38
35	16.27 "	28.95	30.00	30.72	31.67	32.30	32.72	33.27	33.61

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

70	3.79 W	51.12	49.56	48.49	47.16	46.35	45.82	45.15	44.75
60	5.57 "	40.17	39.00	38.22	37.24	36.65	36.26	35.77	35.48
55	6.79 "	35.70	34.69	34.01	33.17	32.67	32.33	31.91	31.66
50	8.29 "	31.90	31.05	30.48	29.78	29.35	29.07	28.71	28/50
45	10.29 "	28.36	27.63	27.15	26.55	26.18	25.95	25.65	25.46
40	12.90 "	25.32	24.69	24.27	23.75	23.44	23.23	22.96	22.81
35	16.27 "	22.86	22.31	21.94	21.48	21.21	21.02	20.79	20.66

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 13

MANIFEST FREIGHT TRAINS
GROUP VI (25.0 HP PER TON ON DRIVERS)

			Ratio of Weights
Typical Locomotives	2 - 6 ≠ 6 - 4	4 - 6 ≠ 6 - 4	
Weight on Drivers	210 Tons	210 Tons	1.00
Weight of Engine	300 "	300 "	1.43
Weight of Locomotive (Engine & Tender)	462 "	462 "	2.20

AVERAGE SPEED
EXCLUSIVE OF TIME STOPPED

MAX SPEED	WEIGHT OF TRAIN (TRAILING WEIGHT)	MILES BETWEEN STOPS 20	25	30	40	50	60	80	100
60	5.47 W	49.15	51.00	52.30	54.02	55.12	55.90	56.85	57.46
55	6.68 "	45.28	46.95	48.15	49.68	50.65	51.35	52.20	52.74
50	8.18 "	41.45	42.90	43.95	45.30	46.17	46.77	47.57	48.02
45	10.22 "	37.43	38.73	39.65	40.88	41.65	42.17	42.85	43.25
40	12.81 "	33.45	34.60	35.40	36.45	37.10	37.55	38.13	38.50
35	16.33 "	29.23	30.25	30.95	31.90	32.45	32.85	33.38	33.69

HP HRS. PER 1000 GROSS TON MILES (TRAILING)

60	5.47 W	40.21	39.09	38.34	37.41	36.85	36.47	36.01	35.73
55	6.68 "	35.70	34.74	34.10	33.31	32.83	32.51	32.11	31.88
50	8.18 "	32.09	31.00	30.47	29.79	29.39	29.12	28.79	28.58
45	10.22 "	28.15	27.46	27.00	26.43	26.09	25.86	25.57	25.40
40	12.81 "	25.06	24.48	24.09	23.61	23.32	23.13	22.89	22.74
35	16.33 "	22.43	21.92	21.57	21.14	20.89	20.72	20.51	20.38

W - Weight of Locomotive (Engine & Tender) in Tons.

of locomotives which are shown at the top of each table and correspond to the definite weight distributions shown in the right-hand columns in the headings for each table. For example, it is assumed that for locomotives in Group II the engine weighs 1.82 tons and the engine and tender weighs 3.21 tons for every ton on drivers and for Group III the engine weighs 1.65 tons and the engine and tender 2.88 tons per ton on drivers. Thus the ratio of the weight of the engine to the weight on drivers will indicate in which group (or between which groups) the locomotive belongs. It is then necessary to assume what the weight of the locomotive (engine and tender) is, obtaining this weight by multiplying the weight on drivers by the corresponding ratio shown for typical locomotives, which in the case of Group II is 3.21 and for Group III is 2.88.

(d) *Types of trains.*—In practice there are four types of trains which need to be considered, namely, passenger trains, coal and ore trains, manifest freight trains and trains consisting of empty cars.

It is assumed that typical passenger trains will consist of 60-ton vestibule cars, coal and ore trains of 80-ton freight cars and manifest freight trains of 45-ton freight cars. No data have been worked up for empty trains.

Modern types of passenger cars are lighter than standard vestibule equipment and are streamlined which would be expected to modify the results of passenger train operation. The following discussion on train resistance clarifies this point.

(e) *Train resistance.*—The resistances of the typical trains have been based on the Davis formulas because they are regarded as more or less standard and because the results of some recent high speed tests made by the Mechanical Division with a train composed of 60-ton vestibule passenger cars checked closely with the Davis formulas and other tests with 80-ton freight cars also conformed with the Davis formula.

By referring to Fig. 1 it will be seen that the resistances of 60-ton vestibule passenger cars and 80-ton freight cars as obtained by the Davis formulas are practically the same.

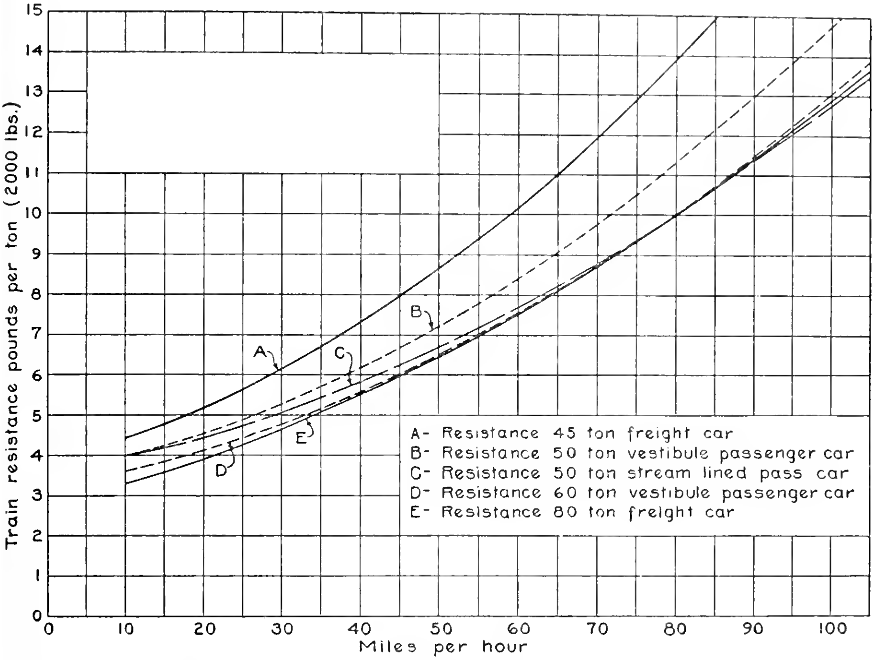


Fig. 1.—Chart of Davis Formulas for Train Resistances of Passenger and Freight Cars.

For this reason data pertaining to coal and ore trains also apply to passenger trains composed of 60-ton vestibule cars.

If it is assumed that streamlining reduces the effective cross section of passenger cars 25 percent then the resistance of 50-ton streamlined cars will also approximate the resistance of 80-ton freight cars and the same data will apply to 50-ton streamlined passenger cars.

Ordinarily it can be assumed that any other steps, such as articulation or reduced cross section which are available for reducing the weight of passenger cars still further, will reduce the resistance of the train. Consequently on this basis the data given for coal and ore trains cover a wide variety of passenger trains of the same total weight.

In the case of freight trains there is no practical way to compensate for the higher resistance of the lighter weight per car, hence it has been necessary to work up separate tables based on 45-ton cars for manifest freight trains. These tables are shorter than those for passenger or coal and ore trains because there is practically no demand for speeds in excess of 70 miles per hour or for trains in excess of 140 to 150 cars in manifest service.

II. Operation

(a) *Grades and curves.*—Grades and curves have a modifying effect on all the relations which are shown in the tables, because they effect the train resistance, the speed and weight of trains, and also the power consumption. These effects are in some respects susceptible of mathematical determination but they are also the cause of speed restrictions which are unpredictable.

TABLE NO. 14

MAXIMUM SPEEDS WITH VARIOUS WEIGHT TRAINS

ON DIFFERENT GRADES

PASSENGER OR COAL AND ORE TRAINS

MAX SPEED	PERCENT GRADE -0.2	-0.1	Level	0.1	0.2	0.4	0.6	1.0
110	1.69 W	1.26 W	.95 W	.71 W	.52 W	.25 W	.07 W	0.00 W
100	2.91 "	2.19 "	1.70 "	1.33 "	1.06 "	.66 "	.40 "	.06 "
90	4.35 "	3.21 "	.2.47 "	1.95 "	1.56 "	1.04 "	.68 "	.26 "
80	6.59 "	4.66 "	3.53 "	2.77 "	2.23 "	1.52 "	1.06 "	.51 "
70	10.62 "	7.14 "	5.25 "	4.08 "	3.28 "	2.25 "	1.62 "	.90 "
60	17.39 "	10.68 "	7.56 "	5.76 "	4.58 "	3.14 "	2.29 "	1.33 "
55	23.06 "	13.30 "	9.17 "	6.89 "	5.45 "	3.72 "	2.72 "	1.62 "
50	31.27 "	16.65 "	11.17 "	8.25 "	6.48 "	4.40 "	3.23 "	1.94 "
45		21.24 "	13.74 "	10.01 "	7.79 "	5.27 "	3.87 "	2.36 "
40		27.84 "	17.27 "	12.35 "	9.54 "	6.40 "	4.70 "	2.91 "
35		36.74 "	21.70 "	15.23 "	11.64 "	7.75 "	5.70 "	3.56 "
30			27.43 "	18.84 "	14.24 "	9.40 "	6.90 "	4.33 "
25			34.90 "	23.37 "	17.45 "	11.42 "	8.34 "	5.27 "

W - Weight of Locomotive (Engine & Tender) in Tons.

TABLE NO. 15

MAXIMUM SPEEDS WITH VARIOUS WEIGHT TRAINS

ON DIFFERENT GRADES

MANIFEST FREIGHT TRAINS

MAX SPEED	PERCENT GRADE -0.2	-0.1	Level	0.1	0.2	0.4	0.6	1.0
70	6.30 W	4.75 W	3.78 W	3.10 W	2.59 W	1.87 W	1.38 W	.79 W
60	9.76 "	7.13 "	5.54 "	4.46 "	3.69 "	2.66 "	2.00 "	1.20 "
55	12.52 "	8.86 "	6.75 "	5.39 "	4.43 "	3.19 "	2.38 "	1.49 "
50	16.25 "	11.05 "	8.25 "	6.52 "	5.33 "	3.80 "	2.86 "	1.79 "
45		14.03 "	10.24 "	7.97 "	6.49 "	4.60 "	3.47 "	2.19 "
40		18.12 "	12.87 "	9.88 "	7.95 "	5.61 "	4.24 "	2.70 "
35			16.18 "	12.23 "	9.75 "	6.83 "	5.15 "	3.31 "

W - Weight of Locomotive (Engine & Tender) in Tons.

(b) *Weights of trains.*—Tables 14 and 15 show the relation between the maximum speed and weight of train for a number of different grades starting with —0.2 percent and increasing up to +1.0 percent. These data are only indicative because they are difficult to apply in practice, so that over an actual profile it is generally necessary in the final analysis to resort to first principles.

(c) *Frequency of stops.*—The relation of the average speed to the maximum speed for trains on level track making frequent stops varies somewhat with different types of locomotives. When the distance between stops is short it is sometimes impossible for the train to reach maximum speed before applying brakes. In this study, the ratio of average speed to maximum speed is based upon:

1. Operation of the locomotive at normal capacity
2. An assumed uniform braking distance for all speeds of 75 miles per hour or less and a uniform retardation rate for speeds in excess of 75 miles per hour

Normal horsepower capacities are based on Table 1601 in the Manual. The time and distance consumed in braking will vary with the type of train, speed, manner in which brakes are applied and the type of brake equipment. Tables 1 to 13 are based on the average of several classes of locomotives and give a reasonably close approximation of speed relations. Should the method outlined be employed in the examination of any typical operation, appropriate factors, applicable to the service on the railway involved, must be substituted. The heavy dividing lines in the tables have been inserted to indicate the approximate distance between stops required, under the stated conditions of acceleration and braking, to permit the attainment of maximum speed before the brakes must be applied.

When using these tables it is important to adjust for the duration of stops, and include an allowance for slow downs.

(d) *Slow downs.*—It is variously estimated that two to three slow downs from maximum to 70 percent speed on level track for a distance of ½ mile are equivalent to making a stop. Two slow downs correspond to high speed passenger trains and three slow downs to slow speed drag freight trains.

The time lost making stops can be obtained by speed-time-distance calculations according to the method presented in Chapter 16 of the Manual.

(e) *Power consumption.*—The horsepower-hours are based on the normal output of the boiler exclusive of auxiliaries. It is generally assumed that 1.0 horsepower-hour is equivalent to 15 lb. of steam, and that 15 lb. of steam corresponds to 30,000 to 32,000 B.t.u. fired, or about 2.3 lb. of 13,000 to 14,000 B.t.u. of coal per horsepower-hour.

Some authorities include the steam required for auxiliaries and use 18 lb. of steam per horsepower-hour or 36,000 to 39,000 B.t.u. fired. This is equivalent to about 2.75 lb. coal per horsepower-hour. In the final analysis it is usually more satisfactory to make separate allowances for auxiliaries.

Conclusions

It will appear from the application of the data contained in these tables that high speed has a wide-spread influence not only as regards fuel and water consumption, crew wages, and way and equipment maintenance, but also as regards capital expenditures.

Actually, the operating expenses and capital expenditures will very likely be greater than those anticipated, based on the theoretical data presented in this report.

This report is offered as information.

Report on Assignment 8

Economics of Railway Location and Operation as Affected by Railway Electrification

Collaborating with Electrical Section, Engineering Division, AAR

E. E. King (chairman, subcommittee), T. B. Ballantyne, V. T. Boughton, L. E. Dale, E. K. Eugene, F. N. Nye, E. H. Roth, H. A. Shinkle, C. B. Stanton, H. M. Stout.

This year the subcommittee has brought together data on the electrification of steam railroads in Mexico, Cuba, Costa Rica, Argentina, Bolivia, Brazil, Chile, Venezeula, Australia, and New Zealand. These data are shown in Table 1. The materials for all of these countries except Brazil were obtained by United States consuls, commercial attaches, and trade commissioners in those several countries upon the request of the Railway Section, Transportation Division, Bureau of Foreign and Domestic Commerce, Department of Commerce of the United States. The division has been very generous in its help in getting together these data for the use of the subcommittee. The information on the Paulista Railway in Brazil was obtained directly from charts, profiles, and tables secured by the United States embassy in Rio de Janeiro. That for the other two lines in Brazil, the Western Minas and the Central Railway of Brazil, was obtained from the report of the Electrification committee of the National Electric Light Association as indicated in its last issue, Publication No. 247, March 1933, Electrification of Steam Railways, and from the issues of the *Railway Gazette*, London.

Table 1 shows the locations of the electrified sections, the gage of the track, the total number of miles electrified, and gives information concerning tunnels, ruling grades, systems of electrification, kinds of traffic involved, number and capacity of motive-power units, energy requirements, and reasons for electrification. As the last column of the table indicates, some of these lines were electrified on account of tunnel operation, some on account of heavy grades, some on account of scarcity of fuel, some on account of density of traffic, and some to bring about general economy in operation.

Practically all installations are direct current with overhead type of distribution system. The voltages on the d.c. projects vary from 600 to 3,000. The only a.c. installations are on the Pacific Electric Railway in Costa Rica, where the power is single phase with a voltage of 15,000, and on the Guaqui to La Paz Railway in Bolivia, where the power is three phase with a voltage of 575. In suburban service, motor cars are commonly used, but for through freight and passenger service, locomotives are generally employed.

With the exception of one line, The Chile Iron Mines Company, the report includes only those lines that were at one time operated wholly or in part by steam power, but which are now operated in part, at least, by electric power supplied from a central station.

It was the intention of the subcommittee to secure data on all of electrified lines of the eastern hemisphere as well as those of the western, but the war conditions have made this undertaking practically impossible. This completes the study of this phase of the economics of railway location and operation as affected by railway electrification. It is hoped that at some later date when conditions throughout the other countries have become more stabilized, that the subcommittee will be able to secure data on their electrifications and to include them in a report similar to this one.

The report is submitted as information.

TABLE 1 PRINCIPAL CHARACTERISTICS OF STEAM RAILROAD ELECTRIFICATIONS ON LINES THROUGHOUT THE WORLD

FOR STATISTICAL YEARS INDICATED

Continent	Country	Railway	Location	Gage In	Miles Electrified: Route	Miles Electrified: Main Track	Miles Electrified: All Tracks	End of Statistical Year	Ruling Grade Against Heaviest Traffic: %	Ruling Grade: Length ft	Tunnels: No	Tunnels: Length ft	System of Electrification: Current	Volts	Phase	Cycle	Contact Line	Year Electrification Began	Year Electrical Operation Began	Freight Locomotives: No	Freight Loco: Weight Tons (2000 lb)	Freight Loco: Tractive Effort lbs	Freight Loco: H P	Passenger Locomotives: No	Passenger Loco: Weight Tons (2000 lb)	Passenger Loco: Tractive Effort lbs	Passenger Loco: H P	Passenger Motor-Cars: No	Motor-Cars: Weight Tons (2000 lb)	Motor-Cars: Tractive Effort lbs	Motor-Cars: H P	KW-Hrs of Energy Supplied During the Last Year: Generated	Purchased	Total Consumed	Traffic Affected	Principal Reasons for Electrification
NORTH AMERICA	UNITED STATES	See report in Proceedings of A R E A Vol 40, 1939, page 180																																		
	CANADA	ditto	ditto																																	
	MEXICO	El Potosi Ry (Smelter Line)	Near Chihuahua	30	18	18	23	12/31/38	1.50 1.57-3.77	6580 Mountain section	1	500	D.C.	600	-	-	O.H.	1924	1925	5 2	25 13	11,500 5,980	400 200	-	-	-	-	-	-	-	-	0	1,280,600	1,280,600	Freight	Greater Efficiency of Elec. Power
		Mexican Ry Co Ltd	Esperanza to Paso del Macho	56.5	64	64	75	1938	4.70	52,800	16	3,409	D.C.	3000	-	-	O.H.	1923	1925	12[a]	154.5	54,000	2800	SEE FREIGHT				-	-	-	-	0	17,520,000	17,520,000	Freight	Heavy Grades; Congestion; Heavy Repair Expenses
	CUBA	Hershey Cuban Ry	Havana to Matanzas	56.5	81	81	103	1939	2.50	4,237	0	0	D.C.	1200	-	-	O.H.	1919	1920	11	60	20,000	820	-	-	-	-	21	32.5	1800	220	0	5,241,808	5,241,808	Passenger	Heavy Grades, Fuel scarce
		Hershey Terminal Ry	Casa Blanca - Regla	56.5	3.5	3.5	6.0	1939	2.11	360	0	0	D.C.	1200	-	-	O.H.	1919	1920	Uses Hershey Cuban Ry Rolling Stock																
		United Railways of Havana	Havana & Suburbs	56.5	84.4	103.2	143.2	6/30/39	1.56	4,560	0	0	D.C.	600	-	-	O.H.	1905	1906	8 5	40 60	20,000 30,000	640 800	[illegible]	36.60 38.37 25.50 8.42	14,640 14,658 9,160 6,570	300 380 240 80	-	-	-	-	0	3,142,810	3,142,810	Passenger & Freight	Economy
CENTRAL AMERICA	COSTA RICA	Pacific Electric Ry	San Jose to Puntarenas, Circuelas to Alajuela and El Roble to Esparata	42	87	87	92	1938	2.50	22,966	1	1,100	A.C.	15000	1	20	O.H.	1929	1930	10[a]	66	39,648	800	SEE FREIGHT				13				6,465,400	0	6,465,400	General & Freight	Water abundant; High Cost of Coal
SOUTH AMERICA	ARGENTINA	Central Argentine Ry	Buenos Aires to Tigre Central, Tigre East, and KM 24 on Main Line to Rosario	66	44	94	120	6/30/39	0.8	5,906	0	0	D.C.	800	-	-	3R	1916		-	-	-	-	-	-	-	-	111 79	62 58	11,200 10,800	630 500	81,723,288	0	73,421,850	Suburban Passenger	Improve Schedules
		Buenos Aires Western Ry	Buenos Aires to Moreno	66	22	63	82	1937	3.80	410	2	18,762	D.C.	800	-	-	3R	1915	1923	2	70	19,700	920	-	-	-	-	74	63	13,600	800	0	35,405,460	35,405,460	Freight & Suburban	Improve Service; Increase Capacity, Tunnel Operation
		Argentine Transandine																																		
	BOLIVIA	Guaqui to La Paz Ry	La Paz to Alto	39.4	5	7	9	1939	7.00	1,476	0	0	A.C.	575	3	50	O.H.		1905	3	22	6500	200	2	220	7200	250	3	100		100	0	469,799	420,000	Passenger & Freight	Shorter Ascent & use Average Grade of 6.5%, Fuel Economy
	BRAZIL	Paulista Ry	Jundiahy to Rincão	63.0	179	206	252	1939	1.80	29,651	0	0	D.C.	3000	-	-	O.H.	1919	1922	8 4 2 8	100 147.3 117 118	30,600 45,100 40,260 37,400	1600 2418 1610 1590	4 5 4 3 1 1	120 147.3 182 142 133 111	15,680 30,600 34,500 56,000 28,100 21,000	1600 2418 4050 2140 3140 2130	-	-	-	-	0	69,469,275	69,469,275	Passenger & Freight	High Cost of Imported Coal; Improve Traffic
		Western Minas Ry	Barra Mansa to Augusto Pestana	39.4	46		48	1933	2.08	158,400			D.C.	1500	-	-	O.H.	1927	1929	8			960					-	-	-	-				Passenger & Freight	High Cost of Imported Coal; Improve Traffic
		Central Ry of Brazil	Rio de Janeiro to Nova Iguassu and branch line from Deodoro to Bangu	63.0	27		82	1937					D.C.	3000	-	-	O.H.	1936	1937	15	84		1,580	5 6 Mixed	143 52		2862 700	-	-	-	-				Passenger & Freight	Dense Traffic; Steep Grades
	CHILE	Bethlehem Steel Co. Chile Iron Mines Co. Caleta-Cruz Grande - El Tofo	Tofo to Cruz Grande	56.5	15	15	18.6	1939	0	-	0	0	D.C.	2400	-	-	O.H.	1914	1922	3	120	42,200	1,370	-	-	-	-	-	-	-	-	742,600	0	739,600	Freight	Heavy Grades; Water scarce
		Compañía Salitrera Anglo-Chilean Tocopilla-Toco Ry	Tocopilla to Tigre, Toco & Pedro de Valdivia	42	24	24	33	6/30/39	4.50	126,720	0	0	D.C.	1500	-	-	O.H.	1927	1927	7	66	28,460	1,118	-	-	-	-	-	-	-	-	0	5,465,664	5,465,664	Freight & Mixed	Heavy Grades; Fuel & Water scarce
		Southern Section Chilean State Ry	Valparaiso to Los Andes & Santiago	66.1	144	181	245	1939	2.25	48,230	6	3,498	D.C.	3000	-	-	O.H.	1921	1924	15	113	34,729	1,680	10 Express 9 Local	126.8	28,180	2250 1500	-	-	-	-	0	48,387,744	48,387,744	Passenger & Freight	Heavy Grades; Fuel scarce; Increase Capacity
		Juncal Transandine Ry Chilean Transandine Ry	Rio Blanco, Chile to Argentine Border	39.4	22	22	24	1939	8.00	5,709	51	21,080	D.C.	3000	-	-	O.H.	1925	1927	3	94	16,200	888	SEE FREIGHT				-	-	-	-	0	802,530	802,530	Passenger & Freight	Heavy Grades, Tunnels; Fuel scarce
	VENEZUELA	La Guaira & Caracas Ry	La Guaira to Caracas	36.0	23	23	25	12/31/38	4.25	101,711	8	1,312	D.C.	1600	-	-	O.H.	1926	1928	6	355	3,660	456	-	-	-	-	4	30.8	1,180	264	1,560,000	0	592,800	All Traffic	Fuel scarce; Improve Service
OCEANIA	AUSTRALIA	New South Wales Government Railways	Sydney & Suburbs	56.5	94	231	281	6/30/39	3.33 2.50	2,865 983	3	20,872	D.C.	1500	-	-	O.H.		1926	-	-	-	-	-	-	-	-	456	53.76 56.84	10,000 14,000	2 @ 360	474,259,177	0	203,714,725	Passenger	Increase Capacity, Accelerate Services; Underground Operation
		Victorian Railways	Melbourne & Suburbs	63.0	173	349	439	6/30/38	3.30	3,168	3	1,075	D.C.	1500	-	-	O.H.		1919	12	61.6	22,150	620					359	53			179,747,383	3,194		Suburban Passenger	Increase Capacity
	NEW ZEALAND	New Zealand Government Railways	Otira to Arthur's Pass	42	8	8	13	3/31/39	3.15	33,000	1	28,092	D.C.	1500	-	-	O.H.	1920	1923	5[a] 3	56 54	14,000 18,000	680 1240	SEE FREIGHT				-	-	-	-			1,872,200	Passenger & Freight	Long Tunnel & Steep Gradient
			Christchurch to Lyttleton	42	6	11	19	3/31/39	0.67	3,960	1	8,514	D.C.	1500	-	-	O.H.	1926	1939	6[a]	56	14400	1188	SEE FREIGHT				-	-	-	-			2,239,960	Suburb Pass & Frt	Tunnel
			Wellington to Paekakariki	42	26	41	57	3/31/39	1.75	5,280	7	21,325	D.C.	1500	-	-	O.H.	1931		8[a]	97.5	18,000	1240	SEE FREIGHT				-	-	-	-				Main Line and Suburb Pass & Freight	Tunnel & Gradients
			Wellington to Johnsonville	42	6	6	8[b]	3/31/39	2.78	700	7	3,104	D.C.	1500	-	-	O.H.	1935	1938	1[a] One of the 8 above to be used interchangeably on this and the Wellington-Paekakariki Line								6	48	10,000	660			1,694,960	Suburb Pass & Freight	Tunnels & Gradients

(b) Not including Wellington Yard

(a) Freight & Passenger Service

Report on Assignment 11

Train Resistance of Freight Trains Under Various Conditions of Loading and Speed

L. K. Sillcox (chairman, subcommittee), J. A. Anderson, J. W. Barriger III, L. E. Dale, J. M. Farrin, A. W. Laird, M. F. Mannion, L. G. Morphy, J. W. Porter, O. E. Selby, R. R. Strother.

Foreword

The organization of a new subcommittee and the assignment of investigation of freight train resistance inaugurates a new subject for report by Committee 16. Various elements of train resistance have been studied as specially assigned subjects of AREA committees at various times. The work of this committee then consists of investigating all available data bearing upon the subject, evaluating their appropriate application under modern conditions and, if possible, presenting a final preferred method with modifying factors to meet specific conditions.

This introductory report endeavors to assemble many of the general train resistance formulas, both freight and passenger, which have had at least limited or local use through the years and to discuss the effect of various train resistance components. Factors derived through the operation of passenger trains have been reported since many resistance components have their equivalents in both principal services and many of the best train resistance data have been accumulated through the operation of test passenger trains.

Train Resistance

Train resistance, the combination of forces which must be overcome to set a train in motion, continue it in motion at a constant speed, or to accelerate it to a higher speed, is customarily divided into two main divisions; first, those resistances inherent to all train operation; and second, those encountered only on grades, curves, during the acceleration cycle, or when operating in adverse winds, called incidental resistances. They may be segregated as follows:

A. Inherent Resistances
  1. Track or flange resistance
  2. Rolling resistance
  3. Oscillatory and miscellaneous frictional resistance
  4. Journal friction
  5. Air resistance in still air

B. Incidental Resistances
  1. Grade resistance
  2. Curve resistance
  3. Acceleration resistance
  4. Wind resistance

In addition to the above, there is to be considered the machinery friction of the steam locomotive and the motor gearing, bearing, and other transmission losses of electric or Diesel-electric power units, active between the power source and the rails, but this resistance does not enter into practical consideration of power requirements inasmuch as power ratings are usually referred to tractive effort at the rail.

Inherent Resistances

Inherent resistances are defined as those met when operating at constant speed on tangent, level track in still air. As will be noted from the preceding paragraph, they arise from five main sources:

A (1) *Track or Flange Resistance.*—As the car truck moves along the rails, it generally oscillates laterally, the wheel flanges bearing first upon one rail then the other, at each impact introducing a force tending to change its direction. Further, frictional resistance results from the rubbing action between wheel flanges and rail heads. Light equipment exhibits this oscillating or nosing tendency to a greater degree than do the heavier, conventional cars with their greater inertia combined with six-wheel trucks resisting the development of resonant oscillation. Moreover, a wheel flange throat, worn to a shorter radius than that of the rail head, superimposes a wedging action between the flange and rail head, materially increasing the rubbing friction between the two surfaces.

A (2) *Rolling Resistance.*—Low track joints and track in poor surface from any cause aggravate the condition, since the impact at speed of a car wheel upon any track irregularity initiates or intensifies the oscillatory motion and increases flange pressure. A resilient track structure constantly presents an uneven surface to the rolling wheel, introducing an equivalent adverse grade, the extent of the tendency varying directly with the yielding properties of the track. Rolling resistance is so closely associated with track and lateral oscillatory resistances that it is impossible to segregate and measure the effect of any one component. The deformation of the wheel and rail surfaces extends further into a bending and depression of rails, thus providing an uneven track, indirectly augmenting flange pressure.

A (3) *Oscillatory and Miscellaneous Frictional Resistance.*—Oscillatory or miscellaneous frictional resistance as here defined is intended to include all undirected but unavoidable motions which are incidental to train operation; the swaying and interaction of car bodies with consequent energy absorption, spring compression and recoil, recurrent surges throughout the train, friction at coupler faces, journal box pedestals, bolsters, and center plates, along with many other miscellaneous unproductive motions, combine to form an important fraction of total train resistance.

A (4) *Journal Friction.*—Journal friction arises from contact between the rotating axle journal and its relatively stationary bearing. This resistance component varies over a wide range of values depending directly upon journal box temperature, viscosity and other characteristics of the lubricant employed, and its proper distribution between journal and bearing. Indirectly, atmospheric temperature and length of period of rest or motion are important in so far as they influence bearing temperatures. Much of the lubricant is squeezed from the journal bearing of a car at rest, draining into the journal box, leaving a partially and poorly lubricated surface. The viscosity of the oil may be increased due to lower temperature, increasing its shearing resistance.

A (5) *Air Resistance in Still Air.*—Head-end resistance, the most important of these components when rail motor cars and very short trains are operated, is a function of frontal area, shape and nature of the surface, and vehicle speed. It is due to displacement of the air by a vehicle and the production of a high pressure zone through which the vehicle endeavors to press. Rear-end suction is closely associated with head-end resistance but is negative in its effect, retarding forward motion of the vehicle. Air resistance of a locomotive is reported by Goss to be approximately four times the corresponding resistance of the last car of a train, based upon laboratory tests conducted in still air. Rear-end suction is dependent upon tail fairing, cross-sectional area at the rear, and train speed. Mathematically, it combines readily with head-end resistance, responding to similar factors, and generally is so treated. Skin friction is caused by the dragging action created by the relative motion of air with respect to the sides of car bodies and the formation of eddies and pressure strata. As train length increases, skin friction dominates in air resistance effects. It can be controlled by provision of smooth car sides and roofs, which carry less depth of air in the high pressure stratum adjacent to the exposed areas, reducing eddy and shearing resistances. Ground effects, truck resistances, and the obstruction to free air flow created by attachments beneath car floors combine all the effects of head-end, rear-end suction, and skin friction in a complex and still indeterminable manner.

Incidental Resistances

Incidental resistances are those which are not common to train operation under all conditions.

B (1) *Grade Resistance.*—Grade resistance is a fixed and unalterable quantity which is dependent only upon the rate of rise of track. It is equal to 20 lb. per ton of train weight per one percent of grade, or 0.3788 lb. per ton of train weight per foot rise per mile.

B (2) *Curve Resistance.*—Curve resistance arises; first, from the additional force required to change direction of motion along a curved path; second, from the slippage of wheels fixed to a common axle traversing rails of different lengths; and third, from the increased and sustained flange pressure. Practice superelevates the outer rail to compensate at least partially for the centrifugal action of vehicles as they negotiate curves but the amount of superelevation provided can be perfectly adapted only to one speed for any given degree of curvature and height of center of gravity of locomotive or car equipment. Curve resistance may be reduced by the use of rail or flange lubricators, as disclosed in the report of Committee 16 on page 151 in Vol. 41 of the Proceedings. Experiments have furnished various values for the allowance necessary for curve resistance but it is customarily taken as 0.8 lb. per ton per degree of curvature regardless of train speed except for locomotives with their longer wheel bases and guiding duties where it is taken as two pounds per ton of weight on drivers.

B (3) *Acceleration Resistance.*—The resistance which opposes increase in speed of a vehicle is termed acceleration resistance and, when expressed in terms of pounds per ton, is dependent only upon the acceleration rate. From the basic equation, $F = ma$, where F is the force in pounds required to accelerate mass, m, at a rate of "a" feet per second per second, can be developed the formula:

$$F = 91.1 \frac{V_2 - V_1}{t}$$

where $\frac{V_2 - V_1}{t}$, the ratio of increase of speed to time, represents average acceleration rate during time, "t". Here V_1 and V_2 are initial and final speeds, expressed in miles per hour and referred to time "t" in seconds. To include the inertia effect of rotating wheels it is necessary to increase this value by an estimated five percent from which:

$$F = 95.65 \frac{V_2 - V_1}{t}$$

When applied to problems involving electric cars, the coefficient is increased to 100 in recognition of the rotational inertia of traction motor rotors. In this case:

$$F = 100\,\frac{V_2 - V_1}{t}$$

$$\text{or } F = 100\,A$$

Where A = acceleration rate in miles per hour per second, if it is desired to express F directly in terms of acceleration.

B (4) *Wind Resistance.*—Adverse natural winds increase the resistance of trains at a rate which varies approximately with the square of the speed. Early investigators of train resistance ignored this source of power consumption or interpreted it quite inaccurately as is evidenced by the omission of any term containing the second power of speed. Wind resistance differs from the resistance of trains in still air only in its possibility of directional effects. That is, with a head wind (zero deg. yaw, the angle between the longitudinal axis of the train and wind direction) the effect is only that of increasing relative train speed by an amount equal to wind speed when confronted by a directly opposing wind or decreasing the speed of the train relative to the air in a tail wind. As the direction of opposing air flow varies from 0 deg. yaw, its effect is intensified until the worst condition is reached at 45 deg. yaw (quarterly wind). Side winds force wheels against rail heads, thereby increasing flange pressure and its accompanying flange friction a measurable amount. Wind tunnel tests conducted in recent years have been of great value in comparing one vehicle contour against another; the advantage of various expedients such as shrouding, recession of protruding accessories, etc., having been determined.

A study of the numerous train resistance formulas written in an effort to accurately predict requirements of a given train, well indicates improvement in the understanding of all the elements involved. It has been noted that, in many cases, early equations contain no term variable with the second power of vehicle speed. Sometimes no effort was made to associate the general equation with variable speed, and the effect of average car weight was neglected. Representative equations and their sponsors are listed below. These, of course, are not recommended for use but are presented as of historical interest, illustrative of the refinements incorporated in present-day, accepted formulas when viewed in the light of their predecessors.

Train Resistance Formulas

R = resistance in pounds per ton
R_t = resistance in pounds (total)
R_a = air resistance in pounds
R_m = machinery resistance in pounds
V = speed in miles per hour
W = weight of train in tons
C = number of cars in train
A = frontal area in square feet
W_a = weight per axle in tons
n = number of axles
P = weight of power unit in tons
T = weight of trailing unit in tons
L = length of train in feet
G = perimeter of cross-section in feet
t = weight on drivers in tons
n_1 = number of driving axles
t' = total weight of locomotive and tender in tons
n' = total number of locomotive and tender axles

Source	*Formula*	*Notes*
D. K. Clark	$R = 7.2 + 0.0053\, V^2$	Date: 1855
Baldwin	$R = 3 + \frac{V}{6}$	
Engineering News	$R = 2 + \frac{V}{4}$	
	Freight	
Baltimore & Ohio	$R_t = 2.2W + 122C$ (Speed range 7–35 m.p.h.)	Temp. above 35° F.
" " "	$R_t = 3.0W + 137C$	" bet. 20° & 35° F.
" " "	$R_t = 4.0W + 153C$	" " 0° & 20° F.
" " "	$R_t = 5.4W + 171C$	" below 0° F.
S. L. Cluett	$R = 5.4 + 0.001V^2 + \frac{70}{(V+3)^2}$	Empty cars
S. L. Cluett	$R = 3.8 + 0.0076V^2 + \frac{16.4}{(V+1)^2}$	Loaded cars
E. C. Schmidt	$R = 1.5 + \frac{106 + 2V}{W+1} + 0.001V^2$	....
Kiesel	$R_t = 100C + 1.5W + 0.01V(V+16)\sqrt{WC}$	....
	Passenger	
C.B. & Q.	$R = 2.5 + \frac{V^2}{468}$	
P. R.R.	$R = 3 + 0.1315\, V$	
General Electric	$R = \frac{50}{W} + 0.03V + \frac{0.002V^2}{W} A \left(1 + \frac{C-1}{10}\right)$	
Blood	$R = 3 + 0.12V + \left(0.0014 + \frac{0.40}{W}\right) V^{1.8}$	
Cole	$R = 5.4 + 0.002\,(V - 15)^2 + \frac{100}{(V+2)^3}$	
Davis	$R = 4 + 0.13V + \frac{0.33V^2}{W}\left(1 + \frac{C-1}{10}\right)$	
Mailloux	$R = 3.5 + 0.15\,V + \left(\frac{0.02C + 0.25}{CW}\right) V^2$	
Westinghouse	$R = 4 + \frac{V}{10} + \frac{10V^2}{36W}$	
Pullman	$R = \frac{9.4}{\sqrt{W_a}} + \frac{12.5}{W_a} + \frac{0.03V(3P+T) + .00095\,AV^2}{W_a n} + \frac{.0000095\, L^{0.94}\, G\, V^{1.93}}{W_a n}$	
C.M.St.P. & P.	$R = 18.7\,t + 80\,n_1 + 2.6t' + 20n' + 0.002AV^2$	
Kiesel	$R_m = [22 + 0.15(n_1 - 1)V]t$	Machinery friction only
	Air Resistance	
Goss	$R_a = 0.1V^2$	Head end
Goss	$R_a = 0.11V^2$	Locomotive and tender
Goss	$R_a = 0.001V^2$	First car
Goss	$R_a = 0.00026V^2$	Last car
Goss	$R_a = 0.0001V^2$	Intermediate car

Various investigations of train resistance components have been conducted to evaluate the effects of the following variables:

1. Curve resistance as modified by rail lubrication
2. Rail weight
3. Curve resistance as affected by train speed
4. Temperature of the air
5. Track construction
6. Car weight
7. Locomotive contour
8. Passenger train contour
9. Air conditioning
10. General formulas

1. Rail Lubrication (Reported in AREA Proceedings, Vol. 41, page 151)

Prior to the installation of mechanical lubricators on the Denver & Salt Lake, a test train was made up and a series of tests was run, maintaining comparable speeds, on the unlubricated curves. Subsequent to the installation of the lubricators, and after the track section had been in operation for a period, another series was run with the same test train to determine the reduction in curve resistance effected by lubrication of the rails and flanges. It was found that the reduction approximated 50 percent, as follows:

	Curve Resistance per Degree in Pounds per Ton	
	Average	*Maximum*
Before lubrication	0.552	0.79
After lubrication	0.274	0.422
Reduction	0.278	....
Percent reduction	50.4	....

The test train consisted of a dynamometer car, 4 cars loaded with coal, 25 empty gondolas, and a caboose, total weight 899 tons.

2. Rail Weight and Condition (Reported in AREA Proceedings, Vol. 31, page 1524)

These tests were conducted by the Kansas City Southern to determine resistance on two weights of rail laid upon the same roadbed. New sections of 85 and 127-lb. rail were used along with 85-lb. old rail. The three types were laid consecutively on main line roadbed. One series of tests was conducted with rail laid in the following order: 85-lb. old rail; 127-lb. new rail; followed by 85-lb. new rail. The positions of the new rails were then interchanged and another series was run, the worn 85-lb. rail being retained in its original position as a check on the constancy of factors other than rail section weight. New and worn wheels were tested in this manner except that the second series was made only with new wheels. The test train consisted of four loaded gondolas and a dynamometer car, the locomotive being detached from the cars before test was made and after journals had been initially warmed. The following conclusions were drawn:

(1) The 127-lb. rail exhibited 0.3 lb. per ton less resistance than the 85-lb. rail throughout the 7–19 m.p.h. speed range

(2) Worn wheel resistance proved to be greater on new rail than on old rail of the same weight (is not supported by data below)

(3) Worn wheel resistance was greater on new 127-lb. rail than on new 85-lb. rail (see (1) above and table below)

(4) No difference was observed in train resistance between worn and new wheels on rail which had been worn to fit the worn wheel contour (see table below):

Test Section	Rail	New Wheels Speed m.p.h.	New Wheels Resistance Lb. per Ton	Worn Wheels Speed m.p.h.	Worn Wheels Resistance Lb. per Ton
1	New 85 lb.	14.8	3.8	14.8	4.3
2	New 127 lb.	15.7	3.7	15.7	5.1
3	Worn 85 lb.	17.0	4.5	17.0	4.5

An investigation to determine why old rails were causing more resistance than new contours on new rail developed the following:

(1) A wedging action is set up between worn wheel treads and new rail, since the wheel treads are worn to a shorter radius of curvature than that of the new rail head

(2) Two distinct areas of contact and pressure at different wheel circumferences on the hollowed wheel treads result in slippage at one or both areas and consequent resistance

(3) Contact areas at different wheel circumferences on the two wheels of a single axle result in slippage at one or all areas and consequent resistance

(4) Contact areas of new rails on worn wheels were found to be on the unworn and unpolished part of the wheel in some instances

It was concluded that probably (3) was the only factor of any consequence.

3. **Train Speed on Curves** (Reported in University of Illinois Bulletin No. 92, September, 1916)

A 28-ton, electrically propelled, car was used in these tests. The test car was run first in one direction and then in the other over one of the curves and its adjacent tangent. The curves varied in degree from 2 to 14½ with superelevation of 0.75 to 5.9 in., respectively, on the extreme curves. By operating in both directions consecutively, and on curved and tangent track, under like conditions, it was possible to very nearly eliminate wind effects and to obtain a direct measure between tangent and curved track resistance. It was observed that curve resistance varied directly with car speed and degree of curvature and it was possible to write the following equation for curve resistance in pounds per ton:

$$R_c = 0.058\,S\,C$$

where, S = speed in miles per hour
C = curvature in degrees

The report points out the danger involved in extending the use of this equation beyond the conditions of the test. That is, train speed above 40 m.p.h., curvature greater than 15 deg., and cars exhibiting design features differing widely from those of the test car: 56,000 lb. in weight, carried on two, four-wheel trucks, spaced 23 ft. 3 in., center to center, truck wheel base, 6 ft. 4 in., and self-propelled with four, 50-hp. motors.

Tests reported in University of Illinois Bulletin No. 74 developed a resistance formula for level tangent operation which, when combined with the foregoing equation, provides the following for total car resistance on a level curve at uniform speed, expressed in pounds per ton:

$$R = 4 + 0.222\,S + \frac{0.00181\,A\,S^2}{W} + 0.058\,S\,C$$

where, A = cross sectional area of car in square feet
W = weight in tons
and other units are expressed as above.

4. Temperature (Reported in University of Illinois Bulletin No. 59, May, 1912)

The temperature of a cold journal is gradually increased as the vehicle which it is supporting is moved until, after a certain distance has been traversed, it has reached its maximum or equilibrium temperature for the speed operated. This equilibrium temperature is higher in value and is reached in a shorter distance as atmospheric temperature increases. The tests indicated that in cold weather and at the speeds operated, 12, 15, 17, and 21 miles per hour, the maximum temperatures and minimum resistance values were reached 35 miles distant from the starting point of the test, constant speed being maintained throughout the run.

Train Resistance—Pounds per Ton (Average Car Weight = 17.2 Tons)

Speed m.p.h.	*Temp.: 64° to 80°, Start to End of Test*	*Temperature: 30° to 42°, Start to End of Test* 35 Miles From Start	5 Miles From Start
12	8.0	10.0	13.7
14	8.25	10.4	13.9
16	8.5	10.9	14.3
18	8.75	11.5	15.0
20	9.0	12.1	15.9
21	9.1	12.4	16.4

Train Resistance—Pounds per Ton (Average Car Weight = 17.2 Tons—Temperature: 30° to 42° Start to End of Test Runs)

Miles From Start	*12.0 m.p.h.*	*15.0 m.p.h.*	*17.25 m.p.h.*	*21.3 m.p.h.*
4	14.1	14.7	...	...
8	12.5	13.0	13.5	14.5
12	11.3	11.8	12.4	13.6
16	10.7	11.2	11.8	13.1
20	10.4	11.0	11.5	12.8
24	10.2	10.8	11.4	12.7
28	10.1	10.75	11.35	12.6
32	10.05	10.65	11.3	12.5
36	10.0	10.6	11.25	12.5

5. Track Condition (AAR Passenger Locomotive Tests—October, 1938)

The results of AAR passenger train resistance tests presented in the following table were obtained with a 16-car test train consisting of 14 coaches, one baggage and one dynamometer car, all carried on four-wheel trucks with conventional friction bearings, average car weight, 62.82 tons for a total trailing weight of 1,005 tons. The identical train was operated in moderately warm weather, 50 to 88 deg., and in wind whose velocity varied from 2 to 19 miles per hour, over the tracks of the three railways indicated. The rail weight on the Pennsylvania was 131 lb. per yd., and on the other railways was, in general, 100 lb. per yd. A short stretch of the Union Pacific was laid with 110-lb. rail. Results obtained from applying the Davis formula,

$$R = 1.3 + \frac{29}{W} + 0.03\,V + \frac{0.041\,V^2}{Wn}$$ (see page 85)

are included for comparative purposes. In fact, the AAR report recommends its use as representative of the results obtained during the road trials.

Speed m.p.h.	Passenger Train Car Resistance—Pounds per Ton Pennsylvania	C. & N. W.	U. P.	Davis
50	5.55	5.9	...	6.3
60	6.3	7.25	7.9	7.35
70	7.35	8.6	8.8	8.4
80	8.6	10.0	9.7	9.7
90	9.95	11.35	10.6	11.15
100	...	...	11.5	12.7

It is interesting to note the graphical representation of these data. Whereas some components of train resistance are confidently expected to vary with the square of vehicle speed, curves of the North Western and Union Pacific resistance values, as plotted in the committee report, are straight lines of different slope, intersecting at 74 miles per hour. The Union Pacific values are lower for speeds above that figure. The shape of the Pennsylvania curve closely follows that obtained by use of the Davis formula but presents values approximately one pound per ton less than those calculated. The known difference in rail weight, and a possible difference in roadway construction, could very well explain the difference in absolute values at given speeds, but it is difficult to explain the straight line characteristics and widely varying slopes of the curves obtained by tests on the Union Pacific and North Western. The slope in each case represents the analyst's judgment in the averaging of points.

6. Equipment Weight (Reported in University of Illinois Bulletin No. 43, May, 1910)

The purpose of the road tests reported in this bulletin was the determination of train resistance values as they vary with average car weight and train speed. The results, empirical in nature, should be used only within the following limits:

- Tangent level track
- Air temperature above 30 deg.
- Wind velocity not over 20 m.p.h.
- Train in motion sufficiently long to warm journals
- Train speed between 5 and 40 miles per hour

The following equation is presented as approximating the values of the tests:

$$R = \frac{S + 39.6 - 0.031\,W}{4.08 + 0.152\,W}$$

where, $R =$ train resistance in pounds per ton
$S =$ train speed in miles per hour
$W =$ average car weight in tons

This equation has been spot checked against the test results from which it was derived, with the following results:

S	W	R	Measured R	Error in R	Percent Error in R
5	20	6.18	6.8	—0.62	—9.0
10	30	5.65	5.8	—0.15	—2.6
15	40	5.25	5.1	+0.15	+2.9
20	50	4.98	4.6	+0.38	+8.3
25	60	4.75	4.4	+0.35	+8.0
30	70	4.57	4.5	+0.07	+1.6
35	60	5.5	5.4	+0.10	+1.9
40	50	6.7	6.8	—0.10	—1.5
25	30	7.38	7.4	—0.02	—0.27
15	50	4.55	4.2	+0.35	+8.3
5	70	2.88	3.1	—0.22	—7.1

For more accurate results, the following equations are given for the several car weights listed:

Car Weight, Tons	*Resistance Values, R, in Lb. per Ton*
15	$7.15 + 0.085\,S + 0.00175\,S^2$
20	$6.30 + 0.087\,S + 0.00126\,S^2$
25	$5.60 + 0.077\,S + 0.00116\,S^2$
30	$5.02 + 0.066\,S + 0.00116\,S^2$
35	$4.49 + 0.060\,S + 0.00108\,S^2$
40	$4.15 + 0.041\,S + 0.00134\,S^2$
45	$3.82 + 0.031\,S + 0.00140\,S^2$
50	$3.56 + 0.024\,S + 0.00140\,S^2$
55	$3.38 + 0.016\,S + 0.00142\,S^2$
60	$3.19 + 0.016\,S + 0.00132\,S^2$
65	$3.06 + 0.014\,S + 0.00130\,S^2$
70	$2.92 + 0.021\,S + 0.00111\,S^2$
75	$2.87 + 0.019\,S + 0.00113\,S^2$

Using these equations for the same resistance calculations as above:

S	*W*	*R*	*Measured R*	*Error in R*	*Percent Error in R*	*Percent Error in R Based Upon General Equa.*
5	20	6.77	6.8	—0.03	—0.44	—9.0
10	30	5.8	5.8	0	0	—2.6
15	40	5.07	5.1	—0.03	—0.59	+2.9
20	50	4.6	4.6	0	0	+8.3
25	60	4.42	4.4	+0.02	+0.45	+8.0
30	70	4.55	4.5	+0.05	+1.11	+1.6
35	60	5.37	5.4	—0.03	—0.56	+1.9
40	50	6.76	6.8	—0.04	—0.59	—1.5
25	30	7.4	7.4	0	0	—0.27
15	50	4.24	4.2	+0.04	—0.95	+8.3
5	70	3.05	3.1	—0.05	—1.61	—7.1
				Average	0.57	4.68
				Maximum	—1.61	—9.0
				Minimum	0	—0.27

7. **Locomotive Contour** (Reported by J. J. Green, junior research physicist, National Research Laboratories of Canada, under the title, "The Wind Tunnel Development of a Proposed External Form for Steam Locomotives")

In 1931, at the request of the Canadian National Railways, the National Research Laboratories initiated an investigation of air flow around a steam locomotive with several objectives in view. Contemporary design was such that smoke from the stack swept back over the boiler and downward in front of the cab windows, seriously impairing vision, and it was the purpose of the study to evolve a contour which would correct this condition to the greatest practicable degree and at the same time offer the least resistance to air flow compatible with economical design and operating requirements. A model of the then current locomotive design was tested in a wind tunnel along with various modified forms to determine which would provide the nearest approach to the objectives desired. The following results, valuable for comparative purposes only, were obtained during the tests; *R* being defined as drag of the model in pounds as measured in the wind tunnel, while *V*, is the speed expressed in miles per hour.

Modification	*Relationship* $R/V^2 \times 100$
Original unmodified model	0.1089
1. Shrouding fitted below running boards and extending down to level of the bottom of pilot and from pilot to rear of cab. Solid pilot added along with sloping sheet from top of pilot to bottom of smoke box	0.1088
2. Same as (1) plus shroud extended along tender from runways to same lower level, front to rear of tender	0.1036
3. Same as (2) except feedwater heater, head lamp, and side staircases removed, with an approximately hemispherical front to smoke box	0.0763
4. Same as (3) with whistle and bell removed, and metal cowling, flush with the center of the cab roof and having the same roof contour but vertical sides, was fitted over the turrets, valves and dome extending from the center of the sand dome	0.0710
5. The front of the metal cowling added in (4) was sloped down in a gentle curve to the top of the boiler just behind the stack and a streamlined tail was added to the stack	0.0698
6. Same as (5) with cowling conforming to the cab roof fitted over the entire tender	0.0666
7. Same as (6) with space between cab and tender closed by cowling flush with the sides and roof of cab	0.0656
8. Same as (7) except that the front of the cab was modified to slope backward from the running board, and the overhang of the cab roof was eliminated. Various fillets and curves were employed to eliminate corners and sharp edges	0.0620
9. Cowling on top of boiler extended two inches past front of boiler and its sides dropped down to the rounded nose. The two sides of the cowling were opened out to give a flared entrance, and a slot was cut where it butted on to the old cowling in order to allow exit for air caught in front of the stack. Side plates were fitted to the cab so that they protruded forward a short distance from the cab front. All this was done in an effort to prevent smoke from interfering with vision	0.0727
10. Two-inch extension added in (9) removed	0.0685
11. Leaving the sides of the extended cowling untouched on either side of the stack, the forward portion of the roof was removed	0.0665
12. Front ends of running boards were rounded off to remove sharp corners and gap, stack to curved surface to cowling, reduced	0.0654
13. Cylindrical surface added between rounded nose of the boiler and the sloping front	0.0647
14. Because of operating restrictions, cowling was removed from over water tank and runways at the sides of coal bunker	0.0633
15. For the same reason, modification of full shrouding was necessary and, as a measure of the contribution of shrouding, several modifications were examined:	
(a) Full shrouding	0.0633
(b) Shrouding removed below the level of driving wheel centers and from behind cylinders to the center of the rear driving wheel	0.0650
(c) Shrouding removed below the level of driving wheel centers from the rear of the cylinders to the rear of the cab	0.0656
(d) Shrouding completely removed from the rear of the cylinders to the rear of the cab	0.0695
(e) Shrouding removed below the level of the top of the driving wheels from rear of cylinders to rear of cab	0.0702
(f) Tender shrouding removed below level of frame	0.0715
(g) Shrouding completely removed from locomotive	0.0846
(h) Shrouding completely removed from locomotive and tender	0.0865

These results show how very vital shrouding is when the rest of the model is streamlined, yet the addition of shrouding to the original otherwise unmodified model had practically no effect on resistance. Model 15(f) was selected as the most practical, considering operating restrictions.

Modification	Relationship $R/V^2 \times 100$
16. To simplify the front end, a sloping solid pilot running in one plane from as near the rail level as possible up to the running boards was substituted for the original arrangement. Otherwise same as 15(f) above	0.0700
17. Bell was placed in front of stack with its supporting frame parallel to the longitudinal axis of the locomotive	0.0706

It will be noted that the value of $R/V^2 \times 100$, a reasonable measure of the comparative resistance characteristics of various full scale locomotive designs, was reduced from 0.1089 to 0.0706, or 35 percent. This was accomplished with no interference to operating requirements. Had it not been necessary to respect such considerations, a reduction of 43 percent to 0.0620 could have been effected. It is important that recognition be given the fact that a single modification may be of little value when applied by itself but, when applied to a locomotive otherwise streamlined, the saving may be considerable. The shrouding of the running gear of the test model is a case in point. Also of interest is the fact that no effect was discernible from closing the gap between cab and tender with its implication of the questionable advantage of closing the gap between the coupled cars comprising the trailing load.

8. Passenger Train Contour (New York University Wind Tunnel Test Results)

In 1934, a comprehensive series of wind tunnel tests was jointly sponsored by The American Locomotive Company, the American Car and Foundry Company, and the Brill Company. These experiments were conducted in the laboratories of New York University under the direction of Professor Alexander Klemin and data have been released by the sponsors. Models of standard railway motive power and rolling stock were examined along with models of streamlined equipment with various nose, tail fairing and enclosure shroud forms. These variations are noted below in connection with the presentation of equations applicable to the several test models.

AIR RESISTANCE FORMULAS FOR TRAINS OPERATING IN STILL AIR

POWER CAR TRAINS

Open skirts (18 in. from skirt to top of rail):

$$\text{Air drag} = 0.00224\, P_c \left(\frac{L}{100}\right)^{0.8} V^2 + \Sigma K V^2$$

Closed skirts (completely under car):

$$\text{Air drag} = 0.0020\, P_c \left(\frac{L}{100}\right)^{0.8} V^2 + \Sigma K V^2$$

Where:

P = Perimeter of car, in feet, from plane of top of rails over car to plane of top of rails

L = Overall length of train in feet

V = Speed of train in m.p.h.

ΣK = Summation of factors ($K_1 + K_2$ + etc.) of the various items whose drag depends on other dimensions than perimeter and length

K_1 = Factor for power car nose shape:

For nose bluntly streamlined, $K_1 = +0.000036 \times$ cross-sectional area of nose at full section, including trucks, in square feet

For nose well streamlined, $K_1 = 0$

K_2 = Factor for tail shape:

For tail bluntly streamlined, $K_2 = +0.000061 \times$ cross-sectional area of tail at full section, including trucks, in square feet

For tail well streamlined, $K_2 = 0$

K_3 = Factor for power car trucks:
For two faired trucks, $K_3 = 0$
For two unfaired trucks, $K_3 = +0.0099$ (This factor is large because. as tested, the truck fairings formed part of the nose and skirt fairing, and when the truck fairings were removed the nose and skirt shape was damaged. On designs in which the truck fairings do not interfere with the nose or skirt contours, $K_3 = +0.00026$)

K_4 = Factor for fairing trailing car trucks on streamlined trains (as tested, neither the trucks nor the fairings interfered with the continuity of the open skirts):
For faired trucks, $K_4 = -0.00013 \times$ number of trailing car trucks
For unfaired trucks, $K_4 = 0$

K_5 = Factor for diaphragm shape:
For smooth diaphragms, $K_5 = 0$
For cowled diaphragms, $K_5 = +0.000037 \times P_c \times$ number of diaphragms

K_6 = Factor for bulge of power car:
For no bulge (as tested), $K_6 = 0$
For a bulge of good streamline shape, $K_6 = +0.00032 \times$ cross-sectional area of bulge in square feet (in order for this coefficient to apply, the bulge must be of such a character that it has a streamline shape as good as, or better than, the power car itself). Under this heading may be classed bulges that are merely expansions of the general power car contours, as well as local bulges having well streamlined noses and tails.
For a bulge of relatively poor streamline shape, $K_6 = +0.00051 \times$ cross-sectional area of bulge in square feet (this coefficient applies where the bulge has relatively poor shape, such as sharp edges or corners, blunt tail, a blunt nose, etc.)

STREAMLINE LOCOMOTIVE TRAINS

With open skirts on cars (18 in. from skirt to top of rail)

$$\text{Air drag} = \left[0.023\, L_L^{\frac{1}{3}} + \Sigma K_L + 0.001735\, P_c\left(\frac{L_c}{100}\right)^{0.88} + \Sigma K_c\right] V^2$$

With closed skirts on cars (completely under cars)

$$\text{Air drag} = \left[0.023\, L_L^{\frac{1}{3}} + \Sigma K_L + 0.001535\, P_c\left(\frac{L_c}{100}\right)^{0.88} + \Sigma K_c\right] V^2$$

Where:

V = Train speed in miles per hour
L_L = Length of locomotive and tender in feet
L_c = Length of car consist, in feet, rear of tender to rear of train
P_c = Perimeter of cars, in feet, from plane of top of rails over car to plane of top of rails
ΣK_L = Summation of factors of the various items affecting the locomotive and tender, whose drag depends on other dimensions than those given above:

K_7 = Factor for wheel shrouds on streamline locomotives:
For closed shrouds (all wheels completely enclosed), $K_7 = 0$
For open shrouds (2-ft. by 2-ft. 6-in. inspection openings over the driving wheel journals), $K_7 = +0.0005 \times$ total number of openings
For short shrouds (driving wheels and tender trucks completely exposed), $K_7 = +0.0182$

K_8 = Factor for nose shape on streamline locomotive:
For helmet nose, $K_8 = 0$
For straight nose, $K_8 = +0.0021$
For round nose, $K_8 = +0.0026$

K_9 = Factor for boiler shape on streamline locomotive:
For round top, $K_9 = 0$
For cowled top (domes and fittings enclosed in longitudinal cowl above boiler shroud), $K_9 = +0.0035$

ΣK_c = Summation of factors of the various items affecting the cars, whose drag depends on other dimensions than those given above. These factors are K_2, the factor for tail shape; K_4, the factor for fairing trailing car trucks on streamlined trains; and K_5, the factor for diaphragm shape. Their values are the same as given under the formulas for power car trains

The first two terms in the brackets of the drag equations for streamlined locomotive trains are functions of the locomotive and tender only, while the last two terms are functions of the car consist only.

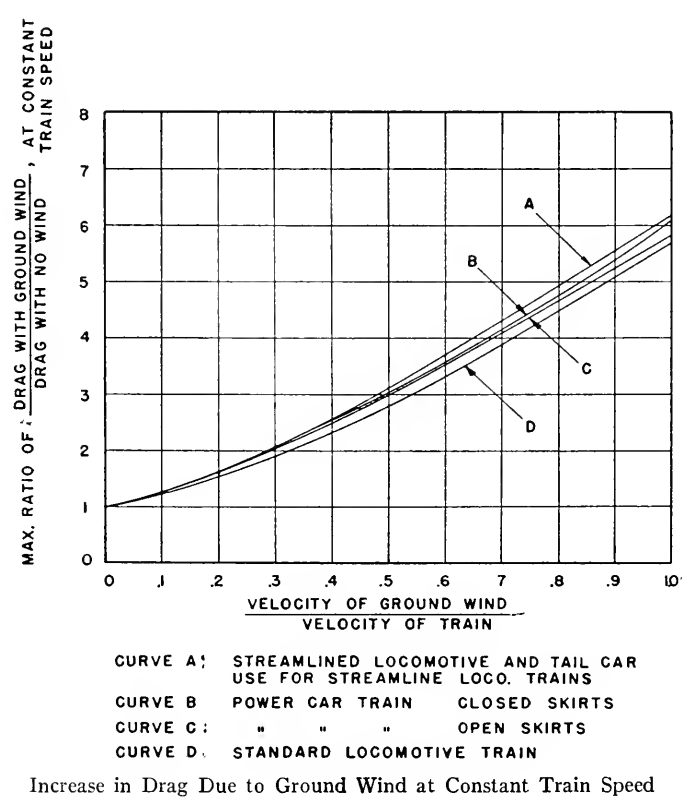
STANDARD LOCOMOTIVE TRAINS—NEW YORK CENTRAL 4-6-4 TYPE

$$\text{Air drag} = \left[0.083\, L_L^{\frac{1}{2}} + 0.0031\, P_c \left(\frac{L_c}{100}\right)^{0.7}\right] V^2$$

Where:

V = Train speed in miles per hour
L_L = Length of locomotive and tender in feet
L_c = Length of car consist, in feet, rear of tender to rear of train
P_c = Perimeter of cars, in feet, from plane of top of rails over car to plane of top of rails

The first term in the brackets of this formula is a function of the locomotive and tender only, while the second term is a function of the car consist only.



Increase in Drag Due to Ground Wind at Constant Train Speed

Range of application:

Trains of 100 to 800 ft. in length—no appreciable error
Trains of 50 to 1,500 ft. in length—small error
(Test range: Streamlined trains—143 to 411 ft.—two to six cars
Standard trains—96 to 330 ft.)

The above equations apply, as indicated, only in still air. In actual operation, ground or natural winds are always encountered and it is necessary in practical usage to modify the values obtained by application of the foregoing equations to include this effect. This is accomplished by multiplying the air drag in still air by a multiplication factor, R_D, which is read from the accompanying chart. The abscissa, r, is the ratio of ground wind velocity, V_g, to train speed, V, so that

$$r = \frac{V_g}{V}$$

and air drag with a ground wind $= R_D \times D_o$
where $D_o =$ air drag in still air at speed V

Ground winds are constantly varying in intensity and in direction, precluding an exact prediction of air drag to be overcome in traversing a given division with a given train. It is recommended that the year-round average ground wind velocity be employed as V_g.

9. Air Conditioning

An additional power demand of considerable proportions was introduced coincident with the air conditioning of passenger cars. Also to be satisfied, but of less magnitude, is the power required for car lighting. To obtain an accurate value of the drawbar pull required to haul a given train of air conditioned passenger cars, it is necessary to give cognizance to these power demands, the most direct method being to transpose them into terms of train resistance by the use of the basic formula,

$$R = \frac{375\,hp}{Wn\,V}$$

where, $R =$ train resistance in pounds per ton
$hp =$ horsepower
$W =$ weight per axle
$n =$ number of axles
$V =$ speed in miles per hour

Totten states that the average maximum requirements for mechanical or electro-mechanical air conditioning may be taken as 25 hp. per car and for electric lighting, battery charging, etc., 5 hp. per car, or a total of 30 hp. per car, at speeds of 30 miles per hour or above. The formula then becomes,

$$R = \frac{11{,}250}{Wn\,V}$$

As a result of an extensive investigation, the Division of Equipment Research, AAR, released its "Summary Report on Air Conditioning of Railroad Cars", dated November 24, 1936, in which were outlined, in part, its findings. The accompanying table is derived from the power demand and efficiency values published therein. It will be noted that, upon a basis of 6-tons refrigeration, the horsepower required at the axles varies from 18.5 to 41.0 and, if one design is excluded, this range is reduced to a maximum limit of 30 hp., substantiating the value of 25 hp. per car recommended by Totten.

POWER REQUIREMENTS OF NINE MECHANICAL COMPRESSION AIR CONDITIONING SYSTEMS AT AIR RESISTANCE PRESSURES OF ZERO AND 0.35 INCHES OF WATER

Conditions: 6-Ton Refrigeration
60-Ton Car Weight
Overall Efficiency of Drives, Generators, and Compressor Motors:
30 m.p.h. = 58.5
50 m.p.h. = 58.8
70 m.p.h. = 56.9
90 m.p.h. = 54.6

SYSTEM	H.P. per Ton of Refrigeration Zero	H.P. per Ton of Refrigeration 0.35	Horsepower At Axle Zero	Horsepower At Axle 0.35	Train Resistance In Pounds per Ton Zero	Train Resistance In Pounds per Ton 0.35
Airtemp-York (5-ton)						
30.m.p.h.	1.81	1.92	18.6	19.7	3.88	4.10
50 "	"	"	18.45	19.6	2.31	2.45
70 "	"	"	19.1	20.25	1.71	1.81
90 "	"	"	19.9	21.1	1.38	1.47
Carrier-Safety						
30 m.p.h.	1.98	2.10	20.3	21.55	4.25	4.49
50 "	"	"	20.2	21.4	2.52	2.68
70 "	"	"	20.9	22.15	1.87	1.98
90 "	"	"	21.75	23.05	1.51	1.60
Trane						
30 "	1.93	2.00	19.8	20.5	4.13	4.27
50 "	"	"	19.7	20.4	2.46	2.55
70 "	"	"	20.35	21.1	1.82	1.885
90 "	"	"	21.2	22.0	1.47	1.53
Airtemp-York (6-ton)						
30 m.p.h.	2.13	2.21	21.9	22.7	4.56	4.73
50 "	"	"	21.7	22.5	2.71	2.81
70 "	"	"	22.45	23.3	2.00	2.08
90 "	"	"	23.4	24.3	1.625	1.69
Airtemp-York (7-ton)						
30 m.p.h.	2.17	2.23	22.3	22.9	4.64	4.77
50 "	"	"	22.1	22.7	2.76	2.84
70 "	"	"	22.9	23.5	2.05	2.10
90 "	"	"	23.8	24.5	1.65	1.70
B. & O.-York						
30 m.p.h.	2.28	2.35	23.4	24.1	4.86	5.02
50 "	"	"	23.25	24.0	2.91	3.00
70 "	"	"	24.0	24.8	2.14	2.22
90 "	"	"	25.0	25.8	1.74	1.785
General Electric						
30 m.p.h.	2.45	2.55	25.1	26.2	5.23	5.45
50 "	"	"	25.0	26.0	3.12	3.25
70 "	"	"	25.8	26.9	2.30	2.40
90 "	"	"	26.9	28.0	1.87	1.945
Frigidaire						
30 m.p.h.	2.63	2.72	27.0	27.9	5.63	5.81
50 "	"	"	26.8	27.7	3.35	3.46
70 "	"	"	27.7	28.7	2.47	2.56
90 "	"	"	28.9	29.9	2.01	2.08
Baldwin-Southwark						
30 m.p.h.	3.32	3.73	34.0	38.3	7.06	7.98
50 "	"	"	33.8	38.0	4.23	4.75
70 "	"	"	35.0	39.3	3.12	3.51
90 "	"	"	36.5	41.0	2.53	2.85

10. General Formulas (Davis Formulas)

The Davis formulas, generally accepted as reasonably reliable in predicting resistance values of a given vehicle or combination of vehicles at the time they were written, were the result of a thorough correlation of existing test data. More recent experiments on current design types have indicated to some authorities the need for minor revision of the constants employed by Davis, but the basic form of these equations has not been disputed and it is unlikely that future experiments will substantially alter that form. According to Davis, total resistance is comprised of three primary components; journal, flange, and air resistances. The first is independent of speed, varying indirectly with average axle loading; the second varies directly with speed; while the third, air resistance, varies directly with vehicle cross-sectional area and the square of the speed. Inasmuch as the combined resistance value, R, is expressed in pounds per ton, total axle loading is introduced into the denominator of the air resistance term. Then,

$$R = 1.3 + \frac{29}{W} + kV + \frac{CAV^2}{Wn}$$

where $R =$ resistance in pounds per ton
$W =$ average weight per axle in tons
$k =$ constant depending upon equipment
$V =$ speed in miles per hour
$C =$ constant depending upon equipment
$A =$ effective cross-sectional area in square feet
$n =$ total number of axles

Values of k and C recommended by Mr. Davis follow:

Equipment	k	C
Locomotives	0.03	0.0024
Freight cars	0.045	0.0005
Passenger cars—vestibuled	0.03	0.00034
Multiple unit—leading car—vestibuled	0.045	0.0024
Multiple unit—trailing cars	0.045	0.00034
Motor cars	0.09	0.0024

Values of A:

Locomotives— 50 tons	105 sq. ft.
Locomotives— 70 tons	110 " "
Locomotives—100 tons and over	120 " "
Freight cars	85– 90 " "
Passenger cars	120 " "
Multiple-unit cars	100–110 " "
Motor cars—two trucks	80–100 " "
Motor cars—one truck	70– 75 " "

Totten Formulas for Lightweight Passenger Trains

Due to developments in design subsequent to the writing of the Davis formulas, such as evidenced in the lightweight, streamlined, articulated trains, Totten recommends substituting the various air resistance values developed by the New York University test results for the final term of the Davis locomotive or passenger car formula. Therefore, for locomotives and power units in combination with lightweight, four-axle, or articulated cars, the resistance formula would read,

$R = 1.3 + \frac{29}{W} + 0.03\,V$ plus the appropriate air resistance term selected from Section 8 preceding.

Conclusions

The Davis equation, with Totten recommended modifications applied when streamlining refinement introduces marked resistance changes, remains the most reliable and widely accepted method for calculation of train resistance. This committee proposes to continue its search for road test data, particularly as they have been developed for freight service application—to weigh all factors—to modernize equations of merit which no longer accurately represent present operating conditions—and, if possible, to submit a preferred general method for calculating train resistance for guidance in such matters as the establishment of locomotive tonnage ratings.

It is recommended that this report be received as information and the committee be authorized to continue its work.

Report of Committee 25—Waterways and Harbors

G. P. Palmer, *Chairman,*	R. W. Marye	E. H. Roth, *Vice-Chairman,*
D. J. Brumley	R. J. Middleton	C. U. Smith
Benjamin Elkind	F. E. Morrow	J. L. Starkie
W. D. Faucette	V. B. W. Poulsen	A. B. Stone
R. P. Forsberg	W. G. Nusz	W. R. Swatosh
I. W. Geer	A. N. Reece	E. F. Wendt
G. F. Hand	P. T. Simons	S. L. Wonson
N. D. Hyde	G. R. Smiley	*Committee*

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

No report.

2. Breakwaters, bulkheads and jetties.

Final report—giving definitions of "breakwater", "bulkhead" and "jetty" for inclusion in the Manual.......... page 88

3. Recommended practices to prevent damage by navigation to:

(a) Bridges—movable and stationary;

(b) Piers, wharves and docks.

No report.

4. Study of metal and other protective casings for pier structures under water.

Progress report—submitted as information.......... page 88

5. Economic principles involved in clearance over navigable waterways.

No report.

6. Seawalls and ocean shore protection, including effect of wave action and ice.

Final report—submitted as information and adding definition of "groin" for inclusion in the Manual.......... page 88

7. Reasonable life of steel casings immersed in sea water.

Progress report—submitted as information.......... page 90

8. Lands subject to servitude of navigation as affecting protection of roadbeds built or to be built on proposed dam pool areas.

No report.

The Committee on Waterways and Harbors,

G. P. Palmer, *Chairman.*

Bulletin 420, November, 1940.

Report on Assignment 2

Breakwaters, Bulkheads and Jetties

G. P. Palmer (chairman, subcommittee), E. H. Roth, R. P. Forsberg, W. G. Nusz, C. U. Smith.

The following definitions have been revised to conform to discussion of them at the March, 1940, Convention and are now submitted for inclusion in the Manual:

Breakwater.—A structure to afford shelter from wave action. *25*

Bulkhead.—A structure to prevent sliding of natural ground or fill material into the water; the limiting wall or structure along a waterfront. *25*

Jetty.—A structure in the mouth of a river, at the entrance of a harbor, or elsewhere, to control the waterflow and currents, to maintain depth of channel, to protect harbor or beach. *25*

Report on Assignment 4

Study of Metal and Other Protective Casings for Pier Structures Under Water

N. D. Hyde (chairman, subcommittee), G. F. Hand, R. W. Marye, V. B. W. Poulsen, P. T. Simons, G. R. Smiley, W. R. Swatosh.

The purpose of this study is to assemble data relative to the use of protective casings for combatting the effects of marine borers upon timber structures submerged in sea water.

Considerable experimental work has already been done and several shield installations are under observation. The principle of the use of shields is based upon the fact that marine borers cannot live below the mud line. If the mud line is raised above the attack line the timber is protected against the borers. Experiments have been under way about nine years with encouraging results. A variety of shields are commercially available.

The committee reports progress in the assembling of data on the subject.

Report on Assignment 6

Seawalls and Ocean Shore Protection, Including Effect of Wave Action and Ice

C. U. Smith (chairman, subcommittee), Benjamin Elkind, W. D. Faucette, G. F. Hand, R. W. Marye, J. L. Starkie, A. B. Stone.

Definitions

The committee has carefully considered a definition for the word "groin" and submits the following with a recommendation that it be approved for insertion in the Manual.

Groin.—A barrier extending into the water from a beach to arrest traveling sand and shingle and to give protection against wave-wash or current. A small jetty. *25*

History

An effort has been made, merely as a matter of information, to obtain some history of seawalls and ocean shore protection. Reference to this type of protection is found in connection with the early ports of Alexandria, Pireu, Rhodes and Antium, but detailed references have not been located. It must suffice to say that seawalls and ocean shore protection have existed since the days of those ocean ports, and in recent years, by reason of the greater economic value of waterfronts, more consideration has been given to this type of protection.

Analysis

From a careful study of authorities on shore protection, it may be said that such protection consists of four types, namely:

1. Artificial constructions which break the force of the waves before they reach the shore.
2. Those which consolidate and elevate the shore itself, so as to enable it to resist the action of the waves.
3. Those which make or assist the accumulation of sand or shingle upon the shore.
4. Permanent breakwaters, which act as islands in the offing and exclude the waves.

To determine the proper usage of any of these four or a combination of them, requires a careful investigation into the various forces which produce the conditions causing shore erosion. In every instance, such diagnosis or study should be completed before any protective structures are placed. In this connection, the following are generally considered as the four forces which tend to cause disintegration of the shore:

1. Sub-aerial agencies
2. Waves
3. Wind currents
4. Tidal currents

These forces may be further explained by the following brief comments:

Sub-aerial.—The chief sub-aerial forces in this connection are wind, rain, frost and running water.

Waves.—Waves may be classified as forced and free. Forced waves consist of those during the continuance of the wind causing them, and free waves run for some time after the wind has subsided.

Wind currents.—These may be on-shore, off-shore, or along-shore or at various angles between these. Attention is directed to the fact that wind currents along-shore are most effective in causing traveling of sand and shingle. The use of groins should be thoroughly investigated where this situation exists.

Tidal currents.—The tidal currents to be investigated are those which run parallel, or approximately so, to the coast line. In places where the shore line is irregular and small bays exist, revolving tidal currents are generated. These are the principal causes of shore erosion and should be carefully studied in connection with any proposed protection.

By reason of the innumerable conditions which may exist, and by reason of single or combined forces, all of which tend to cause erosion of the shore, it is difficult in a report of this character, to make any recommendation with reference to procedure, either in general, or at any given point.

Specific reference is made to Paper No. 2 of the Beach Erosion Board, office of the Chief of Engineers, Washington, D.C., dated December 1, 1938, entitled "Manual of

Procedure in Beach Erosion Studies." In Part 7 of this publication, entitled: "Plan of Improvement—Beach and Shore Protection" extending from pages 65 to 72 inclusive, with appended diagrams, there seems to be a complete answer to the assignment of this subcommittee. This entire publication and Part 7 of it in particular, are recommended to all those who have definite problems of erosion to cope with.

Bibliography

Your subcommittee, in preparing this report, has referred to the official journal of the American Shore and Beach Preservation Association known as *Shore and Beach,* which contains many items of interest in connection with the subject matter of this subcommittee.

In addition to the publication *Shore and Beach,* specific reference has been made to the following:

Manual of Procedure in Beach Erosion Studies, Office of the Chief of Engineers, U.S. Army, Washington, D.C.

Port Dictionary of Technical Terms, The American Association of Port Authorities

Knight's American Mechanical Dictionary, published 1877 by Hurd & Houghton of New York

The Sea Coast, W. H. Wheeler, published by Longmans, Green & Co., London, 1902

The Protection of Seashores from Erosion, Alfred Edw. Carey, published by Greening & Co., Ltd., London, 1907

Coast Erosion and Foreshore Protection, John S. Owen and Gerald O. Case, St. Brides Bros., Ltd., London, 1908

Coast Erosion and Protection, Ernest R. Matthews, publisher—Charles Griffen Co., Ltd., London, 1918

Conclusions

Seawalls of various design and groins may be properly used in protecting shores and beaches after careful studies of all conditions have been concluded to enable the selection of an adequate design of seawall or groin or a combination of both.

No recommendations are made with reference to any effective type of structure by reason of the great variance in conditions.

It is recommended that: (1) The definition in this report be included in the Manual; (2) the balance of the report be received as information and (3) the subject be discontinued.

Report on Assignment 7

Reasonable Life of Steel Casings Immersed in Sea Water

W. D. Faucette (chairman, subcommittee), W. G. Nusz, V. B. W. Poulsen, A. N. Reece, J. L. Starkie, A. B. Stone, S. L. Wonson.

This subject was assigned to Committee 25 five years ago, and after your subcommittee chairman had considered the question of approach to the subject, it was learned that the War Department, through the office of the Chief of Engineers (Major General Julian L. Schley), and more particularly through the Beach Erosion Board at Washington, was investigating at some length a report on steel sheet piling in various parts of the country and was carrying this work on in considerable detail and thoroughness.

In view of the time and care that was being devoted to this investigation by the War Department, it was the opinion of the committee that its study could be pursued to greater advantage, if it were deferred until the War Department's report was more nearly complete.

The problem of "material corrosion" has been the subject of an investigation under the direction of the district engineer, U.S. Corps of Engineers at Boston, Mass., whose latest report, designated Fourth Interim Report, appeared under date of April 1, 1939. The purpose of this investigation was to determine the proper metals for mechanical equipment near, or immersed in, sea water on the Passamaquoddy Tidal Power Project. This interim report was authorized by the Chief of Engineers of the U.S. Army, and the last report was submitted by Col. A. K. B. Lyman, district engineer, Boston, Mass.

This report contains the following figures for loss of weight of steel subjected to "simple exposure" during the years 1937 and 1938.

		Weight Losses in Milligrams Per Square Inch Per Year								
		In Air			*Mean Tide*			*Submerged*		
Class	*Classification*	*Max.*	*Min.*	*Avg.*	*Max.*	*Min.*	*Avg.*	*Max.*	*Min.*	*Avg.*
12	Steel	86.1	37.6	66.9	689.8	546.8	603.3	966.0	691.7	812.7

Quotations from the above reports hereinbefore referred to must be considered only as information currently available, not as conclusive data. Reports prepared in the future on the basis of more complete information may embody data that deviate markedly from the facts now available, and lead to different conclusions.

In view of the many variables that influence the amount of corrosion, such as salinity, abrasion, metallic content, degree of immersion (whether partial or complete), humidity, etc., the committee has deemed it only proper, in its consideration of this subject, to defer the preparation of a conclusive report on this assignment until some of the investigations now under way have reached the stage that warrants the publication of specific conclusions.

The attention of the committee was directed to a pamphlet issued by the Department of Scientific and Industrial Research under the title "Deterioration of Structures in Sea Water" which is designated as the Seventeenth Interim Report of the Committee of the Institute of Civil Engineers, London, England, printed in 1938, which committee has been investigating the deterioration of structures in sea water since 1916. A study of this report, from which the following has been abstracted, is recommended to those who have occasion to undertake an investigation of this general subject.

Summary of Conclusions on the Five-Year Tests of the Committee's Iron and Steel Specimens, by Dr. Carl Benedicks

(from page 32 of the report)

(1) Very approximately, the depth of pitting, in total-immersion as well as in aerial tests, increased roughly in proportion to the air temperature.

(2) The half-tide tests showed that on that influence of temperature on the rate of pitting, there was superimposed an opposite effect, which was weak at high, and strong at low, temperatures. That effect, no doubt, was the easy condensation of water at low temperatures, which was naturally the primary cause of corrosion. On account of the presence of salt, the occurrence of much water, at low temperatures, caused a very strong pitting in half-tide tests.

(3) The most striking fact regarding general wastage under conditions of total immersion was that it did not increase with increasing temperature, as might be

expected. The cause was doubtless that a protecting coating would rapidly be formed on iron or steel surfaces in sea water, the formation of the coating being comparable with what was known regarding certain protecting coatings in industry.

(4) The effect of humidity in accelerating corrosion might under certain circumstances be the opposite to that stated in (2) above. The large amount of rain and fog during a great part of the year was bound to have the effect of cleaning the surface of the specimens, so counteracting corrosion; that was especially true in the tests at Halifax. That cleaning action, however, scarcely appeared to remove the salt existing in the pittings formed.

(5) The fact that the aerial and half-tide wastage at Plymouth was more intense than that at Auckland might be due to the higher relative humidity at Plymouth, but also might possibly be due to a less pure atmosphere there.

(6) Carbon steel was generally more corroded than iron, which was to be expected.

(7) From the foregoing the essential character of the results observed on iron and carbon steel seemed to be fairly well explained by considering the known meteriological factors, on the theory of local elements. The only special assumption made was the formation of a protecting coating in sea water (Conclusion 3), and eventually of a less pure atmosphere in Plymouth (Conclusion 5). No individual differences in the action of the sea water, nor any other unknown factors, were necessary.

(8) An explanation was put forward for the reason why paint adhered better to iron than to iron oxide.

(9) It was pointed out that "corrosion-fatigue" was merely a special case of a general effect, implying that the strength of a material was effectively lowered by the presence of a wetting liquid medium surrounding the material.

In our own country, Dr. William F. Clapp, of Duxbury, Mass., in his laboratory investigation, issued "Laboratory Bulletin No. 2" which dealt with steel corrosion in salt water. His observation, based on various research data which he had collected and selected from published papers, is that it appeared to be a well established fact that under immersed conditions, variations in manufacture, composition and structure do not materially influence the amount or distribution of corrosion, which is controlled by factors external to the metal. Following this line of thought, he emphasized the possibility of metal disease due to extraneous conditions, and thought it well to attempt some research along the angles set forth in his bulletin. The committee believes that a reading of Bulletin No. 2 will be of advantage to any interested student of this subject.

Through the continued cooperation of Major Albert C. Lieber, Jr., of the War Department, resident member and recorder of the Beach Erosion Board at Washington, your committee has been favored with the opportunity to examine certain reports, especially the partial report made on the Investigation of Steel Sheet Piling, covering localities on the east and west coasts of Florida. As aforementioned, this is only a progress report, but the committee feels that it is of value to the profession, even though the conclusions must be considered as tentative. One interesting observation was stated as follows: "It appears from the above that where piles are subjected to frequent wetting from salt water and spray, there is little difference in the rate of deterioration of plain steel and copper steel. In brackish water, the copper steel appears to have a rate of deterioration slightly less than that of plain steel". The tabulation, on page 93, which was included in the report and which impresses the committee as being of importance, lists the average annual losses of metal thickness, in inches, in bulkhead piles for the following conditions:

A. Plain steel, uncoated, exposed on one side to salt water waves and spray
B. Plain steel, coated, exposed on one side to salt water waves and spray
C. Copper steel, uncoated, exposed on one side in harbor waters
D. Copper steel, coated, exposed on one side in harbor waters
E. Copper steel, uncoated, exposed to atmospheric corrosion only

	Annual Loss of Metal Thickness in Inches		
		Elevation	
Specimens	*+7 to +14*	*+3 to +6*	*0 to +2*
A	0.013	0.006	0.004
B	....	0.003	0.002
C	....	0.009	0.002
D	....	0.005	0.003
E	0.002	....	....

This report is submitted as information with the recommendation that the subject be continued.

Report of Committee 13—Water Service, Fire Protection and Sanitation

B. W. DeGeer, *Chairman,*
R. C. Bardwell
W. M. Barr
W. E. Bickel
C. W. Brown Jr.
C. B. Bryant
R. W. Chorley
R. E. Coughlan
W. L. Curtiss
J. H. Davidson
G. E. Durham
P. W. Elmore
F. A. Feikert
R. N. Foster
J. S. Hancock
J. P. Hanley
C. K. Holden
R. L. Holmes
A. W. Johnson
H. F. King
C. R. Knowles
H. M. Laudemann
J. J. Laudig
O. E. Mace
Ray McBrian
W. A. McGee
H. L. McMullin
G. F. Metzdorf
R. H. Miller
E. R. Morris
M. F. Neuzil
A. B. Pierce
E. M. Grime, *Vice-Chairman,*
W. G. Powrie
S. E. Printz
W. A. Radspinner
O. T. Rees
H. E. Silcox
D. A. Steel
R. M. Stimmel
J. E. Tiedt
C. P. Van Gundy
H. W. Van Hovenberg
R. E. Wachter
K. J. Weir
J. B. Wesley

Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

Progress report—recommended for adoption as an addition to material now in the Manual .... page 96

2. Cause of and remedy for pitting and corrosion of locomotive boiler tubes and sheets, with special reference to status of embrittlement investigations.

Progress report—submitted as information........ page 96

3. Value of water treatment.

No report.

4. Progress being made by federal or state authorities on regulations pertaining to railway sanitation, collaborating with Joint Committee on Railway Sanitation, AAR.

No report.

5. Cathodic protection for prevention of corrosion of steel tanks, collaborating with the Electrical Section, Engineering Division, AAR.

Final report—submitted as information........ page 97

6. Effect of lubricating oil in boilers and methods for correction.

Final report—submitted as information .... page 101 (a)

7. Removal of silica from boiler feedwater.

Final report—submitted as information .... page 101 (b)

8. The principal current activities of the Fire Protection and Insurance Section, AAR.

Progress report—submitted as information........ page 106

9. Use of anti-foam compounds to reduce road blowing.

No report.

10. Specifications for welded steel tanks for water service, collaborating with Committee 15—Iron and Steel Structures.

No report.

The Committee on Water Service, Fire Protection and Sanitation,

B. W. DeGeer, *Chairman.*

Bulletin 421, December, 1940.

Report on Assignment 1

Revision of Manual

E. M. Grime (chairman, subcommittee), C. B. Bryant, G. E. Durham, J. J. Laudig, G. F. Metzdorf, R. H. Miller, O. T. Rees, J. A. Russell, H. W. Van Hovenberg.

Under Specifications for Steel Water and Oil Tanks, Manual page 13–38, the first two sentences of paragraph 11 now read as follows:

"For plates not more than ⅜ inch thick, ⅝-inch rivets shall be used. For thicker plates ¾-inch rivets shall be used."

To make this specification more definite and complete, the committee recommends that the following be added as a third sentence:

"For thin plates used in roof construction, ⅛, $\frac{3}{16}$ and ¼ inch thick, use respectively ⅜, $\frac{7}{16}$ and ½-inch rivets."

Report on Assignment 2

Cause of and Remedy for Pitting and Corrosion of Locomotive Boiler Tubes and Sheets, with Special Reference to Status of Embrittlement Investigation

R. E. Coughlan (chairman, subcommittee), R. C. Bardwell, W. M. Barr, W. L. Curtiss, J. H. Davidson, G. E. Durham, E. M. Grime, H. M. Laudemann, O. E. Mace, Ray McBrian, E. R. Morris, R. M. Stimmel, J. B. Wesley.

During the past year your committee has continued its cooperation in the study of embrittlement being conducted by the Bureau of Mines, at College Park, Md., under the sponsorship of the AAR with the National Feed Water Studies Committee. The committee offers the following abstract of a report on this subject as presented by Dr. W. C. Schroeder of the Bureau of Mines, to the Association of American Railroads, Mechanical Division, in June, 1940.

> This report, while reviewing material on which your committee has previously reported, summarizes the present status of this investigation in a definite conclusion that embrittlement, or as it is now being called, intercrystalline corrosion, is not produced in a boiler by direct action of the water, but by a concentrated solution formed from it in capillary spaces in rivet seams in a stressed area.
>
> This concentration, and subsequent cracking, results from minute leakage into a stressed area of the seam. The resulting cracking, independent of the water conditions, depends upon localized stress brought about by cold work or other practices beyond the control of water service engineers. It has been definitely proved that sodium sulphate offers little, if any, protection from this type of cracking in locomotive boilers.
>
> Embrittlement detectors have been developed and applied to locomotives, which will indicate the action of concentrated boiler feed waters on stressed specimens of boiler steel while the locomotive is in actual service.
>
> Sulphite liquors and some tannin compounds have been found to protect boiler steel from intercrystalline corrosion during the past 15 years. The work this year has indicated that the protection by these organic materials is sometimes minimized

where sodium sulphate and sodium chloride are present in any appreciable amount in the boiler feed waters. In the use of these sulphite liquors and other organic material for this purpose, it is necessary that chemical control of the concentration of the organic inhibitors as well as the dissolved solids be maintained in order to provide adequate treatment necessary for the protection of the boiler steel.

There is no doubt, from the results of the studies up to the present time, that a boiler constructed to resist embrittlement will need no other protection throughout the life of such a boiler. Welding of the seams would be one means of accomplishing this purpose, but such construction is not permitted in locomotive boilers at this time. Various types of alloy steel, resistant to intercrystalline corrosion, offer another possibility. In this connection, however, it has been definitely established that some of the low carbon boiler steels containing nickel or silicon-manganese are not as resistant to this type of failure as is standard carbon boiler steel.

While there is no question but that a great deal can be done by the use of organic inhibitors to prevent intercrystalline corrosion in locomotive boilers already built, the importance of careful design, construction, and shop practice cannot be over-emphasized. Every care should be exercised to make the boiler seams tight and to prevent the excessive cold distortion of the metal which produces stressed areas.

The evidence obtained to date from actual railroad operation indicates that a combination of good construction and shop practice greatly reduces the possibility of costly failures from intercrystalline corrosion, or cracking.

This report is submitted as information.

Report on Assignment 5

Cathodic Protection for Prevention of Corrosion of Steel Tanks

Collaborating with Electrical Section, Engineering Division, AAR

H. E. Silcox (chairman, subcommittee), C. W. Brown, Jr., C. B. Bryant, P. W. Elmore, F. A. Feikert, J. P. Hanley, A. W. Johnson, H. F. King, H. M. Laudemann, A. B. Pierce, J. A. Russell, J. E. Tiedt, R. E. Wachter, K. J. Weir.

In the past few years the subject of corrosion has been widely discussed and various methods have been tried by American railroads to reduce the deterioration of steel water tanks. Many methods of preventing corrosion have been found efficient in their application to the exterior surfaces, but they are not proving entirely satisfactory when applied to the interior surface of the tank shell which is subjected to corrosive action of water.

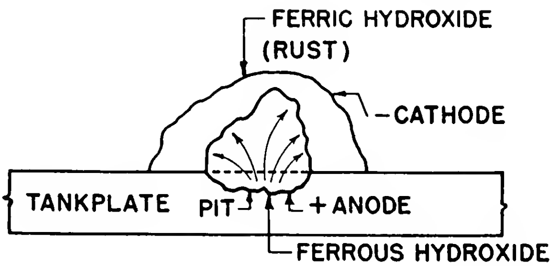
Heavy Losses From Underwater Corrosion

Approximately 6,000 steel water tanks are now in railroad service representing a capital investment of $30,000,000. The expected life of these facilities should be about 60 years. However, due to underwater corrosion this is being materially reduced by the loss of steel. Based on actual tests, the coating of the interior surface of steel tanks with paints of various types affords protection for a period ranging from 1 to 4 years. The labor cost involved in scraping and cleaning the interior of steel tanks averages 2.4 cents per square foot, application of paint 1.9 cents, and painting material for two coats 0.7 cents, or a total of 5 cents. At this rate, the painting cost for the interior of a 50,000-gal. steel tank will be approximately $95 and larger tanks of 40-ft. diameter by 74-ft. high,

$790, together with removal of tank from service for a period of 4 to 15 days, which is the more important item.

The different water qualities in the various sections of the country have a very marked effect on the rates of corrosion of the steel. In mining territories the acid mine drainage waters create a higher rate of corrosion, while the rate with alkaline waters is lower.

Underwater corrosion, as applied to the interior surface in steel water tanks, is based on the generally accepted electro-chemical theory that the metal dissolves and goes into solution by first forming ferrous hydroxide and, with further oxidation from dissolved oxygen in the water, builds up a wall of iron rust around the pitted area. In this reaction, the steel tank shell is the anode or positive pole and rust is the cathode or negative pole



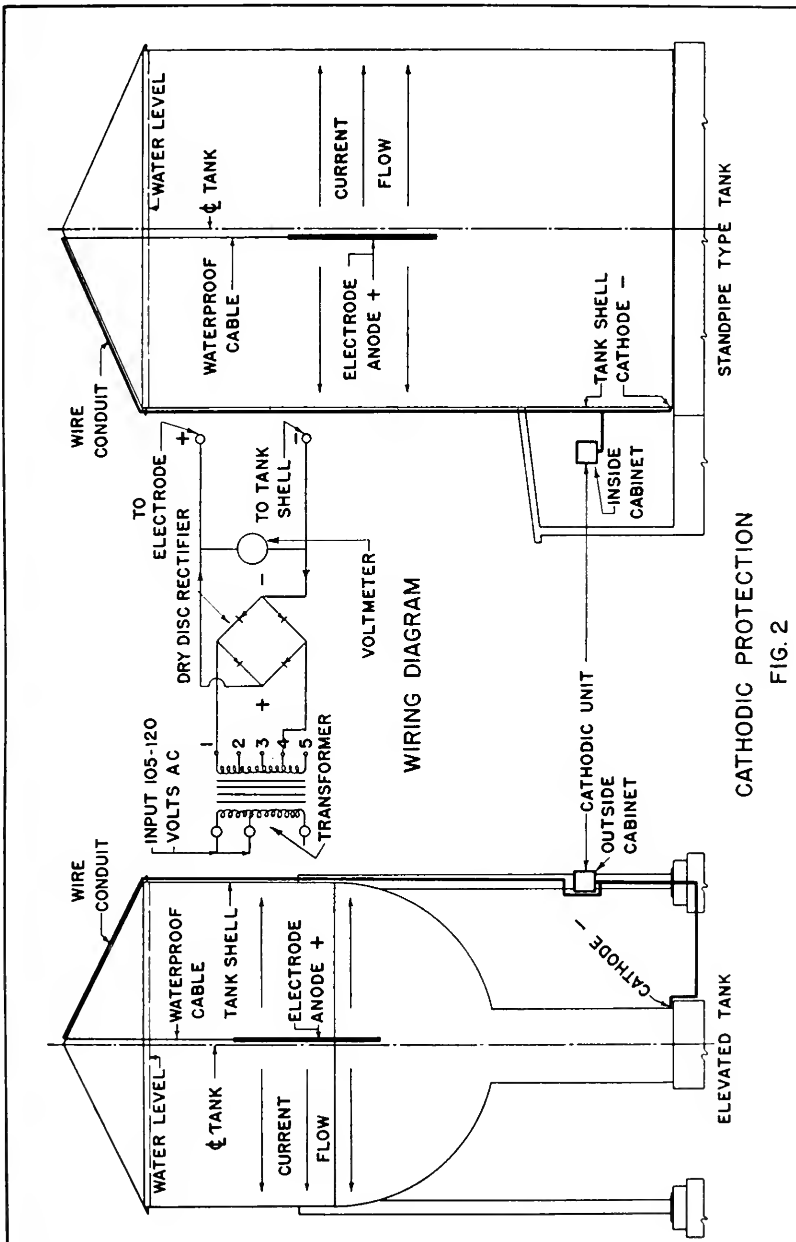
FORMATION OF RUST
CONES AND PITS
FIG. 1

as illustrated in Fig. 1. The fundamental reactions and factors of corrosion are similar to those of a primary electric cell, as in its function one metal or electrode must dissolve and go into solution.

Cathodic Protection

Cathodic protection is a recent development in the control of corrosion on the interior of steel water tanks. This process is based on the principle of an electric cell in which the current flows in one direction from the positive electrode through the water in the tank which acts as an electrolyte to the cathode or negative electrode. In its operation, the steel tank shell becomes the cathode which is protected by a hydrogen film plated on its surface.

In the application of cathodic protection to steel tanks, direct electric current is required to provide a continuous current flow. As direct current is not always available the supply is usually secured from regular 105–120-volt, 60-cycle, alternating-current electric lighting circuit which is connected to a transformer to reduce voltage to the requirements and then to a dry disc rectifier unit which changes the power to direct current. From the rectifier the positive wire or lead is connected to one or more electrodes of carbon, graphite, stainless steel or other metals which are suspended inside the tank at a depth where they will be submerged in water at all times. These electrodes form the anodes (positive pole). The negative wire of the rectifier is connected to the bottom of the tank shell which becomes the cathode. In operation, the current flows from the anode to the cathode, dissociating hydrogen ions by electrolysis of the water. Due to the tank shell being in an electro-negative state, the positive hydrogen ions are attracted, depositing an insulating film on its interior below the water line, thus excluding oxygen which is a requisite of corrosion.



CATHODIC PROTECTION
FIG. 2

Typical installations of cathodic protection in steel elevated and standpipe type water tanks are outlined in Fig. 2.

Equipment Required

The cathodic unit consisting of transformer, rectifier, switches, voltmeter, and fuses is assembled in a steel cabinet with a hinged door for protection. The cabinet for installation on tanks where shelter is not available is of a moistureproof type. In event a location inside a building is possible, an ordinary steel cabinet is used.

The number and size of the electrodes depend on the square feet of area under water to be protected and *pH* of the water in storage. Installations now in operation are provided with one or more electrodes.

In the alternating-current rectification, three types of dry plate rectifiers are available for changing a.c. to d.c., namely, magnesium-copper sulphide, selenium or copper oxide. The safe maximum operating temperature of these units ranges from 55 deg. C. (131 deg. F.) to 85 deg. C. (185 deg. F.). Due to the limited period of service of these units, it still remains to be determined which type has the longer life in continuous hours of service.

The most commonly used electrodes (anodes) are graphite and stainless steel. Graphite anodes now in service range from 2 in. to 3 in. in diameter by 80 in. in length, while the stainless steel runs from ⅜ in. to 1 in. in diameter of varying lengths. As eventually both types are consumed by electrolysis, the ratio of actual consumption and life in cathodic tank protection remains to be determined by their actual performance.

In operation, the d.c. voltage at the positive electrode ranges from 8 to 27 volts and 0.5 to 6 amperes, depending on the condition of the tank and resistance of water to passage of current. Sufficient voltage should be applied to assure complete polarization of the steel surface to be protected, as the operation is based on Faraday's law of electrolysis:

> "The mass of an electrolyte decomposed by an electric current is directly proportional to the quantity of electricity passing through it."

In observation of tank interiors that have had this type of protection, it is noted that the old scale and rust is gradually sloughing off, the metal becoming coated with a gray deposit. This indicates that the equipment is functioning; however, the protection is due to the microscopic hydrogen film instead of the gray deposit.

In order to check the operation of the unit without draining the tank, test specimens are often hung in the tank; one connected to the tank shell by means of wire which affords it the same protection as the tank, and the other by a cord or rope. The wire-connected specimen in time becomes covered with the characteristic gray protective coating, indicating that action is taking place. The second specimen in a short time becomes coated with rust, and pitting develops. This method is being used by the manufacturers to demonstrate the results obtained.

Extent of Use

At the present time about 25 installations of this type are in service on American railroads, the oldest unit having been installed in March 1939.

The cost of the units installed depends on the area to be protected. A unit, with one or two electrodes, for a 50,000-gal. elevated steel tank with an inside area of approximately 1,800 sq. ft. will cost approximately $250 plus the expense of running power to the tank. Units for larger installations, such as a standpipe-type treating tank 40 ft. in diameter by 53 ft. high, with a downtake tube and 13,600 sq. ft. to be protected, requiring 5 electrodes, cost approximately $475. The power cost for operating the cathodic protection unit ranges from 50 cents per month up, depending on capacity of installation.

With cathodic installations, it is still necessary to paint the underside of the roof and the tank shell above the water line, as protection does not extend to the surface area of tank above the water level. This type of installation has an advantage, in that it is not necessary to remove the steel water tank from service for application of the protective coating, as is required in the cleaning and painting operation.

In the event that installations are contemplated in old steel tanks which are badly corroded and pitted, the condition of the plates and rivets should first be investigated, as the cathodic protection through removal of the scale may develop leaks together with loss of rivets.

When contemplating installations in cold regions, consideration should also be given to the possibility that ice forming in the top of tanks might strip the cables and electrodes from their supports.

Periodic inspections should be carried out to determine whether the equipment is functioning, and for recording voltage and ampere readings; also testing switches to detect defective or blown fuses. The interior of the tank shell should also be inspected to observe the extent of the deposit of protective film in order to maintain the correct voltage adjustment to meet the requirements of the respective installations.

Conclusions

Cathodic protection of steel water tanks against the corrosive action of water is still in the experimental stages; however, the indications are that some benefits are being obtained.

Because of the limited period of operation in railroad water service, more time will be required to demonstrate whether cathodic protection is the satisfactory method to prevent corrosion in steel water tanks.

This report is presented as information.

Report on Assignment 6

Effect of Lubricating Oil in Boilers and Methods for Correction

G. E. Durham (chairman, subcommittee), W. M. Barr, C. W. Brown, Jr., R. W. Chorley, E. M. Grime, J. S. Hancock, J. P. Hanley, R. L. Holmes, C. R. Knowles, J. J. Laudig, W. A. McGee, R. H. Miller, E. R. Morris, S. E. Printz, R. M. Stimmel, R. E. Wachter, J. B. Wesley.

The steam cylinder or valve lubricating oils, with which this report is primarily concerned, usually consist of heavy mineral oils containing a small amount (about four percent) of "compounding" such as acidless tallow oil, degras, etc. Steam exhausted from an engine may carry with it under some conditions a quantity of these lubricants; and when such steam is condensed the resulting water will contain oil. Consequently, any condensate returned to a boiler from a condensing system, or from a feedwater heater or exhaust steam injector, is liable to introduce oil into the boiler water.

Circumstances other than the return of condensate may cause the presence of oil in boiler water. For example, improper maintenance of feedwater pumps may permit the oil used for lubricating the pumps to leak by the packing and into the feedwater. Again, the feedwater supply may be originally contaminated by oily industrial wastes.

If oil, which may be derived from sources such as those suggested, is permitted to enter a boiler, the effects may be detrimental or negligible; the nature of the effects actually realized depends to a large extent upon the alkalinity, dissolved solids content, and degree of floc in the boiler water.

In a boiler water of low alkalinity the oil present may be deposited on heating surfaces and thus, because of its low heat conductivity, very materially reduce the rate of heat transfer to the water. Overheating and cracking of firebox sheets, leaking of staybolts and burning out of arch tubes and flues may easily be caused by severe cases of oil deposit. An oil coating on the water side of a heating surface may become hot enough to char, decompose, and suddenly break away from the hot steel, permitting water to come in contact with the overheated area. The resultant sudden contraction of the steel may be sufficient to cause serious damage.

Even a slight oily deposit on boiler heating surfaces produces an insulating effect which reduces boiler efficiency. A discontinuous oil coating may cause pitting in various parts of the boiler if the boiler water is of a nature to support electrolytic corrosion. Oil carried over with water in foaming boilers may cause incrustation of throttle valves and clogging of superheater units.

In boiler waters whose alkalinities are maintained at a minimum of 20 percent of the dissolved solids content, the effect of the oil content ordinarily encountered appears to be slight. Several of the roads reporting in this connection state that they have experienced no trouble caused by oil in boilers, and attribute the absence of trouble to the maintenance in the boiler waters of suitable alkalinity and good coagulation of sludge. Apparently the alkalinity tends to emulsify the oil and the coagulated sludge tends to absorb it, thus preventing any actual oil deposits which might produce the detrimental effects discussed above.

When a boiler develops symptoms which indicate that lubricating oil is present in the water, it may be desirable to analyze both the feedwater and the boiler water for oil content. This may be done as follows: Acidify a 500 c.c. sample with dilute nitric or hydrochloric acid in a separatory funnel. Extract three times with carbon tetrachloride. Draw off the extractions, combine them in a flask, and dehydrate with fused calcium chloride. Filter into a weighed flask and carefully evaporate off the carbon tetrachloride on a steam table at 105 deg. C. Cool in a dessicator and weigh. Reheat the flask on the steam table to constant weight. The weight of the residue in milligrams times two equals parts per million of oil. In taking the original sample, care and judgment must be exercised to insure that the oil content is uniformly mixed in the water at the time of sampling.

Where lubricating oil in a boiler is causing harmful effects, several methods of correction are available. If the oil is introduced with condensate from the engine or from the stoker, the best corrective measure is that of adjusting the lubricator feeds. This adjustment should be such as to reduce to a practicable minimum that excess of oil which is carried out with the exhausts. If oil becomes mixed with the water in the feedwater pump, careful inspection and maintenance of the pump packing and proper feeding of oil to the pumps should be effective remedies.

Various designs of oil strainers or oil traps may be used in the feedwater supply line between the point of condensate introduction and the boiler. These strainers are reported to be effective if they are properly maintained. They are sometimes supplied as standard equipment with appliances such as exhaust steam injectors.

Oil present in locomotive tender water, whether from original contamination or from exhaust of boiler auxiliaries, tends to accumulate on the sides and tops of tenders rather than to become emulsified with the water. Periodical cleaning of the tanks, with special attention to the removal of the oil scum, should prevent oil in the tender water from getting into the boiler.

As has been previously indicated, a boiler water of suitable characteristics can largely emulsify or sludge away any oil introduced into it. Consequently, treatment of feedwater with suitable alkalies and coagulants may be considered as an effective means of correcting boiler troubles caused by oil. The experience of most railroads proves that proper maintenance of boiler auxiliaries, avoidance of excessive lubricator feeds, and proper chemical treatment of feedwater will generally prevent any harmful effects of lubricating oil in boilers.

This report is submitted as information.

Report on Assignment 7

Removal of Silica From Boiler Feed Water

Ray McBrian (chairman, subcommittee), W. M. Barr, C. B. Bryant, R. E. Coughlan, G. E. Durham, R. N. Foster, E. M. Grime, R. L. Holmes, H. M. Laudemann, J. J. Laudig, O. E. Mace, H. L. McMullin, W. G. Powrie, O. T. Rees, R. M. Stimmel, J. B. Wesley.

The presence of silica in boiler feed waters is particularly undesirable since it may react with the calcium present to form a hard dense scale deposit of calcium silicate. Silica scale has become a problem of increasing importance with the trend in the railroad industry towards higher boiler pressures and to the use of Diesel equipment having heating surfaces that are especially sensitive to scale formation. If the silica content of the boiler feed water is kept below five parts per million, the possibility of its concentration and subsequent precipitation as silicate scale is greatly reduced.

Silica scale, of all the mineral boiler scales, possesses the lowest thermal conductivity coefficient, as is shown in the table given by Stumper, which is as follows:

Character of Scale	*Heat Transfer Coefficient, K*
Siliceous	0.2 to 0.5
Calcium sulphate	0.5 to 0.7
Calcium carbonate, amorphous	0.2 to 1.0
Calcium carbonate, crystalline	0.5 to 5.0

The constants are in the metric system of units and are consequently expressed as kilograms per meter per degree centigrade per hour of time. It appears that the ability of the siliceous scale to conduct heat is roughly one-half to one-tenth that of scales in which the chief constituents are calcium carbonate and calcium sulphate. A siliceous scale film of only a fraction of the thickness of a usual scale deposit might exceed other types of scale formation in insulating value, and the danger of these thin deposits on heating surfaces is especially great in the modern boiler wherein the metal temperature is normally at the safe maximum, and it is the elevation of temperature gradient through the boiler metal that is to be most feared from silica scale deposits, especially with the trend in locomotive and power plant practice to increasing pressures.

The nature and formation of silica scales depend upon the composition of the boiler feed water and the conditions of operation. The composition of such scales may range from practically pure silica through simple calcium and magnesium silicates to much more complex compounds such as analcite (sodium aluminum silicate) to other mixtures in which the siliceous components seem to function as cementious agents.

Two fundamental methods have been used to prevent silica scale:

1. The internal treatment type, through a suitable physical chemical treatment of the boiler feed water.

2. The external treatment type, which removes the silica from the feed water before it enters the boiler.

Internal Treatment

This type of physical-chemical treatment has been found to limit certain types of silica deposits satisfactorily. The typical chemicals used are sodium phosphates, iron compounds, sodium aluminate, and organic compounds such as starches, tannins, lignins, tannic acid, and the glucosides. The action of these compounds alone or in combination has been either to maintain the silica in solution or to precipitate it as a non-adherent scale which must then be removed by blowing or washing. The results depend upon the boiler pressure and the condition in which silica and other constituents are present in the boiler salines. In railroad operation, this type of treatment has been satisfactory for particular operating conditions and territories.

External Treatment

It is becoming necessary to improve the methods of conditioning silica containing waters, due to increasing boiler pressures and other operating factors. It is these factors which have placed emphasis on removing silica from the water before it enters the boiler. As a result, many efforts have been made to work out effective methods of silica removal.

Several of these methods have attempted to combine silica removal with some degree of water softening, as neither the standard clarification or lime and soda softening will remove more than a small percentage of the silica present in most water supplies. Where recirculation of sludge has been employed some further silica removal has been observed. The zeolite method of softening waters by either a natural or synthetic silicate base exchange type of product may add silica to the water rather than diminish the amount of silica present, while the carbonaceous exchangers apparently do not alter the silica content of a water passed through them.

In general, methods which have been used or proposed specifically for silica removal have been for the most part unsuccessful except in certain isolated cases. The one general exception to this statement comprises the metallic oxides and hydroxides, particularly those of iron and aluminum.

Iron

This method of silica removal treats the water with ferric sulphate; optimum silica removal by the precipitated hydrous ferric oxide is attained at a *pH* 9, and the treatment must be held closely to this *pH*. The ferric sulphate treatment, while effective in some cases, has several limitations, which seem to prevent it from being considered as the ultimate solution of the silica removal problem. In the first place, the necessity of maintaining a *pH* of 9 usually precludes the possibility of securing silica removal and complete lime and soda softening in one precipitation. While it is possible to precipitate the calcium of raw water rather completely as calcium carbonate at *pH* 9, precipitation of magnesium as magnesium hydroxide does not begin until a *pH* of about 10.2 is attained. Consequently it will be found necessary to accomplish the desired softening and silica removal in a two-stage process which increases the cost and complexity of the treating equipment.

Since the removal of silica by the precipitated ferric oxide is apparently an absorption or quasi-absorption phenomenon, it follows that while an appreciable part of an initially high silica content of a water may be removed with moderate dosages of ferric sulphate, disproportionately large doses will be required to reduce the remainder to a desired minimum. Another consideration from the standpoint of boiler operation is the large amount of dissolved solids added to the boiler feed water by large dosages of ferric sulphate. Every grain per gallon of anhydrous ferric sulphate employed in the treatment adds to the water in its finally softened condition 1.065 grains per gallon of sodium sulphate.

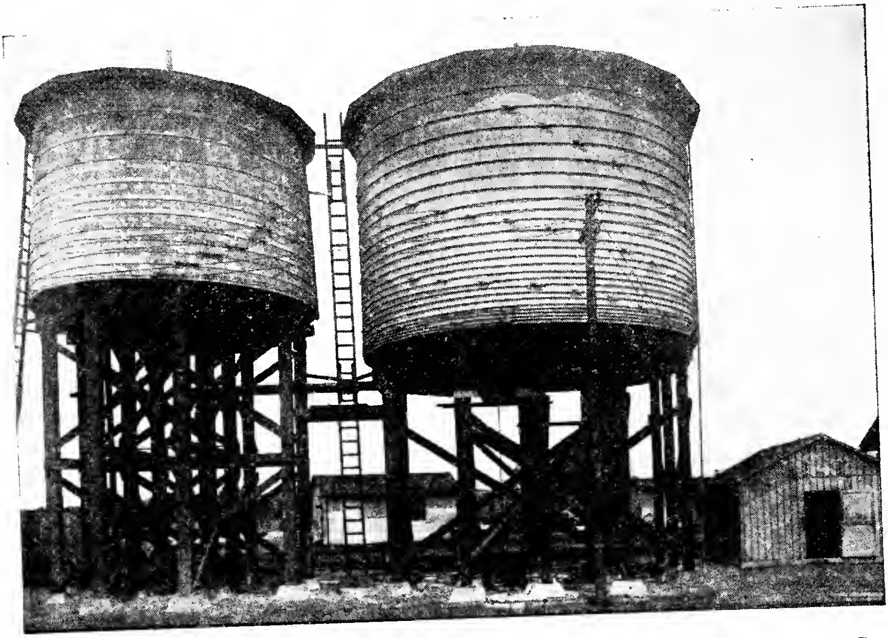
Magnesium

The use of magnesium compounds added where applicable, seems to have several advantages over the use of ferrous sulphate, as silica removal is combined with lime and soda softening at as high a *pH* as may be desired. The use of magnesium sulphate is more economical than ferric sulphate, not so much because of the cost of the reagents themselves, but because of the cost of the alkali necessary to combine with them.

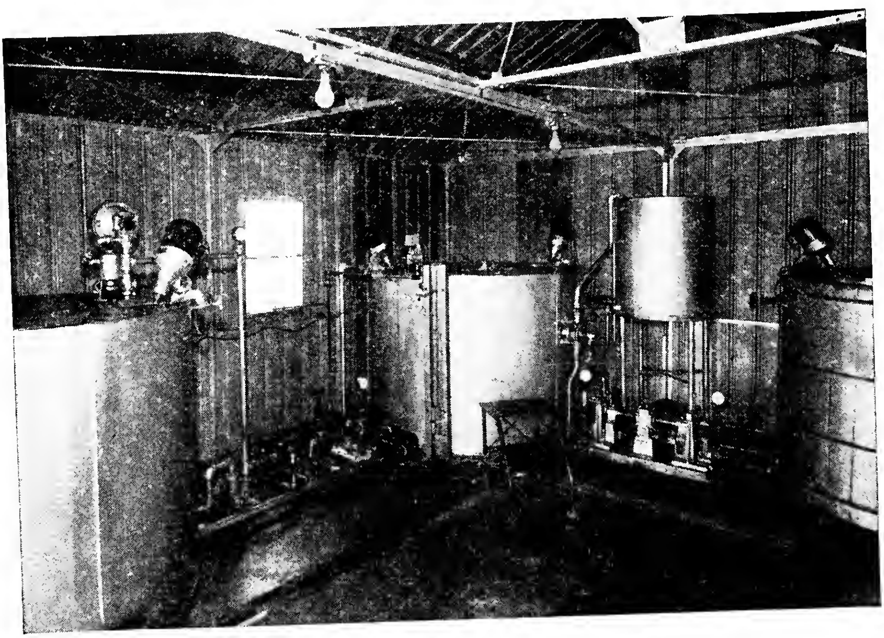
One hundred parts per million of anhydrous ferric sulphate will require theoretically for reaction in lime and soda softening 62 p.p.m. of hydrated lime (90 percent available calcium hydrate) and 81 p.p.m. of soda ash (98 percent sodium carbonate), whereas 100 p.p.m. of magnesium sulphate (Epsom salts) will require only 33 p.p.m. of hydrated lime and 44 p.p.m. of soda ash. On the basis of present market prices, this unit difference in chemical requirements amounts to about 0.567, or one-half cent, per thousand gallons. Also, the use of 100 p.p.m. of ferric sulphate under these conditions will add to the water 100 p.p.m. of sodium sulphate, as against 58 p.p.m. of magnesium sulphate.

Magnesium carbonate (or bicarbonate) has been suggested as an effective source for magnesium. The chief advantage of either of these compounds is that there is no increase in the amount of sodium salts as a result of the treatment. Another advantage is that lime only, without soda ash, is required for precipitation.

Dolomitic lime has been suggested in place of high calcium lime, but it has not been found as successful as magnesium hydroxide, which to be effective in silica removal, must be formed in the water being treated.



Exterior View of the Silica Removal Plant of the Atlantic Coast Line at Savannah, Ga.



A Corner of the Silica Removal Plant at Savannah, Ga.

Aluminum

Anhydrous aluminum oxide is an effective material for the removal of silica from water and it can be prepared from sodium aluminate or other aluminum salts. With the use of sodium aluminate as a source for anhydrous aluminum oxide, a controlled *pH* of about 8.5 is required. This control of the *pH* is essential as is also the build up and the recirculation of the precipitate formed. The completeness of the removal is dependent upon the amount of sodium aluminate used in the auxiliary treatment.

A complete softener has been installed on a railroad at Savannah, Ga., for silica removal. The treating tank consists of a 100,000-gal. wood tank, 30 ft. in diameter and 20 ft. high, inside of which is built another complete tank 15 ft. in diameter and of equal height to the larger tank. The raw water is derived from a deep well and is pumped at the rate of 350 gal. per min., discharging through a pipe entering through the bottom of the two tanks and extending 18 in. above the floor of the smaller tank. The water is discharged through a 2½-in. orifice in a horizontal plane, in order to set up a circular movement of the water in the inside 15 ft. diameter tank. At the point where the raw water is discharged in the tank, a solution of lime slurry and sodium aluminate is added at the rate of 0.9 lb. of lime and 1.25 lb. liquid aluminate per 1,000 gal. of raw water. This produces a precipitate in the water which is fine and light. The lime and aluminate continue to react, moving in an upward direction, and at a height of 12 ft. an alum solution is injected for coagulation. The alum is added at the rate of 0.8 to 0.9 lb. per 1,000 gal. of raw water. The circular and upward movement of the raw water continues to a point 24 in. below the top of the tank, where it passes downward through a 12-in. diameter steel pipe, located in the center of tank, and discharges into the bottom of the larger tank in such a way as to create a circular movement in the outer, larger tank. Coagulation and settling continue in the larger tank; clear water is taken off from the top of the larger tank and goes to a storage tank. Tannin is added to the water when the water passes through the equalizing chamber.

The large treating tank is equipped with the conventional sludge removal system. No sludge accumulates in the center, or smaller, tank. The entire plant is automatically controlled. Laboratory tests have shown that the optimum *pH* for the water reaching the top of the small, or inner, tank is 8.5. It has been difficult to control or hold the *pH* to 8.5 in actual operation.

The following is a typical analysis of the raw and treated water:

Raw	*Grains per Gallon*	*Treated*	*Grains per Gallon*
Silica	3.80	Silica	0.60
Hardness	6.90	Hardness	3.72
Alkalinity	7.08	Alkalinity	5.14
Chlorides	1.00	Chlorides	1.00

The cost per 1,000 gal. for chemicals has been: lime $0.0059, aluminate $0.0462, alum $0.0109, tannin $0.0104, total $0.0734.

The results have been very gratifying in the prevention of silica scale formation.

This report is submitted as information.

Report on Assignment 8

Principal Current Activities of the Fire Protection and Insurance Section, AAR

G. F. Metzdorf (chairman, subcommittee), H. F. King, W. A. Radspinner.

Fire protection and prevention and the allied item of insurance, are important subjects for every railroad.

The organization of a new Fire Protection and Insurance Section in the Operating-Transportation Division of the Association of American Railroads became effective April 1, 1939. The creation of this new section was brought about by absorbing the Railway Fire Protection Association, which had functioned since 1913 as an independent organization of railway employees engaged in fire protection and prevention activities, with an associate membership of interested industrial and insurance representatives. The amalgamation was proposed by the Fire Protection Association, and became effective following approval by the General Committee of the Operating-Transportation Division.

The objectives of this new section are the improvement in methods of fire protection and prevention, the circularization of information on these subjects, the establishment of safeguards against loss of property and life by fire, and the standardization of practices through the interchange of ideas and experiences.

The list of standing committees in the Fire Protection and Insurance section is as follows:

Committee 1—Insurance
Committee 2—Buildings, Bridges, Piers and Other Structures
Committee 3—Engine Houses, Shops and Appurtenant Operations
Committee 4—Flammable Liquids, Compressed and Liquefied Gases and Hazardous Articles
Committee 5—Special Hazards
Committee 6—Statistics and Records
Committee 7—Rolling Equipment
Committee 8—Hand Book
Committee 9—Electrical

The committee work thus far has been devoted to a revision of the Railway Fire Protection Association Hand Book which will now become the Hand Book of the Fire Protection and Insurance Section of the Association of American Railroads. Up to the present time the sections as revised have not been acted upon for publication, but it is anticipated that the Hand Book will be ready for printing before the section's next annual meeting in October 1941.

This Hand Book is a valuable collection of information of approved and recommended practices and as such, proves very useful to the fire prevention inspectors as well as to the managements, and the engineering and other various departments of the railroads.

This report is submitted as information.

Report of Committee 14—Yards and Terminals

C. H. Mottier, *Chairman,*
J. R. W. Ambrose
C. E. Armstrong
J. E. Armstrong
C. J. Astrue
Hadley Baldwin
H. G. Basquin
A. L. Becker
V. J. Bedell
W. O. Boessneck
W. J. Brennen
N. C. L. Brown
H. F. Burch
H. G. Dalton
F. T. Darrow
R. B. Elsworth
W. H. Giles
E. D. Gordon
R. J. Hammond
G. F. Hand
M. J. J. Harrison
E. M. Hastings
W. J. Hedley
H. O. Hem
W. H. Hobbs
J. M. Hood
E. T. Johnston
E. K. Lawrence
H. C. Lorenz
L. L. Lyford
J. M. Metcalf
W. F. Cummings, *Vice-Chairman,*
C. A. Mitchell
H. C. Propst
C. L. Richard
H. L. Ripley
H. M. Roeser
W. B. Rudd
W. C. Sadler
C. U. Smith
D. J. Strauch
J. N. Todd
E. E. R. Tratman
E. P. Vroome
R. W. Willis

Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

The Committee on Yards and Terminals,
C. H. Mottier, *Chairman.*

Bulletin 421, December, 1940.

Report on Assignment 1

Revision of Manual

L. L. Lyford (chairman, subcommittee), J. E. Armstrong, Hadley Baldwin, W. F. Cummings, F. T. Darrow, W. H. Giles, G. F. Hand, M. J. J. Harrison, E. M. Hastings, W. J. Hedley, H. C. Lorenz, J. M. Metcalf, C. H. Mottier, H. L. Ripley, E. E. R. Tratman.

Your committee recommends the following changes and additions for publication in the Manual:

Glossary

Page 42: insert the following:

SIDING.—A track auxiliary to the main track for meeting or passing trains. *14*

Page 50: delete the following under the heading Track:

—PASSING.—A track auxiliary to the main track for meeting or passing trains, limited to the distance between two adjacent telegraph stations. *14*

Insert, in lieu of the deleted definition, the following:

—PASSING.—A track auxiliary to the main track for meeting or passing trains. Same as a *Siding. 14*

Freight Terminals

322. Hump Yards—General

Delete paragraph 322 (e), page 14–21, reading as follows:

(e) *If the classification tracks are also used as departure tracks, it is desirable to provide additional classification tracks for overflow classification space during the inspection and preparation time of a departing train. Lead tracks of sufficient lengths should be provided at the outgoing end so that any doubling may be done without fouling the entering end of the classification tracks and thus interfering with hump operations.*

Insert in its place the following paragraph:

(e) It is desirable to make up and dispatch trains from the classification tracks if local conditions permit, and such a method of operation usually expedites movements through the yard and reduces the expense. This requires that a sufficient number of classification tracks be long enough for each to accommodate a full length outgoing train, or that lead tracks be provided at the outgoing end such that the combined length of a classification track and a lead track be sufficient for a full length train, thus avoiding unnecessary doubling over or interference with hump operation. This may involve a temporary reassignment of classifications during the inspection and preparatory time of a departing train.

Add new paragraph (f) as follows:

(f) Departure tracks may be required for making up and dispatching trains, depending on local conditions. See paragraph 333 (a).

Reletter present paragraphs (f), (g) and (h), as (g), (h) and (i).

332. Classification Tracks

Delete paragraph 332 (c), page 14–23, reading as follows:

(c) *Where cars of single classifications accumulate rapidly enough to permit of forwarding them in whole trains, the classification tracks may be used as departure tracks for such business, with their lengths determined accordingly.*

Insert in its place the following paragraph:

(c) Where cars of single classifications accumulate rapidly enough to permit forwarding them in whole trains or under conditions outlined in paragraph 322 (e) it is desirable to make up and dispatch trains from the classification tracks.

333. Departure Tracks

Insert new paragraph as follows:

(a) When conditions specified in paragraph 332 (c) do not apply, separate departure tracks if required should be provided. Limited length and number of classification tracks, volume and character of traffic to be handled in limited periods of time, or operating requirements which make it impractical to use classification tracks as departure tracks, may also compel provision of separate departure tracks.

Reletter present paragraphs (a), (b), (c) and (d) as (b), (c), (d) and (e).

Specifications for the Manufacture and Installation of Four-Section, Knife-Edge Railway Track Scales

52-X Weighbeams and Accessories

1101. Design

Delete paragraphs 1101 (d) and (e), page 14–55, reading as follows:

(d) *Notches.—On main bars the notches shall not be spaced closer than 6 to the inch. Each notch shall be so made that when the pawl rests in it a line projected from the center of the side of the notch nearer the zero graduation to the axis about which the pawl stem rotates will be perpendicular to that side of the notch.*

(e) *Pawl or Latch.—The tip of the point of the pawl or latch shall be of the same width as the notches of the beam, and shall be rounded off so that a small amount of dust or dirt in the bottom of the notch will not prevent the poise from assuming the correct position.*

Insert in their place the following paragraphs:

(d) *Notches.*—On main bars the notches shall not be spaced closer than 6 to the inch. Notches shall be so formed and positioned that accurate positioning of a poise will automatically result at any graduation at which the poise may be placed.

(e) *Pawl or Latch.*—For a poise on a notched weighbeam, the design and construction of the pawl or latch and its appurtenances shall be such that accurate positioning of the poise will automatically result at any graduation at which the poise may be placed.

Specifications for the Manufacture and Installation of Two-Section, Knife-Edge Railway Track Scales

53-XI Weighbeams and Accessories

1101. Design

Delete paragraphs 1101 (d) and (e), page 14–74, reading as follows:

(d) *Notches.—On main bars the notches shall be spaced not closer than 6 to the inch. Each notch shall be so made that when the pawl rests in it a line projected from the center of the side of the notch nearer the zero graduation to the axis about which the pawl rotates will be perpendicular to that side of the notch.*

(e) *Pawl or Latch.—The tip of the pawl or latch shall be of the same width as the notches of the weighbeam, and shall be rounded off so that a small amount of dust or dirt in the bottom of the notch will not prevent the poise from assuming the correct position.*

Insert in their place the following paragraphs:

(d) *Notches.*—On main bars the notches shall not be spaced closer than 6 to the inch. Notches shall be so formed and positioned that accurate positioning of a poise will automatically result at any graduation at which the poise may be placed.

(e) *Pawl or Latch.*—For a poise on a notched weighbeam, the design and construction of the pawl or latch and its appurtenances shall be such that accurate positioning of the poise will automatically result at any graduation at which the poise may be placed.

Specifications for the Manufacture and Installation of Motor Truck, Built-In, Self-Contained and Portable Scales for Railway Service

54-XIII Weighbeams and Accessories

1306. Notches

Delete the first paragraph of section 1306, page 14–97, reading as follows:

On main bars the notches shall not be spaced closer than 6 to the inch. Each notch shall be so made that when the pawl rests in it, a line projected from the center of the side of the notch nearer the zero graduation to the axis about which the pawl stem rotates will be perpendicular to that side of the notch.

Insert in its place the following paragraph:

On main bars the notches shall not be spaced closer than 6 to the inch. Notches shall be so formed and positioned that accurate positioning of a poise will automatically result at any graduation at which the poise may be placed.

1307. Pawl or Latch

Delete the paragraph of section 1307 reading as follows:

The tip of the pawl or latch shall be of the same width as the notches of the weighbeam and shall be rounded so that a small amount of foreign material in the bottom of the notch will not prevent the poise from assuming its correct position when the pawl is dropped in the notch.

Insert in its place the following paragraph:

For a poise on a notched weighbeam, the design and construction of the pawl or latch and its appurtenances shall be such that accurate positioning of the poise will automatically result at any graduation at which the poise may be placed.

Report on Assignment 2

General Requirements in Terminal Facilities for Various Later Types of Equipment

W. H. Giles (chairman, subcommittee), C. J. Astrue, W. O. Boessneck, W. F. Cummings, H. G. Dalton, W. J. Hedley, W. H. Hobbs, H. C. Lorenz, J. M. Metcalf, C. A. Mitchell, C. H. Mottier.

For the purpose of this report later types of equipment are considered to be the so-called streamline passenger cars or power units developed by the railways of this country within the last decade. Servicing facilities for such power units are to be discussed in a report on another assignment of Committee 14, limiting the assignment of subcommittee 2 to the servicing of streamline units of equipment other than power units.

The first streamline equipment was introduced by western railways during 1934. During 1940, more than 90 such trains were in operation in this country and additional trains were being constructed. In about 50 train units the motive power is Diesel-electric, the remainder being either steam or electric. The Diesel-electric trains are usually built to order from plans incorporating special designs, including the streamline features. Some of the steam trains have been converted from standard equipment by adding skirting and other special features. In general, the streamline appearance of the equipment in the trains has been accomplished by the addition of skirting below the under side of the car body.

Application of air conditioning to railway passenger equipment within recent years has added to the number of mechanical appliances attached to the underframe of cars and, therefore, to the amount of inspection, adjustments and repairs to be performed below the floor. The addition of skirting obscures from view a large part of the running gear and mechanical appliances, and detailed inspection of those parts of a streamline car is difficult. In most cases, complete inspection can be accomplished best by means of an inspection pit. With the exception of a pit track of required capacity for inspection, the general requirements in terminal facilities for streamline cars are usually included in the servicing facilities of a modern coach yard. Consideration should be given to the location of the inspection pit track at a coach yard to permit handling the train into the facilities without delays and to reduce the switching operations to a minimum.

The car unit capacity or length of the inspection pit and the necessity for appurtenant servicing facilities at the pit track, such as are usually maintained in passenger car servicing yards, depend upon the requirements of the individual railway. The number of trains requiring terminal inspection, repairs and servicing; the length of trains; and the schedules or layover time are factors to be considered.

Typical Facilities

Many railways operating streamline trains are servicing the car units at existing terminal passenger car facilities. In some cases the existing inspection pit has been extended as requirements demand, or an inspection pit of desired capacity has been provided.

One western railway operating a large number of streamline trains from one terminal has supplemented its passenger car servicing facilities by providing an inspection pit of sufficient length to accommodate the train. The pit is used exclusively for inspection and all equipment is moved to the coach yard for servicing and repairs after inspection has been completed. The coach yard is modern and includes repair pits as well as other appurtenant servicing facilities.

Another western railway that has pioneered in the development of streamline trains has provided a separate car servicing unit for handling such equipment at one of its terminals. This includes a combination inspection and repair pit of train length capacity, with appurtenant coach servicing facilities. Upon arrival, trains are placed on the pit track where inspection, repairs and servicing are completed.

Conclusion

It is the observation of your committee that one or more pit tracks are necessary for the complete inspection of streamline passenger car equipment. The number and length of the pits will depend upon individual requirements, considering the number of trains requiring terminal inspection, the length of trains, and the schedules or layover time as factors. The servicing facilities required for streamline cars are usually included in a modern coach servicing yard. If the pit track is to be used for inspection, servicing and repairs, appurtenant facilities should be provided.

This report is submitted as information.

Report on Assignment 3

Terminal Facilities Required for Servicing Electrical and Air Conditioning Equipment in Passenger Cars, Collaborating with Committee 1, Electrical Section, Engineering Division

W. J. Hedley (chairman, subcommittee), J. R. W. Ambrose, C. J. Astrue, A. L. Becker, H. G. Dalton, W. H. Giles, W. H. Hobbs, J. M. Metcalf, C. A. Mitchell, C. H. Mottier, H. L. Ripley.

Terminal facilities required for servicing electrical and air conditioning equipment in passenger cars must be available at coach yards and along station tracks at terminals or other stations where cars are to be serviced or held for considerable periods of time.

Electrical Equipment

Practically all passenger cars use 32-volt direct current for lighting and other incidental purposes. A few cars use 64-volt, and at least one railroad uses 110-volt direct current. Certain types of air conditioning equipment require electric current for standby use; hence, in many installations the facilities required are similar for servicing electrical equipment and for air conditioning equipment.

The general requirement for servicing this equipment at terminals is that a source of direct current power be available for the purpose of charging batteries or for floating batteries at times when cars remain in use in the terminal for an extended period. This source of power may be provided from a direct current line with convenient receptacles, or it may be furnished from portable battery charging sets, sometimes called "buggies," which convert 220-volt alternating current to direct current of varying voltages above 32 volts. Generally in coach yards, where most of the battery charging is done, it is necessary to use a controlled-current method, which provides the variable voltages required by batteries while they are being brought up from a run-down condition to that of having a satisfactory charge. Required voltages vary from 32 to 75, and obviously in a terminal of any size various voltages are needed simultaneously. If charging is to be done while cars are on station tracks, current of variable voltage should be available alongside. However, if operations are such that batteries need to be floated only during time cars are standing in station, a constant potential method may be employed, with outlets along the station tracks all providing current of the same voltage. An installation of this type is much less expensive than one which permits separate voltage control on a large number of circuits.

The first cost of installation is generally less for the 220-volt lines and portable charging sets than for a controlled-current installation. However, portable charging sets have relatively higher maintenance cost, and they occupy platform space and may interfere considerably with the other uses of the platform; consequently, in many installations the necessary additional expenditures have been made to provide low voltage direct current lines.

Because battery charging requires variable voltage, the circuit must be under constant supervision during the process of charging. If direct current lines are placed along the tracks for the purpose of battery charging, they not only require the use of relatively heavy copper in order to avoid heavy loss in transmission, but it is also necessary that numerous separate circuits be provided in order that the voltage may be controlled. Voltage control of this system must be handled from the generator house, thus requiring the presence there of an attendant who must be kept informed of the progress of the charging on the various circuits. If portable charging sets are used, each set is controlled individually, and control is handled by someone working along the platform who is in a position to observe the progress of the charging operation.

Location of Electrical Outlets

If direct current is to be used, either for charging or floating batteries while cars are on station tracks, receptacles may be located along edge of platform or between tracks. When the location of the electrical outlets is being determined, consideration should be given to construction problems, relative accessibility of receptacles, possible passenger injury from cables carelessly left on platform, and employee hazard from use of outlets located between tracks. If outlets are located between tracks it may be necessary to provide wider track spacing. If direct current is used in coach yard, similar considerations are involved. If batteries are to be charged from "buggies" operating from 220-volt, 3-phase line, receptacles for "buggy" connections should be available both along station tracks and in coach yards. These connections would be to lines also used for air conditioning operation, where such stand-by service is required. Receptacles should be so designed and located that they will suffer no damage from water or snow.

Air Conditioning

Air conditioning systems now in use are of five types:

1—Ice activated
2—Steam ejector
3—Mechanical gas-engine driven
4—Direct-mechanical
5—Electro-mechanical

The following tabulation shows the number of cars which have been equipped with each of the various systems during each of the past few years:

	Ice	*Steam Ejector*	*Mechanical Gas-Engine Driven*	*Direct-Mechanical*	*Electro-Mechanical*	*Total*
Prior to 1935.......	1,036	229	0	1,200	171	2,636
Year 1935	962	545	5	1,014	705	3,231
Year 1936	1,131	322	61	643	394	2,551
Year 1937	482	515	184	861	507	2,549
Year 1938	253	285	41	189	68	836
Total	3,864	1,896	291	3,907	1,845	11,803

This tabulation, taken from a compilation published in *Railway Electrical Engineer*, shows the number of cars equipped with each of the various systems during each calendar year. Similar figures for the year 1939 have not been compiled.

Ice activated systems are popular in northern areas, and steam ejector systems are used considerably in the South and Southwest. A proper determination of the facilities required at any particular terminal can be made only after investigation has been made to determine which and to what extent the various systems are employed on cars entering it.

1. Terminal Facilities Required for Ice Activated Cars

For cars of this type, both train shed and coach yard should be equipped with ice storage facilities and platform trucks for handling and distributing ice to the bunkers. Low platform trucks may be used to advantage for hauling ice along platforms to the bunkers under car floors. Attention should be given to reducing as far as possible the accumulation of water on platforms in the vicinity of ice storage. For complete servicing of cars equipped with the ice activated system, it is necessary that platforms be available on both sides of the track on which the car is located.

2. Facilities Required for Steam Ejector System

Cars equipped with this system require a steam connection for stand-by use. Pressure in the steam line should be sufficient to maintain a minimum of 50 lb. per sq. in. at the car located farthest from the point of connection. This frequently requires a line pressure of 125 lb., dependent upon the number of cars connected in line and the amount of drop in pressure experienced per car. Provision must be made to furnish dry steam, as steam ejector equipment will not function on steam carrying excessive water or condensate.

3. Facilities Required for Mechanical System—Gas-Engine Driven

No special terminal facilities are required for servicing cars using this system, other than that a sufficient supply of the proper fuel and lubrication be available for periodic refueling and lubrication of the engines.

4. Facilities Required for Direct-Mechanical and Electro-Mechanical Systems

Most cars recently equipped with these systems require 220-volt alternating current supply for stand-by use.

It is the intention of the committee to make further investigation and submit definite recommendation next year for the location and spacing of outlets both for direct and for 220-volt alternating current.

Progress report, offered as information.

Report on Assignment 4

Scales Used in Railway Service

M. J. J. Harrison (chairman, subcommittee), J. E. Armstrong, Hadley Baldwin, H. G. Basquin, W. J. Brennen, E. D. Gordon, E. M. Hastings, H. O. Hem, E. K. Lawrence, C. H. Mottier, H. C. Propst, C. L. Richard, H. M. Roeser, C. U. Smith, D. J. Strauch, J. N. Todd, E. P. Vroome.

On December 1, 1921, effective January 1, 1922, the American Railway Association issued its "Grain Circular No. 1". This document was issued pursuant to recommendation of the Interstate Commerce Commission, as set forth in the commission's Supplementary Report, Claims for Loss and Damage of Grain, decided January 13, 1920, Docket 9009 (56 ICC 347). It contained various rules applicable to the handling of grain in bulk, and of claims arising from its transportation. It also contained specifications and tolerances for various types of scales used in weighing grain.

Section II-B of Appendix 1 of Grain Circular No. 1 applied to hopper scales. This section was further considered after the issuance of Grain Circular No. 1, and certain emendments were agreed to by the principal parties at interest, and informally approved by the Interstate Commerce Commission. The emended material was promulgated by the National Bureau of Standards on March 7, 1925, as its Circular No. 199. There was no reissue of ARA Grain Circular No. 1.

By recent direction of the Association of American Railroads, your committee has reviewed critically the material identified as Section II-B, Appendix 1, ARA Grain Circular No. 1. The requirements of that section have been considered in the light of (1) corresponding requirements of NBS Circular No. 199, (2) corresponding requirements of currently effective AREA specifications applying to other types of scales, (3) current manufacturing practices, and (4) practical requirements. As a result, there is now submitted, as information and for discussion, a tentatively proposed specification for the manufacture and installation of hand-operated, grain-hopper scales.

For obvious reasons, your committee has solicited the collaboration of other parties at interest, and many constructive and helpful suggestions have been received from such parties. It is the sincere wish of your committee that the material herewith proposed may be further studied and criticized, to the end that the ultimate form may be acceptable to all interested parties.

56. PROPOSED SPECIFICATIONS FOR THE MANUFACTURE AND INSTALLATION OF HAND-OPERATED GRAIN-HOPPER SCALES

INTRODUCTION

(In course of preparation)

56—I CAPACITY

101. Scale Capacity Defined

The capacity of a hand-operated, grain-hopper scale is the weight of the greatest load which may be equally distributed on the knife-edges of the main load pivots without producing stresses in any member or part of the structure in excess of those specified in Section 56—III hereof.

102. Nominal Capacity Defined and Limited

The nominal capacity of a scale is the largest weight indication which can be obtained by the use of all the reading elements in combination, including the amount represented by any removable weights furnished with the scale, fractional bars totaling 2½ percent or less of the remaining elements being neglected. The nominal capacity of a hand-operated, grain-hopper scale shall not exceed the scale capacity as defined in Paragraph 101 hereof.

103. Nominal Capacities Standardized

For purposes of design, a hand-operated, grain-hopper scale shall be assumed to be one of the following nominal capacities: 18,000 pounds, 30,000 pounds, 48,000 pounds, 72,000 pounds, 120,000 pounds, or 150,000 pounds.

56—II PLANS

201. Plans to Be Furnished

Assembly plans shall be furnished by the scale manufacturer to the purchaser, showing the location of field connections and all information necessary for the purchaser to design and construct all elements of the assembly not furnished by the scale manufacturer. On request, the scale manufacturer shall submit to the purchaser plans showing materials, stresses and detailed dimensions for all scale parts.

56—III WORKING STRESSES AND FORMULAS

301. General Working Stresses

The maximal permissible unit stresses referred to in Section 56—I hereof are given below.

TABLE 1417

ALLOWABLE UNIT STRESSES IN POUNDS PER SQUARE INCH FOR IRON AND STEEL

Material	*Transverse Bending* *Tension*	*Transverse Bending* *Compression*	*Direct Stress* *Tension*	*Direct Stress* *Compression*	*Shear and Torsion*
Cast Iron (gray)					
Thickness of section *Inches*					
0.25	5,000	8,500	3,500	10,000	5,000
0.3	4,780	8,130	3,350	9,560	4,780
0.35	4,600	7,820	3,220	9,200	4,600
0.4	4,450	7,560	3,110	8,900	4,450
0.45	4,320	7,340	3,020	8,640	4,320
0.5	4,200	7,140	2,940	8,400	4,200
0.6	4,020	6,830	2,810	8,040	4,020
0.7	3,870	6,580	2,710	7,740	3,870
0.8	3,740	6,360	2,620	7,480	3,740
0.9	3,630	6,170	2,540	7,260	3,630
1.0	3,540	6,020	2,480	7,080	3,540
1.1	3,450	5,860	2,410	6,900	3,450
1.2	3,380	5,750	2,370	6,760	3,380
1.3	3,310	5,620	2,320	6,620	3,310
1.4	3,250	5,520	2,270	6,500	3,250
1.5	3,190	5,420	2,230	6,380	3,190
1.6	3,140	5,340	2,200	6,280	3,140
1.8	3,050	5,180	2,130	6,100	3,050
2.0	2,970	5,050	2,080	5,940	2,970
2.5	2,810	4,780	1,970	5,620	2,810
3.0	2,690	4,570	1,880	5,380	2,690
3.5	2,580	4,390	1,810	5,160	2,580
4.0	2,500	4,250	1,750	5,000	2,500
Steel					
Structural (SAE 1010 to 1020)	10,000	10,000	10,000	10,000	7,000
Castings (SAE 1020 to 1030)	10,000	12,000	10,000	12,000	8,000
Pivots and Bearings					
SAE 1095, hardened	24,000	24,000	24,000	24,000	
SAE 6195 or 52100, hardened	30,000	30,000	30,000	30,000	

In designing cast iron members to sustain stress of any character, the maximal allowable unit stress shall be determined by the greatest thickness, exclusive of fillets, of the portion of the section carrying the stress being considered. In the main portion of a beam, the thickness of the web or flange shall be used, whichever is the greater. The thickness of the flange shall be considered either as the average depth of the outstanding portion, or the breadth of flange, outside to outside, whichever is less.

The bearing stress on steel pins shall not exceed 15,000 pounds per square inch on any diametral cross section.

In proportioning rivets, nominal diameters shall be used.

The effective bearing area of a pin, bolt or rivet is the diameter of the member multiplied by the thickness of the member upon which the member bears. In metal ⅜ inch thick and over, half the depth of countersink shall be omitted in calculating bearing area. In metal less than ⅜ inch thick, countersunk rivets shall not be assumed to carry bearing stress.

302. High-Strength Alloys

For materials intended or represented to be "high-strength" alloys, unit working stresses other than those given in Table 1 may be used, provided these do not exceed one-third the unit stresses at the yield point established according to the test routine followed or prescribed by the American Society for Testing Materials for parts of the same analysis, heat treatment and size, and provided further that the unit working stresses for any combination of gray iron and carbon steel exclusively shall not exceed those given in Table 1 for steel castings. The purchaser, if he requests, shall be furnished with sufficient data or test specimens to enable him to determine the physical properties of the particular "high-strength" material proposed to be used.

303. Knife-Edge Bearing Stresses

The load per inch of knife-edge shall not exceed 5,000 pounds for high carbon steel (SAE 1095), or 6,000 pounds for special alloy pivot steel (SAE 6195 or 52100), when the fulcrum distance of the lever is not less than 8 inches. For each inch or fraction thereof that the fulcrum distance is decreased from 8 inches, the permissible load per inch of knife-edge for that lever shall be decreased from the value above given by 11 per cent.

304. Concrete Bearing Stresses

Bearing stresses on concrete shall not exceed 300 pounds per square inch under scale lever stands.

305. Projecting Pivots, Formula for Stresses

Where practicable, pivots shall be supported their full length by integral parts of the containing lever.

When impracticable so to support the pivots, external bending moments shall be determined as follows:

Let $M =$ the required bending moment in inch-pounds
$L =$ the length in inches of the moment arm
$T =$ the distance in inches between the friction faces of the loop
$W =$ the total load in pounds on both ends of the pivot
$D =$ the length in inches of bearing in the loop
$B =$ the width in inches of the boss or sustaining member enveloping the pivot
Then $L = D/2 + (T - B) + 1/4$ inch
And $M = WL/2$

306. Levers, Formula for Loading

For design purposes, each corner of the scale shall be assumed to carry 30 percent of the nominal capacity which is contemplated for the scale; the weighbeam and shelf lever, and their appurtenances, shall be assumed to carry 150 percent of the load due to such assumed nominal capacity.

56—IV SCALE LEVERS

401. Limitation of Type

Truss rods shall not be used in parts of the lever system except to stiffen levers laterally. Truss rods designed as parts of a lever structure to support vertically applied loads will not be permitted.

402. Qualities of Castings

Castings used for levers shall not be warped. They shall be clean, smooth, uniform, and free from blisters, blowholes and shrinkage holes and cracks. Steel castings shall be annealed.

403. Machined Ways for Nose Irons

Levers that are to be equipped with nose irons shall have those portions of the lever ends receiving them machined for the full distance over which the nose irons may be moved.

404. Leveling Lugs

In scales of other than the torsion lever type, each lever shall be provided with leveling lugs for longitudinal alinement. In scales of the torsion lever type, leveling lugs shall be provided on the pipe or torsion member for transverse alinement, and on the extension arm for longitudinal alinement. Each pair of lugs shall be spaced 11 inches apart. The leveling surfaces of each pair of lugs shall be finished to a common plane, which shall be parallel to the plane through the knife-edges of the end pivots.

405. Marking of Levers

Figures denoting the nominal ratio of each lever shall be cast or otherwise permanently marked on the lever.

406. Permanency of Adjustment

The design, workmanship and factory adjustment of all levers shall be such that the proper ratio of the lever arms will be maintained.

56—V PIVOTS AND BEARINGS

501. Material

The material used for pivots and bearings shall be either:

(a) Special alloy pivot steel (SAE 6195 or 52100), hardened to not less than 58 on the Rockwell C scale, or

(b) High carbon steel (SAE 1095), hardened to not less than 60 on the Rockwell C scale.

502. Design

Pivots shall be so formed that the included angle of the sides joining to form the knife-edge will not exceed 90 degrees, and the offset of the knife-edge from the center line of the pivot will not exceed 10 percent of the width of the pivot. Pivots intended to be held in place in their respective levers exclusively by friction shall be tapered not more than ⅛ inch per foot.

503. Mounting

(a) Fastening.—Pivots shall be firmly fastened in position without swaging or calking.

(b) Machined-In Pivots.—Pivots shall be machine-finished and fitted into machined ways.

(c) Continuous Contact Required.—Pivots shall be so mounted that continuous contact of the knife-edges with their respective bearings for the full length of the parts designed to be in contact will be obtained. In loop bearings, the knife-edges shall project slightly beyond the bearings in the loops.

504. Position

In any lever the pivots shall be so mounted that:

(a) Each knife-edge will be maintained in a horizontal plane under any load within the capacity of the scale.

(b) A plane bisecting the angle of a knife-edge will be perpendicular to the plane through the knife-edges of the end pivots.

(c) The actual distance between the end knife-edges of any lever will not differ from the nominal distance by more than 1/100 inch per foot of length of lever.

(d) The knife-edges in any lever will be parallel.

505. Support for Projecting Pivots

The reinforcing on the levers to support projecting pivots shall be tapered off to prevent accumulation of dirt next to the pivots and to provide proper clearances.

506. Design of Bearings

Bearing steels and the parts supporting or containing them shall be so applied to the mechanism that permissible movement of the weighbridge will not displace the line of contact between any bearing and the opposing pivot.

507. Interchangeability of Bearing Steels

All bearing steels of the same nominal dimensions or parts identification shall be interchangeable or mounted in interchangeable bearing blocks. The interchangeable part shall be securely mounted in the part containing it.

508. Finish of Bearing Steels

The bearing surfaces shall be brought to a smooth, true and accurate finish to insure continuity of contact with opposing pivots.

56—VI NOSE IRONS

601. Design

Nose irons shall be so constructed that:

(a) They will be positioned by means of adjusting screws of standard size and thread.

(b) They will be retained in position by screws or bolts of standard size and thread.

(c) The surfaces of nose irons intended to be in slidable contact with the levers will be machined true, so as to obtain an accurate fit in or on the levers.

(d) When adjustments are made, the knife-edge will be held parallel to its normal position.

602. Screws and Bolts

Adjusting and retaining screws and bolts shall be made of a corrosion-resistant material.

603. Retaining Device

Provision for retaining each nose iron in position shall be provided, and shall be so designed and constructed that:

(a) It will be independent of the means provided for adjustment of the nose iron.

(b) It will not cause indentations in the lever.

(c) Loads applied to the scale will not cause tension in the retaining bolts or screws.

(d) The nose iron will remain in position when the bolts or screws are loosened.

604. Marking of Position

The position of each nose iron as determined by factory adjustment shall be accurately, clearly and permanently indicated by well defined marks on the lever and nose iron, which meet in a common line.

56—VII LEVER FULCRUM STANDS

701. Qualities of Castings

Castings for lever stands shall be clean, smooth, uniform, and free from blisters, blowholes and shrinkage holes and cracks.

702. Proportions

Each lever stand shall be so designed, constructed and installed that, under any practical condition of loading, the resultant force through the bearing will fall within the middle third of the length and width of the base.

703. Finish of Bases

The base of any lever stand shall be machined true within a tolerance of $\frac{1}{32}$ inch to a plane perpendicular to a vertical line through the center of the knife-edge bearing carried by the upright portion of the stand.

704. Finish of Tops

The top of any lever stand receiving a bearing steel, cap or block shall be finished smooth and shall be parallel to the base within $\frac{1}{32}$ inch.

705. Anchor Bolt Holes

Two or more anchor bolt holes, not less than 1½ inches in diameter, shall be provided in proper places in the base of every lever fulcrum stand, unless other equally effective means for anchorage is provided.

706. Height Adjustment

For scales of 120,000 pounds and 150,000 pounds capacity, the main lever stands shall be adjustable in height.

56—VIII LOOPS AND CONNECTIONS

801. Material

The requirements for material and hardness of bearing surfaces in loop connections shall be the same as those prescribed in Paragraph 501 hereof for pivots and bearings.

802. Design

All connections and their elements shall be so constructed and installed as to result in the maximal practicable flexibility. Bearings shall be self-alining. In loop bearings, the internal radius of the eye of the loop shall in no case be less than the diagonal of the cross section of the square pivot, or the short axis of the chestnut pivot, to be used in the loop.

803. Length and Adjustment

Loops in like connections, except when adjustable, shall be of the same length. The length of the steelyard rod shall be adjustable. The means for adjustment provided in any connection shall be of such design and construction that accidental change in the length of the connection cannot occur under practical service conditions.

56—IX CHECKS

901. Arrangement

When check rods are used, they shall be adjustable. All checks shall be so designed, constructed and installed as to impose no restraint upon the weighbridge or hopper under any practical condition of loading, and insofar as practicable shall, for any scale, be positioned in the same horizontal plane.

56—X WEIGHBEAMS AND ACCESSORIES

1001. Limits for Nominal Capacity

See Paragraphs 101 and 102 hereof.

1002. Capacity to Be Marked

The nominal capacity shall be explicitly and conspicuously marked on or near the weighbeam.

1003. Type of Weighbeam

At the option of the purchaser, two types of weighbeam are permitted under these specifications:

(a) A weighbeam comprising a single bar, with its poise, and a counterpoise hanger, on which all or a major portion of the applied load is intended to be counterpoised with counterpoise weights applied on such hanger; or

(b) A weighbeam of the full-capacity type.

When specified, registering means may be furnished for either type of weighbeam named above.

1004. Multiple

For all scales covered by these specifications, the designed multiples at the load and tip knife-edges of the weighbeam shall be:

(a) When equipped with a weighbeam utilizing counterpoise weights, 100:1 to the load knife-edge and 1000:1 at the tip knife-edge of the weighbeam.

(b) When equipped with a full-capacity weighbeam, 200:1 to the load knife-edge and 3500:1 at the tip knife-edge of the weighbeam.

1005. Graduations

(a) Readability.—A weighbeam shall be so marked and graduated, and the poise shall be so constructed, that the weight corresponding to any poise position can be easily and correctly read without moving the poise; this requirement shall be met regardless of whether the weighbeam is or is not a registering weighbeam.

(b) Value.—For a full-capacity weighbeam, the notches and graduations on the main bar shall be made at 1000-pound intervals. For weighbeams using counterpoise weights, the capacity of the weighbeam bar shall be 1,000 pounds. For either type of weighbeam, the value of the minimal graduation shall be:

Nominal capacity of scale, not over 30,000 pounds................	5 pounds
" " " " more than 30,000 pounds..............	10 "

1006. Poise Stops

Each weighbeam shall be provided with stops to prevent any poise with which it may be equipped from traveling and remaining back of the zero graduation.

1007. Notches

On all notched weighbeams, the notches shall face either horizontally or downward. Notches shall be so formed and positioned that accurate positioning of a poise will automatically result at any graduation at which the poise may be placed. Notches on the main bar of a full-capacity weighbeam shall be spaced not closer than four to the inch.

1008. Poises

(a) Readability.—See Paragraph 1005-(a) hereof.

(b) Projections and Recesses.—Poises shall be so designed and constructed as to reduce to a minimum the number and size of projections and recesses that will retain foreign material, and shall be as nearly dust-tight as practicable. On a full-capacity weighbeam, the ends of the main poise shall be completely closed.

(c) Poise Bearings.—Each poise shall be constructed to move along its bar without side play. On a full-capacity weighbeam, the main poise shall be equipped with dust-tight ball bearings.

(d) Material.—The exterior shell of a poise shall be made of a corrosion-resistant alloy, steel, iron, brass, or any other metal or alloy of metals not softer than brass. Poises shall have no metal softer than brass making contact with the weighbeam.

(e) Movable Parts.—All movable elements forming parts of a poise shall be so constructed as not to be detachable without manifest mutilation of the poise. Set screws, if designed to secure a poise at any point on a weighbeam, shall not be readily removable.

(f) Adjusting Material.—Any material inserted in a poise for adjusting its mass shall be securely fixed in position and shall not be accessible without at least partial disassembly of the poise.

(g) Pawl or Latch.—For a poise on a notched weighbeam, the design and construction of the pawl or latch and its appurtenances shall be such that accurate positioning of the poise will automatically result at any graduation at which the poise may be placed.

(h) Poises on Type-Registering Weighbeam.—The poise or poises on a type-registering weighbeam shall be constructed to stop positively at each graduation, and to prevent movement beyond the last graduation. A substantial type of hand grip shall be provided to facilitate the registration of the weight. The natural operation of the registering mechanism shall not cause lateral displacement of the weighbeam.

1009. Registering Weighbeam

When a registering weighbeam is furnished, the receptacle or receptacles for the weight ticket shall be so positioned and formed that accurate registration of the indicated weight will result when an appropriate ticket is used.

Type figures, if used, shall be of a material sufficiently hard that, under the designed conditions of use, the figures will not become battered or defaced. The figures shall be plain and of such design as to insure clear impressions, and shall be so attached that they cannot become loosened or detached without a positive indication that the weighbeam is out of order.

If pin registration is to be used, the dimensions and disposition of the printing on the ticket for which the device is designed shall be definitely specified by the manufacturer, and the pins shall be accurately located to result in correct registration when such ticket is used.

1010. Balance Ball

A balance ball shall be provided, and its movement shall be controlled by means of a hand-operated screw or other device which will not require that the ball be rotated in making any adjustments. The balance ball shall be provided with means for vertical adjustment.

1011. Weighbeam Fulcrum Stand

(a) Design.—The weighbeam shall be supported on a stand fitted with self-alining bearings. Weighbeam fulcrum stands shall be so designed, constructed and installed that the resultant force through the bearing will fall within the middle third of the length and width of the base.

(b) Height.—The height of the stand, measured from the bottom surface of the base to the knife-edge line, shall not exceed 20 inches.

(c) Finish.—The bearing surface of the base of the stand shall be finished to a plane perpendicular to the axis of the upright portion of the stand, and the knife-edge line of the bearing shall be parallel to the base.

1012. Trig Loop

(a) Weighbeam Travel.—The permissible travel of the weighbeam in the trig loop shall be not less than:

Length of Weighbeam—Fulcrum Knife-Edge to Trig Loop	*Minimal Travel*
Under 12 inches	0.4 inch
Over 12 inches, including 20 inches	0.5 inch
Over 20 inches, including 40 inches	0.7 inch
Over 40 inches	0.9 inch

(b) Indicator.—The weighbeam shall be fitted with an indicator to cooperate with a graduated target or other device on the trig loop, or vice versa, to indicate a central position in the trig loop when the weighbeam is horizontal.

(c) Material.—The contact parts of the trig loop shall be made of a non-magnetic material.

1013. Support for Weighbeam Outfit

The weighbeam fulcrum stand and trig loop stand shall be supported on a metal shelf mounted on metal pillars, or equivalent in strength and durability. The shelf shall be sufficiently rigid that, within the capacity of the scale, deflection can not occur to such an extent as will affect the weighing performance. The height of the shelf shall be such, in conjunction with the height of the weighbeam fulcrum stand, that the knife-edge line of the weighbeam will be not more than 5 feet, 6 inches above the floor surface at the weigher's normal position. The shelf pillars shall be supported by the structure which supports the scale.

1014. Counterpoise Weights

(a) Design and Material.—Counterpoise weights shall be made of corrosion-resistant alloys, steel, iron, brass, or any other metal or alloy of metals not softer than brass. They shall be smooth, without sharp edges or corners, and of such form that the minimum of surface consistent with convenience of use will be exposed to wear and corrosion. When counterpoise weights are to be used with a registering device, the effective thickness of each weight shall conform to the designed thickness within such limits that, at no point within the range of the registering device, will any measurable error in registration be caused by variation in weight thickness.

(b) Corrosion Protection.—Counterpoise weights made of corrodible material, such as cast iron or steel, shall be protected from corrosion by the application of a durable chemical coating.

(c) Marking.—Each counterpoise weight shall be clearly marked with its nominal value, i.e., 1 pound, 2 pounds, etc., and also with the value of the load which it is intended to counterpoise, i.e., 1,000 pounds, 2,000 pounds, etc.

(d) Adjustment Cavity.—Each counterpoise weight shall be provided exclusively in its side with one or more adjustment cavities of adequate size to receive sufficient adjusting material to compensate for normal wear of the weight's surface. Each such cavity shall be securely closed by a screw plug of brass or similar material, covered by a soft cap. No part of any such plug or cap shall project above the surface of the weight.

(e) Sealing.—After each counterpoise weight is adjusted to its proper value, all plugs or caps closing adjustment cavities shall receive the impression of a seal or stamp, appropriate in character and design to attest the authenticity of the sealing.

1015. Weight Lifting Device

For scales of more than 30,000 pounds capacity, designed for the use of counterpoise weights, there shall be provided a device, designed and constructed for manual operation, which may be used to elevate and hold clear of the weighbeam and the counterpoise hanger the entire applied counterpoise-weight load. The construction and operation of the device shall permit normal oscillation of the weighbeam, both under zero-load balance and under any condition of loading in which a load in the hopper is counterpoised by one or more counterpoise weights applied on their hanger. The cup or holder at the bottom of the counterpoise hanger shall be securely attached to the stem, and any balancing material contained in such cup or holder shall be fixed in position.

1016. Weight Racks

For each weighbeam equipped with counterpoise weights, a weight rack shall be provided. The surfaces of any weight rack which contact or support the counterpoise weights shall be formed of a relatively soft material, such as rawhide, fiber, etc.

1017. Counterbalance Weights

The design and construction of the weighbeam shall, insofar as practicable, be such as not to necessitate the use of counterbalance weights. When counterbalance weights are to be used, the lower end of the counterbalance hanger stem shall be threaded, a cup for the loose balancing material shall be screwed to the lower end of the stem, and each additional weight shall be provided with an elongated hole in the center, through which the hanger stem may pass. No slotted counterbalance weights are to be used. When no counterbalance weights are necessary on top of the counterbalance cup, the cavity shall be closed by a cover secured in a positive manner. No counterbalance weights shall be used in any place in the scale except at the weighbeam.

56—XI ANTI-FRICTION POINTS AND PLATES

1101. Material and Design

Hardened steel anti-friction contacts shall be used to limit longitudinal displacement between knife-edges and bearings. They shall be smooth and so designed and applied as to provide contacts on the knife-edge line.

1102. Clearances

The total clearance between anti-friction plates and points shall not exceed $\frac{1}{16}$ inch on the weighbeam, $\frac{1}{8}$ inch on the shelf lever, and $\frac{1}{4}$ inch on all other levers. The minimal clearances shall be not less than one-half these respective amounts.

56—XII CLEARANCES

1201. General

The clearance around and between the live parts of the lever system shall be at least $\frac{1}{2}$ inch except at points where other clearances are specified. (See also Paragraphs 1102, 1503 and 1605 hereof.)

56—XIII INTERCHANGEABILITY

1301. Identification Required

Units or parts of units intended to be interchangeable with like units or parts of the same design or manufacture, shall be identified on the scale plans or in the subject matter of the proposal in such a manner as will clearly indicate the interchangeable parts, the manner of replacement, and the adjustments required, if any, after replacement.

56—XIV HOPPER AND GARNER

1401. General

The hopper and garner shall be of substantial construction, preferably of steel, and shall be braced as necessary to prevent distortion under load. They shall be grain-tight and self-clearing of any kind of grain that it is expected will be handled through them.

1402. Capacity

The net capacity of the hopper shall be at least 23.05 cubic feet per thousand pounds of nominal capacity of the scale.

The capacity of the garner shall be as large as practicable, and preferably shall exceed the volume of the largest carload of grain which it is expected will be handled.

1403. Valleys

The bottoms of hoppers and garners shall be so formed, or the valleys so filled that sharp V-valleys will be avoided. Valleys of wooden hoppers and garners shall be metal-sheathed. The pitch of valleys shall be not less than 36 degrees in the hopper and 40 degrees in the garner.

1404. Gates

Hopper and garner gates shall be grain-tight and shall operate freely. Devices for operating the gates shall be located on the weighbeam side of the hopper, within convenient reach of the weigher, and shall be provided with means to indicate the closed position of the gates and to prevent accidental opening of them. All gate levers shall be moved in the same direction to perform similar functions. No operating device shall impose any lateral or vertical restraint on a hopper except at the time of operation. The garner gate shall be so located as to discharge grain centrally into the hopper.

1405. Canvas Dust Guards

When canvas or similar material is used to enclose the opening between the garner and the hopper, it shall be attached only to the garner, and provision shall be made for the free escape of air.

56—XV FOUNDATION

1501. General

The supporting structure for a hopper scale shall extend up from the main foundation of the elevator and shall, insofar as practicable, be rigid, integral, and free from all secondary vibration under normal conditions of elevator operation. The immediate support for the scale shall be the scale floor, which shall preferably be of reinforced concrete and shall be constructed with a minimum of openings through which air currents may flow to disturb the balance condition of the scale. A hopper scale shall not be installed in a bin, over an open bin or open pit, or on bin cribbing. Suitable provision for anchoring the lever fulcrum stands and shelf pillars shall be provided. The design shall permit reasonably convenient removal of the scale parts for reconditioning.

1502. Weighbeam Location

Unless impracticable, the weighbeam shall be so located that it will be "right-handed", and that no levers other than the shelf lever are necessary between it and the main levers.

1503. Hopper Clearances

The design and construction of the building shall provide a clearance of not less than 6 inches around each hopper.

56—XVI INSTALLATION

1601. Stands

The lever fulcrum stands shall be set level and plumb, without shims or grouting, and securely anchored in proper alinement and position.

1602. Alinement

All levers shall be level and connections plumb.

1603. Weighbridge and Hopper Supports

The weighbridge shall be constructed of steel, and shall be so designed and constructed that the tops of the main load bearing assemblies may be bolted to it in proper alinement. Insofar as practicable, the hopper supports shall transmit the load to the weighbridge vertically over the main load knife-edges of the scale. The design and assembly of the hopper and weighbridge on the lever system shall produce, as nearly as may be, equal distribution of load to the main bearings of the scale, without measurable tendency to alter the horizontal alinement as a result of normal filling or emptying of the hopper or application or removal of test weights.

1604. Test Weight Hangers

Means shall be provided for applying test load. The arrangement shall permit test-load application substantially at the vertical center lines through the main load bearings. Detachable rods are recommended, and the arrangement should permit movement to proper position of wheeled cradles carrying test weights, and their ready hooking to and unhooking from the lower ends of the hanger rods.

1605. Safety Piers or Hangers

Suitable piers, posts or hangers shall be provided to prevent excessive drop of the hopper or scale levers should failure of the scale parts occur. A clearance of not to exceed one inch shall be provided between the pier, post or hanger and the part which it is intended to protect.

1606. Vents and Signal Lines

Vent or other pipes connected to any fixed part of the elevator shall not be attached to scale hoppers. No signal wires or cords or other similarly objectionable devices shall pass through a scale hopper or be attached to it or to the scale parts.

1607. Accessibility

The scale parts shall be reasonably accessible, under normal elevator operating conditions, for cleaning, painting, adjustment, etc.

1608. Protection from Corrosion

The finish and treatment of all surfaces shall be such as to insure good appearance and satisfactory resistance to corrosion. The surface treatment shall be durable and appropriate to the intended uses.

56—XVII PERFORMANCE REQUIREMENTS

1701. Scale Tolerances

The tolerance on ratio, in excess or deficiency, for a new hand-operated grain-hopper scale, after installation corrections, shall be 0.05 percent of the test-weight load symmetrically applied to the main load bearings.

(Tolerances on scales equipped with full-capacity weighbeams are under consideration.)

1702. Testing Equipment

The equipment used to test a hand-operated grain-hopper scale shall comprise:

(a) A complement of test weights adjusted to National Bureau of Standards tolerances for class C weights, and

(b) A complement of slotted counterpoise weights, adjusted to National Bureau of Standards tolerances for class B weights.

1703. Method of Test

The tolerance stated in Paragraph 1701 hereof comprehends that the scale is tested to its capacity by applying test weights exclusively. When circumstances do not permit this, the minimal test-weight load to be used shall be 8 percent of the nominal capacity of the scale, increased as necessary to equal a simple multiple of 1,000 pounds. The cradles referred to in Paragraph 1604 hereof shall be considered a part of the test-weight load if their masses are individually known to be adjusted to within class C tolerances.

The test-weight hangers shall be applied to the weighbridge or to the bearing assemblies, and a complement of "error weights" shall be placed on some convenient shelf or other surface of the hopper or weighbridge. With the hopper empty, the scale shall then be brought to accurate zero-load balance. The available test-weight load shall be applied, distributed equally among the four corners of the scale, and a corresponding amount of standard counterpoise weights shall be placed on the counterpoise hanger. The weighbeam shall then be brought to an accurate balance condition by adding or removing "error weights", and the indicated error shall be taken as the value of the "error weights" so added or removed.

This procedure shall be followed, in addition to the foregoing, with the hopper approximately one-half full, and again with the hopper loaded to the scale capacity less at least the value of the test load being used. In the case of all observations made with grain in the hopper, sufficient time shall elapse before the test-weight load is added or removed, as the case may be, to establish that there is no leakage of grain through the hopper or garner gates.

1704. Counterpoise-Weight Tolerances

Counterpoise weights furnished with or belonging to a grain-hopper scale shall be separately tested by comparing them on a sensitive, equal-arm balance with the standard counterpoise weights required by Paragraph 1702 hereof. The tolerances to be allowed in excess or deficiency on new counterpoise weights for a grain-hopper scale shall be:

Nominal Value of Weight (pounds)	*Tolerance (grains)*
10	10
8	9
5	6.5
4	6
3	5
2	4
1	2.5

1705. Sensibility Reciprocal

The sensibility reciprocal (SR) is the change in load required to turn the weighbeam from a position of equilibrium in the center of the trig loop to a position of equilibrium at either limit of its travel. The value of the SR shall preferably be determined by adding or removing "error weights".

At any load within its capacity, the weighbeam of a new hand-operated grain-hopper scale shall be in stable equilibrium, and the SR shall not exceed:

Nominal Capacity of Scale (pounds)	*Permissible SR (pounds)*
18,000	5
30,000	5
48,000	10
72,000	10
120,000	10
150,000	10

Report on Assignment 5

Terminal Facilities Required for the Care of Diesel Locomotive Equipment

H. C. Lorenz (chairman, subcommittee), C. J. Astrue, A. L. Becker, V. J. Bedell, W. O. Boessneck, H. G. Dalton, F. T. Darrow, W. H. Giles, W. J. Hedley, W. H. Hobbs, L. L. Lyford, C. H. Mottier, J. M. Metcalf, J. N. Todd.

General

Many Class I railroads employ some Diesel-electric switchers and contemplate extending their use, and at least 17 railroads are using Diesel-powered trains for passenger service. The use of Diesel-electric locomotives is becoming so general that it is desirable to assemble information regarding the facilities that have been provided by the railroads for their proper care and maintenance. Insofar as possible they are using existing facilities but as these are not always adequate or suitable, it is necessary in many cases to construct new facilities to take care of the immediate requirements.

General Requirements

For the ordinary servicing of a Diesel-electric locomotive, fuel, sand, radiator water and crank-case oil must be replenished from time to time and the locomotive thoroughly inspected. The ideal situation would be to locate fuel tanks or the fuel supply lines, inspection pit and sand houses so that all of this work could be done with one spotting of the locomotive. The inspection pit should be in such a location that the motors, journals, etc., can be inspected while the locomotive is being serviced.

Dependent upon local restrictions, the fuel tanks may be either above ground or underground. With a tank set above ground so that its bottom is about eight feet above top of rail, gravity fueling is possible. In that case, however, fuel will have to be pumped from the tank car to the storage tank. For this purpose an electric pump with a capacity for handling at least 100 gal. per min. should be provided, and so arranged that in case of emergency the fuel can be pumped directly from tank car to locomotive. In some instances fueling must be done by a pressure system, as gravity fueling is too slow. Both the pump and the track should be thoroughly insulated to prevent any sparking. Strainers should be provided for both the inlet and outlet lines and should be so installed that they may be readily removed for cleaning, as it is essential that fuel be entirely free from foreign matter. A meter should be placed on the supply line for the determination of fuel consumed per unit of work performed, and to measure the quantity of fuel received.

At points where fuel oil is readily available, a tank with a capacity of from 15,000 to 20,000 gal. will generally be sufficient. If it is advisable to purchase oil in more than single carload lots, the storage capacity must be increased accordingly.

A sand house should be provided with at least two flexible pipes of sufficient length so that when the locomotive is properly spotted they will reach all of its sand boxes.

The most common repairs necessary to a Diesel locomotive, in addition to those which can be made at the inspection pit, are the replacement of rings and cylinder liners, adjustment of bearings, and turning of wheels. Shop equipment must be provided to the end that all of these repairs can be made quickly and easily.

Experience with the care of these locomotives indicates that for economic maintenance operations, facilities somewhat different from those for steam locomotives are required. Operations should be separated. Facilities are required, first, for running repairs at outlying points and at major terminals, to avoid interference with regular shop routine; and, second, for repair shops where heavy or classified repairs are handled. It seems desirable that facilities for servicing Diesel-electric power units should be kept apart from the coach yard facilities and be properly housed. As to track layout, turntable, etc., the normal equipment used in the steam locomotive terminal will also serve the Diesel locomotives.

Facilities for Running Repairs

Truck removal is occasionally required, but there is frequent need for the removal of wheels, as wheel and journal troubles develop. The motors also must be removed occasionally. It seems, therefore, that the minimum requirement is for a two-screw drop-pit table, equipped with a drop-pit machine of sufficient capacity for the power handled, using detachable table tops, 6 ft. 6 in. across the pit and 9 ft. 6 in. parallel with the pit, having a drop of 4 ft., with a floored depression of at least 12 in. between the rails of the table top. The adjacent floor should be level with the base of rail to obtain all working space possible. A checkered plate floor is desirable. The pit should be so located that any wheel of the Diesel locomotive may be removed without moving the locomotive beyond the doors or without fouling adjacent tracks.

Service tracks should have inspection pits, and some roads recommend a small pit in the release track large enough to accommodate workmen when removing such parts as motors, gears, etc. The inspection and drop pits should be adequately lighted and the drop pits should be equipped with steps and effectively drained.

As parts being handled have considerable weight, it is recommended that a light traveling crane be provided. It should be of the one, two or three-motor type, afford an adequate lift, and be operated from the floor if it is to serve only the release track If made to serve two or more tracks, it should clear the tops of the locomotives, so that it can handle the interior parts. The crane bridge should be parallel with the length of the drop pit, and should pass over the drop pit and its release track.

A western railroad has installed a two-screw drop-pit table with a detachable top. 6 ft. 6 in. across the pit by 9 ft. 6 in. parallel with the pit, of 35-ton capacity, 4-ft. drop and a speed of 3 ft. per min. A 10-ton overhead traveling crane serves the release track only, to handle parts removed.

Diesel-Electric Shops for Heavy Repairs

The width of the building will be determined by the number of tracks, usually two or three at 24-ft. centers, with ample space each side. The length will depend upon the number of locomotives being handled, with an adequate space between and at the ends of locomotives. Approximately opposite the center of the building a machine shop bay should be provided, including space for an electric shop, air brake room, tool room, paint shop, wash room, toilets, offices, etc., with a broad walkway extending transversely across the main building and the tracks, for convenient access to the machine shop bay. There should be an overhead traveling crane of ample capacity, cab operated, with a runway the full length of the building at a sufficient height to handle parts from within the locomotive as well as locomotive trucks, etc.

Inspection pits should be of sufficient depth, with steps at each end, and adequately lighted and drained. The floor may be level with the top of rail. Some railroads prefer to have the top of rail about one foot above the floor to facilitate truck repairs, in which case the cross walk should be level with top of rail, with ramps to the lower level on each side. Provision should be made for jacking at any point on both sides of the tracks.

Truck and Wheel Removing Equipment

Various types of equipment are now being used to remove trucks and wheels. The four principal types are enumerated below, together with a few examples indicating variations and combinations of the several types.

1. Electric high-lift portable jacks for the removal of trucks seem to be preferred at this time, as a pit is not required and it is not necessary to spot the locomotive accurately. However, head room should be considered and the necessity for disengaging connections for both trucks where only one is to be removed. Jacks of 25-ton capacity are obtainable for switchers, and of 35-ton capacity for passenger units, with 4-ft. lift, but higher lift may be obtained if necessary. When raising the locomotive body, the load is carried on a base casting instead of the wheels of the jack. The column with side lifting bracket and large base gives greater stability and safety than the conventional pedestal jack. Each jack is equipped with a motor, and push-button control. Through proper plug-ins of the control cable, each jack can be operated from its own push-button station or one pair or two pairs can be operated simultaneously from a single push-button station.

An eastern railroad handles its locomotives at Cleveland with four of these jacks. A steel corporation at Cleveland uses four of the 25-ton jacks for handling its switchers, and a southwestern railroad uses four 35-ton jacks for its streamlined passenger units.

2. Two traveling cranes of ample capacity may be used, one at each end of the locomotive, for raising the locomotive body for truck release. For large scale operations, where numerous units are handled, the idea is not objectionable; however, for most shops it is generally believed that the cost would be too high.

3. A drop-pit table of 100-ton capacity with detachable table tops, 22 ft. long across the pit, by 12 ft. wide parallel with the pit, provides an economical arrangement. The tops should be of the plain type, with a depression of approximately two feet between the rails of the top, and checkered plate flooring outside the rails, either at the level of the base or top of the rail as required. Such a machine should have a hoisting speed of two feet per minute, should be motor racked with a speed of 25 ft. per min., and should be equipped with a spring-operated cable take-up reel. The truck drop should be not less than four feet.

Two of these machines are in service on a western railroad, one at Denver and the other at Los Angeles. Still another is in service on an eastern railroad at Boston, for handling trucks of a streamlined passenger train. This type of machine is a satisfactory facility for railroads with a limited number of locomotives, and experience has demonstrated that it can serve three service tracks economically.

In 1934, a western railroad installed a drop pit and table and a crane for handling trucks from power units, coaches and sleepers, adjacent to its passenger yard at Chicago. For inspection under the cars, a short inspection pit was installed, together with fuel oil facilities, condensate lines for furnishing water to heating system boilers, airconditioning outlets, etc., and special connections for water, steam and air. Since that time the railroad has installed longer inspection pits, larger capacity drop tables, car pullers, etc., and has provided similar facilities at Minneapolis, St. Louis, Denver and Lincoln, Nebr.

4. A southwestern railroad employs a transfer table for the handling of Diesel locomotive trucks at its engine terminal in Chicago, where an entire section is used for locomotive repairs. The procedure is to run the power truck on the transfer table, and jack up one end of the locomotive about eight inches by means of power-operated jacks. The transfer table is then racked sidewise to a releasing track where the removed power truck is rolled off to an overhead 10-ton crane for dismantling.

The objection to this low cost installation is that there is a tendency to center plate clamping action on short wheel base switchers, when only one end of the locomotive is raised eight inches (or higher on some locomotives because of skirting). The open pit is also objectionable.

A belt railroad, operating in a large Gulf city, has adapted its steam locomotive terminal shop for the servicing and repair of Diesel-electric switching locomotives.

For turnaround points where heavy repairs are not made, some railway officers recommend the two-screw drop table, previously described. This machine would be accessible for quick work on running repairs without interfering with regular shop equipment. It seems to be the ideal equipment for removing single pairs of wheels with or without motors.

Horse-Shoe or Sectional Drop Table for Shops

Some roads prefer a drop table of approximately 100-ton capacity, serving two service tracks, because it requires less head room and less power and is faster in operation than jacks. Each track is equipped with a main top, having within the top either one or two auxiliary tops, and a release track is provided between the two service tracks. With this arrangement, four and six-wheel trucks can be dropped on the main and auxiliary tops, and individual pairs of wheels on one of the auxiliary tops. The length of the main top is 22 ft. across the pit, while the length of the auxiliary top is 6 ft. 6 in. to 7 ft. 6 in.

A northwestern railroad has a table of this type at its Chicago shops; another railroad has one in Minneapolis, both being used to handle streamline Diesel locomotives. An eastern railroad also uses a table of this type.

Other Equipment Necessary

Equipment usually required by the mechanical department and which should be considered in connection with the design of facilities, includes the following:

An hydraulic press of sufficient capacity (approximately 300 tons) to remove and apply rolled steel wheels on axles equipped with gears.

A wheel lathe of a size sufficient to turn locomotive wheels.

Portable grinding machines to be used in conjunction with lathes; a boring mill and a planer for grinding valves, valve seats, rollers, and for miscellaneous operations requiring extremely accurate reconditioning.

Engine lathes which may be used for turning commutators and contact segments on reversers, boring mills, planers and shapers similar to those now used in the maintenance of steam locomotives.

Most repair parts when purchased are finished by the manufacturers, and the greater part of repair work consists in assembling and accurate adjustment of such parts.

Platforms for Working at Locomotive Deck Level

The Diesel-electric locomotive is different from the steam locomotive in that it has most of its mechanism above the deck, and there is a considerable loss of time if the workers must frequently move to the floor and return. For this reason, fixed or movable platforms as high as the locomotive deck, and with steps or risers, should be provided. The platforms should contain lockers, benches, bench tools and small repair parts.

Requirements Desirable in Diesel-Electric Locomotive Details to Facilitate Repairs

To facilitate making repairs on Diesel-electric locomotives conventional jacking pads should be located at the ends of the body bolsters at the middle of the truck. Many roads lack crane facilities and must depend on electric high-lift jacks or drop tables for removing wheels and trucks. For electric high-lift jacks, the jacking pads at the ends of the body bolsters may be used. Unfortunately, some manufacturers of Diesel-electric locomotives have placed cab ladders at this point with the result that they must be removed before the jacks can be placed in position. Furthermore, these ladders foul the locomotive truck if the truck transfer table is used, and they must be removed before the trucks can be moved sidewise. Ladders should be located on the side sills beyond the ends of the trucks. If jacks are to be used in the removal of trucks, the bodies of Diesel-electric locomotives should have a width of at least one foot in excess of the widest part of the truck so as to provide necessary clearance between the jacks to permit the rolling of the trucks from beneath the locomotive.

When drop-pit tables are used, it is highly important to place additional jacking pads on the side sills immediately behind the trucks, thus making it possible to support the locomotive body at the side walls of the pit while the truck is being lowered. In doing work of this kind on a drop-pit table, the jacking pads at the bolsters are over the pit and are therefore of no value.

Where possible, Diesel-electric switchers should have a set of jacking pads at the extreme end of the locomotive near or at the end sill. All types of Diesel-electric locomotives should be designed so that the ends may rest on shop trucks for movement to a new location after the regular trucks have been removed.

It is recommended that the pedestals on the trucks of switch engines be so placed that a thick shoe can be inserted, making it possible after this shoe is removed to advance a pair of wheels, either with or without the motor, far enough for easy removal.

This report is offered as information.

Report on Assignment 6

Classification Yards, Collaborating with Committee 16—Economics of Railway Location and Operation

G. F. Hand (chairman, subcommittee), C. E. Armstrong, J. E. Armstrong, C. J. Astrue, Hadley Baldwin, W. O. Boessneck, N. C. L. Brown, H. F. Burch, W. F. Cummings, R. B. Elsworth, W. H. Giles, R. J. Hammond, M. J. J. Harrison, E. M. Hastings, W. H. Hobbs, E. T. Johnston, E. K. Lawrence, L. L. Lyford, C. A. Mitchell, C. H. Mottier, H. C. Propst, W. B. Rudd, W. C. Sadler, C. U. Smith, J. N. Todd, R. W. Willis.

This year the subcommittee has selected, under its general assignment, the "Study of the Departure End of the Classification Yard", for the purpose of discussing and setting down certain factors of design bearing on the track arrangement and operation of this portion of hump classification yards that should receive careful consideration so as to permit prompt and economical handling of cars.

During the last ten years there have been radical changes in the method of operation of the railroads as a whole, which have materially affected the makeup of trains and, hence, the method of handling cars in yards. The decrease in total time for freight from consignor to consignee occasions not only higher road speeds and more expeditious handling through yards, but also the almost universal makeup of trains of more than one classification or commodity. Whereas formerly it was often the practice to hold cars of a particular classification until a trainload of that classification was available, this is not now the practice except with a very few commodities. This factor materially alters the operation of building up trains for dispatching from a hump classification yard as compared with the method that was probably in effect when the yard was built.

Proper coordination of the layout of a particular yard and the method of making up and dispatching trains from the departure end of the yard, requires investigation of the following possibilities:

1. A sufficient number of the classification tracks each long enough to hold a full length outgoing train, so that trains can be dispatched direct from these long classification tracks.
2. Classification tracks with lead tracks, such that the combined length of a longer classification track and a lead track will be sufficient for a full length outgoing train and permit dispatching therefrom without interfering with other yard operations.
3. Comparatively short classification tracks and separate departure tracks, the trains to be made up in and dispatched from the departure tracks.

By means of a questionnaire and discussions with operating men, information was obtained regarding the design and operation of representative hump classification yards, particularly as to whether trains are made up in and dispatched from the classification tracks or whether separate departure tracks are used for making up and dispatching trains, and the advantages and disadvantages of both methods in relation to the effect on economical handling and prompt dispatch of trains.

The following information in respect to existing hump classification yards was developed:

1. Quick handling in the classification yard and quick dispatch of outgoing trains are of prime importance.

2. The factors which govern the necessity for departure tracks in addition to the classification tracks, are the number of cars to be handled in given periods of time, the number of classifications to be made, and the length of the classification tracks.

3. It is economical in time and cost to make up and dispatch trains from the classification tracks where there are a sufficient number of such tracks each long enough for a full length outgoing train, or where there are lead tracks at the outgoing end, so that a train can be made up on a classification track and a lead track without interfering with other yard operations.

4. With the combination of short classification tracks and a large number of cars to be handled in a given period of time, it becomes desirable to make up trains on separate departure tracks.

5. The desirability of separate departure tracks becomes more pronounced as the number of classifications exceeds the number of classification tracks.

6. Making up trains for divergent routes may make separate departure tracks necessary, even though some trains are made up and dispatched directly from classification tracks.

7. In some cases departure tracks have been discontinued because they are no longer needed, due to a reduction in the number of cars passing through the yard and changes in the methods of operation. The operation of so-called "mainliners" has, in itself, reduced the number of cars passing through certain yards.

In considering the information obtained from this study, as presented above, it should be kept in mind that numerous existing hump classification yards have been designed and built for a considerably larger volume of traffic than is now being handled through them, and which are generally being used as built to avoid the expenditure which might be necessary to permit changes in the method of operation.

Conclusions

Proper design and operation in respect to the making up and dispatching of outgoing trains from a hump classification yard demand a study of all the factors involved in the above seven points, which, under existing conditions, represent good practice.

This report is presented as information, with the recommendation that the general subject of classification yards be continued.

Report on Assignment 7

Terminal Facilities Required for the Washing of Passenger Cars Mechanically

J. M. Metcalf (chairman, subcommittee), C. E. Armstrong, A. L. Becker, W. O. Boessneck, H. F. Burch, W. H. Giles, W. J. Hedley, H. C. Lorenz, C. H. Mottier, E. E. R. Tratman.

Mechanical washing of passenger equipment is quite extensively practised on buses and trolley cars by urban and interurban transportation companies. Comparatively few steam railroads have installed machines for that purpose. Two which have done so report a substantial saving in cost compared with hand washing where there is a sufficient number of cars to be washed and where the layout is such as to facilitate the operation during the movement of cars between passenger station and coach yard without delay and extra switching expense. The saving in labor of the washing crew must be balanced against the switching service handling cars through the washer. With increasing labor costs, and the desirability, for advertising purposes, of keeping passenger equipment clean and attractive, it seems likely that other roads may be interested in such installations at terminals where large numbers of passenger cars are to be cleaned.

The usual installation for the mechanical washing of railroad passenger cars, as well as lighter passenger equipment, consists of cylindrical revolving brushes kept wet by sprays, each operated by an independent motor, supported in a vertical position by rigid frames on each side of the track on which the cars move for washing. Springs force the brushes against the car sides during the washing operation, and they may be so arranged as to tip, within limits, out of the vertical, so as to keep the brushes with full bearing against the sides of the car when tilted. One brush on each side usually extends the full height of the car side, and a shorter brush, usually revolving in the opposite direction, is designed for washing the windows. Additional inclined brushes may be added for washing car roofs if required. No provision is made for washing the ends of cars. This must be done by hand work as a supplemental operation. Outside mechanical washing is usually discontinued in freezing weather.

In addition to the brush sprays, at a short distance beyond the brushes, in each direction along the track, are sets of vertical pipes equipped with water sprays, one set to wet the car sides before they reach the brushes and the other to rinse them as they leave the washer. With such an arrangement cars can be washed, as they move in either direction past the washing machine, at speeds up to about one car a minute.

The installation generally includes a floor of concrete, provided with drains, to keep the water, as it drops from the car sides, from saturating the track structure. Some of the bus and street car washers are controlled automatically by an electric eye or by a low voltage rail control, but hand-operated switch control is more generally used in the steam railroad installations.

One railroad operating such a washing machine has installed, in addition, a short distance ahead of it, what is known as a "scrubbing machine", for loosening the dirt, when required, in advance of washing. This machine is equipped with horizontal brushes which move up and down the car sides in conjunction with a spray of cleaning fluid.

Among the advantages claimed for mechanical washing are the following:

1. Reduction of labor costs
2. Saving of time
3. Concentration of most of the car washing in one place, with suitable drainage, thus helping to keep the remainder of the coach yard dry and clean
4. Improved appearance and reduced deterioration of car finish, due to more efficient washing

The following are suggested as desirable features to be incorporated in installations for mechanical washing of passenger equipment:

1. Location on tangent on a track connected at both ends, so arranged as to facilitate washing of cars while moving between station and coach yard, without extra switching movement and without interfering with other yard and switching operations
2. Designed for washing with equal efficiency while cars are moving by the machine in either direction
3. Brushes on each side of track wet by sprays and arranged to maintain the required pressure against the car sides, and to accommodate probable variations in widths of cars and tilting of cars out of the vertical

4. Separate brushes for car sides and windows, arranged to reach effectively all parts to be washed
5. Water sprays in each direction along the track beyond the brushes, designed to wet the sides of cars thoroughly before and after washing
6. Concrete or other floor on the track at the washing machine, with adequate drainage facilities
7. Brushes of conventional design to facilitate ready replacement, and with only enough bristles to provide fluffiness.

This report is offered as information.

Report on Assignment 8

Terminal Facilities Required for the Handling of Highway Trucks and Trailers on and off Railroad Cars

H. L. Ripley (chairman, subcommittee), J. R. W. Ambrose, J. E. Armstrong, C. J. Astrue, A. L. Becker, H. F. Burch, W. F. Cummings, F. T. Darrow, R. B. Elsworth, R. J. Hammond, G. F. Hand, W. J. Hedley, L. L. Lyford, C. H. Mottier, H. M. Roeser, W. B. Rudd, W. C. Sadler, E. E. R. Tratman.

This is a new assignment to the Yards and Terminals committee and, relatively, is a new venture by the railroads in an endeavor to recover some of the freight transport tonnage that has been lost to the over-the-road trucks and trailers. It shows promise of success, and this report describes facilities that are in use on some of the railroads.

Accessibility and Appointments

The terminal must be conveniently located and readily accessible from the industrial centers; must be provided with proper driveways and parking space, special lighting, and with a ramp and loading platform located at the end of one or more stub-end tracks where specially equipped flat cars may be set up in tandem, all as more particularly described below.

Loading Platform and Ramp

Opinions of operating men handling the movement differ as to the best gradient for the loading ramp and best length for the level platform between the top of the ramp and the first of the flat cars set up in tandem. A western road uses 40 ft. and says that is not too much. An eastern road uses 15 ft. and the crew at one of its terminals says it is enough. However, at two other terminals the crews think that the distance is short for easy maneuvering, although the difficulty is encountered only in loading the last trailer.

Curbs or timber guides properly located are used to prevent spills and are helpful in centering the vehicles, especially the last one nearest the platform. These guide timber curbs are set along the edge of the ramp and platform and on the cars, using the regular stake pockets to hold them in place.

Ramp Gradient

The gradient recommended by a western road which is performing this kind of service in the Chicago district is the one they are accustomed to use, namely, 7.5 percent. On the other hand an eastern road, where the service has been in operation over two years, uses a 12 percent gradient successfully and without difficulty. A plan illustrating this construction and showing further data is filed with the secretary of the American Railway Engineering Association. Such a ramp and platform for a single-track set-up, built of timber, would cost from $2,000 to $3,000, depending upon location and local conditions.

Bridge Aprons

Aprons are used to bridge the gap between the platform and the first car and the gaps between the cars themselves. These aprons are hinged to one end of each car.

Handling and Loading

A truck or trailer is backed up the ramp and over the cars by and ahead of the tractor and moved to the end of the string or to the last empty space. Care must be exercised in handling the vehicles to insure that they are not "bumped", as that may cause air connections, markers, tail lights and the like to be knocked off or damaged. Sand boxes should be provided for use in case the ramp or platform becomes slippery from ice or other causes.

Blocking and Fastening

Blocks, chocks and wedges are usually provided in ample quantities. Sets of soft wood blocks about 5½ in. by 12 in. by 2 ft., hardwood blocks 2 in. by 8 in. by 17 in., hardwood wedges 4 in. by 4 in. by 17 in., some boards 1 in. by 8 in. by 17 in., and a quantity of wheel chocks of hardwood cut 8 in. by 12 in. by 17 in., shaped on a radius to fit the contour of the tires and fastened to the car floor, have proved convenient for regular and emergency service.

Two or three wooden horses three feet four inches high are usually provided to be placed under the front end of semi-trailers when the landing gear fails to work when detached from the road tractor or when the trailer becomes detached in handling and the front end drops down.

Anchor and sway chains equipped with turnbuckles (with check nuts, as provided in water ferry service) are frequently used, but are not relied upon alone to hold the unit in position, as the construction of the vehicle is too frail to take the eccentric stresses. Moreover, a flat tire enroute might loosen the chains, allow the vehicle to shift position and cant over enough to collide with fixed structures along the right-of-way, so the wheels are securely blocked and the weight supported on the jacks, horses or blocking; usually on the three jacks as described below.

The small wheels on the landing gear have, in a few instances, broken the car floor and it is desirable that a steel plate be so placed to receive them as to take the shock, spread the load and protect the floor.

On the flat car itself is placed a steel channel, bored for dowel pins at about 4-in. centers, and hardwood blocks dowelled to fit the channel borings are placed therein to take the foot of the front screw jack, faced at a slight angle towards the back of the unit; the channel assembly itself being so placed that it laps past the center of the car, forward about 18 in. and back about 8 ft.

Another similar slot plate or channel assembly about six feet long is set at the front of the flat car. These assemblies allow for spotting vehicles of differing lengths. The hook brackets attached to the frame of the vehicle itself are spotted in locations specified by the railroad, for the same reason.

At the rear of the vehicle two screw jacks are used, set against a wooden beam spanning across their tops and bearing against the underframe of the vehicle; thus forming a yoke and preventing side-sway, independent of the chains. At the front, the screw jack set against the center block bears against a plate attached to the frame of the vehicle located just behind the center pin.

In some cases close clearances may make it necessary to provide flat cars of special construction in order to permit the handling of vehicles with higher loads than could be transported on a standard flat car. Additional clearance can be gained by providing channels in the floor of the car to take the wheels of the vehicle. About six inches can be gained thereby, but the opportunity for gain is limited because of the low housings on the vehicles themselves.

A plan illustrating this construction and showing further details is filed with the secretary of the American Railway Engineering Association.

Emergency Equipment

Portable jacks are supplied to the loading crew. A convenient set used at some terminal loading points includes two 25-ton ratchet jacks, one 35-ton ratchet jack and one low journal jack.

Inspection

Each unit is inspected carefully before acceptance for loading and any defects or evidence of a damaged condition of a vehicle or its lading noted and recorded. The inspection determines whether any part of the vehicle or its load projects outside of the proper clearance limit, whether the canvas tarpaulin on open-tops is tight and securely fastened down, whether the brackets attached to the unit for hitching the hold-down chains are in good condition, and whether the anchors and sway chains themselves are also in good condition and properly fastened.

In no case should any of the lading of the trailer project onto the tailboard and all tailboards should be raised and fastened securely before loading the trailer on the flat car.

Vehicle Attachments

Thrust plates and brackets attached to the vehicle are made by, and their location specified by, the railroad; and the truck operators have them attached to the unit as directed.

Working Force

The loading and unloading of the trailers on and off the cars is usually done by a tractor operator regularly assigned to this work, either by the railroad or by the trucking contractor, as the operation of backing the trailers up the ramp and spotting them accurately on the cars is a "tricky" job and is difficult for an operator who is not experienced in such work.

Experience shows that a gang consisting of an inspector foreman in charge and three helpers will, together with the tractor operator, pick up, deliver and spot a unit, centered in position on the flat car, in about eight to fifteen minutes in good weather, as an average. The tractor is then detached, run off and is ready for the next unit to be placed, while the gang is blocking, jacking and chaining the first unit solidly in place on the flat car. This blocking, jacking and chaining takes from seven to ten minutes and the gang is then ready for the next unit.

Lighting

The lighting is highly important and should have careful attention. It has been found by experience that flood lighting is needed for general illumination and that a spot light attached to the undercarriage of the loading tractor, near the left rear wheel and pointing to the rear, is very helpful, and it is helpful also if the timber curbs on the ramp, platform and cars, be painted yellow or white, at least on the side of the driver. All members of the loading gang should be provided with carbide lanterns for night work.

Communication

Access to a telephone conveniently located is highly desirable, especially for communication with shippers and particularly in the event of late or unexpected shipments, or to advise them about faulty equipment or faulty loading and the like.

Volume Handled

The eastern road referred to above, reports 2,646 vehicles handled at two of its stations in five months (December 1939 to April 1940) or an average of 264 units per month per station, and a third station reports an average of about 11 units per day or about 300 per month. The average haul is about 200 miles on this eastern road.

Tariff Rates

Tariffs are promulgated to cover this service and are subject to approval by the ICC, as in the case of other freight service. On the eastern road indicated the present schedule is numbered ICC No. F-3631—Effective January 17, 1939.

Certain special provisions are incorporated in the schedule relating to commodities accepted or barred, perishables, over-weight, etc., and minimum charges are named, this minimum being the tariff rate for a full flat car load of loaded vehicles, or one-half the full load rate if vehicles are empty. The weight limit is set at 32,500 lb. (gross) for a single vehicle moved at the above rates, and an over-weight charge of 15 cents per cwt., for all weight above that limit, except, if two trailers are offered by the same shipper, one heavy and one light, then the over-weight charge does not apply unless the combined weights of the two units exceed 65,000 lb. (gross) when the over-weight charge is applied to the excess.

The scheme was first developed by the Chicago, North Shore & Milwaukee Railroad during or previous to 1934 and it obtained U. S. letters Patent No. 1,611,882 on this means for transporting goods, having particular reference to the railway car upon which highway trucks or trailers are loaded and carried and the means of attaching the latter to the floor of the car, also U. S. letters Patent Nos. 1,675,512; 1,990,562; 2,001,935; 2,023,971 and 2,023,972 in connection with the same form of transportation, and has leased the right to use it to various railroads.

This report is offered as information.

Report on Assignment 9

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Grain Traffic—Record on the Great Lakes for 1939—Canadian Transportation, 1940, June, p. 332.

Marine Railway—Cable-operated incline at La Guardia airport, New York—Marine Engineering, 1940, March, p. 85.

Piers—Types of pier construction—AREA, Proceedings, 1940, p. 180.

Port Terminals—New Westminster, B.C.; port activity and terminal extensions—Canadian Transportation, 1940, January, p. 45.

Port Terminals—New York; organization, belt railroad, Bayonne terminal for ship–rail transfer—Civil Engineering, 1940, March, May and July, pp. 157, 281 and 425.

Port Terminals—Terminals and export traffic—Railway Age, 1940, June 22, p. 1103.

Port Terminals—Uniform charges and operating practices needed for municipal, private and railroad docks—"Port Book", Houston (Tex.) Port Commission; 1939, November, p. 9; 1940, May, p. 9.

Steamer—Self-unloading coal steamer "Jason" for Atlantic coast service—Marine Engineering, 1940, May, p. 62.

Towboat—Oil-engine twin-screw boat "Wm. Penn" for Ohio and Mississippi River service —Marine Engineering, 1940, September, p. 68.

Wharf—Long Beach, California; concrete piles deteriorated and replaced with steel H-beam piles and steel tube piles—Engineering News–Record, 1939, December 7, p. 750.

Progress report—Submitted as information.

Report of Committee 9—Highways

J. G. Brennan, *Chairman,*
F. D. Batchellor
H. D. Blake
H. E. Brink
A. P. Button
A. R. Dewees
A. F. Dorley
G. N. Edmondson
C. F. Edwards
P. W. Elmore
H. L. Engelhardt
H. W. Fenno
P. M. Gault
A. S. Haigh
J. P. Hallihan
H. A. Hampton
W. J. Hedley
Warren Henry
C. D. Horton
Maro Johnson
R. B. Kittredge
A. E. Korsell
Fred Lavis
E. E. Mayo
G. P. Palmer
W. C. Pinschmidt
Bernard Blum, *Vice-Chairman,*
T. M. Pittman
L. J. Riegler
Frank Ringer
H. M. Shepard
C. K. Smith
W. C. Swartout
C. A. Taylor
V. R. Walling
R. E. Warden
J. L. Way
W. L. Young

Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

Progress report—submitted as information.............................. page 150

2. Design and specifications for highway crossings at grade over railway tracks, both steam and electric, collaborating with Committee 1—Roadway and Ballast, and with American Society of Municipal Engineers, and American Transit Association.

Progress report—submitted as information.............................. page 150

3. Comparative merits of various types of grade crossing protection, collaborating with Committee 10—Signals and Interlocking, Signal Section, AAR, and Highway Research Board.

Progress report—submitted as information.............................. page 151

4. Prepare drawings of typical location for grade crossing signals, for various degrees of crossing angles, collaborating with Signal Section, AAR.

Progress report—submitted as information.............................. page 152

5. Method of classifying grade crossings with respect to hazard.

No report.

6. Report requisites for flexible barrier type of grade crossing protection, collaborating with Signal Section, AAR.

No report.

7. Recommend methods of protecting highway crossings and flangeways against obstructions and damage caused by use or passage of highway work equipment.

Final report—with recommendation for inclusion in the Manual.......... page 152

The Committee on Highways,
J. G. Brennan, *Chairman.*

Bulletin 421, December, 1940.

Report on Assignment 1

Revision of Manual

P. M. Gault (chairman, subcommittee), Bernard Blum, H. E. Brink, A. P. Button, P. W. Elmore, A. S. Haigh, Maro Johnson, R. B. Kittredge, E. E. Mayo, G. P. Palmer, T. M. Pittman, Frank Ringer, H. M. Shepard, C. K. Smith, C. A. Taylor, V. R. Walling, J. L. Way, W. L. Young.

Several letters have been received by the chairman of the committee to the effect that, for daylight indication, a white background on the reflectorized cross buck sign, Fig. 903-A of the Manual (AAR Signal Section 1691A), gives a better indication than the present standard, especially where trees or other dark objects form the background. The subcommittee, collaborating with Committee VIII of the Signal Section, is making a thorough study to determine whether the present standard, which calls for white letters on a black background, should be reversed so that the letters will be black on a white background. Representatives of this committee have been designated to confer with designated representatives of Committee VIII of the Signal Section to make the study and such tests and observations as may be necessary to determine if any change in the present standard should be made.

Progress is being made with the study and it is expected that report will be made to the next annual convention.

Report on Assignment 2

Design and Specifications for Highway Crossings at Grade Over Railway Tracks, Both Steam and Electric

Collaborating with Committee 1—Roadway and Ballast, and with American Society of Municipal Engineers and American Transit Association

W. J. Hedley (chairman, subcommittee), F. D. Batchellor, H. D. Blake, A. P. Button, G. N. Edmondson, C. F. Edwards, P. W. Elmore, H. W. Fenno, J. P. Hallihan, A. E. Korsell, Fred Lavis, H. M. Shepard, C. K. Smith, R. E. Warden, J. L. Way, W. L. Young.

The subcommittee has under consideration a design and specifications for a solid plank crossing. Its investigation to date has raised a doubt as to whether there is need for a design and specification for this type of crossing. The subcommittee is to continue its study and make a thorough canvass of the situation with the view of developing a design and specification for a solid plank crossing for use where that type of crossing will prove economical.

Report on Assignment 3

Comparative Merits of Various Types of Grade Crossing Protection

Collaborating with Committee 10—Signals and Interlocking, Signal Section, AAR, and Highway Research Board

H. M. Shepard (chairman, subcommittee), F. D. Batchellor, H. D. Blake, H. E. Brink, A. R. Dewees, A. F. Dorley, C. F. Edwards, H. W. Fenno, J. P. Hallihan, H. A. Hampton, Warren Henry, R. B. Kittredge, Fred Lavis, W. C. Pinschmidt, C. K. Smith, R. E. Warden.

This subcommittee has confined its work this year largely to assembling data on various types of sheet reflectorized crossbuck signs now on the market, which have been developed for use at grade crossings. It is claimed that these signs can be manufactured in quantity lots for about one-tenth the cost of reflector button crossbuck signs. Consideration has been given to the following materials:

Mir-O-Ray.—Manufactured by Arcturus Radio Tube Company, Newark, N.J. The manufacture of this material has been temporarily suspended.

Alzak.—Manufactured by the Reflecting Metal Corporation, Chicago. These signs are made with Arbuckle reflecting metal, and it is claimed that they can be seen 750 ft. away at night and clearly read at 500 ft. Test signs are being made by the manufacturer and will be erected at a grade crossing in Chicago for test of visibility and wear.

Scotchlite Reflectors.—Manufactured by the Minnesota Mining & Manufacturing Company, St. Paul, Minn. This is a luminous material using a powdered glass for reflecting light and is said to be waterproof, with visibility to 1,000 ft. and legibility at 400 ft. The material is cemented to a wooden crossbuck sign and the letters are painted on the material. These signs can also be used on a metal base. A demonstration was made for Committee 9 at Chicago in June. Two signs have been erected at 113th street and Rockwell street in Chicago for test as to wearing qualities. These were placed in service August 21, 1940.

Permi-base.—Manufactured by the Prismo Safety Corporation, Huntingdon, Pa. This is the same material as Scotchlite, being the trade name under which it is being sold in the East.

Decalcomania Transfer Process.—Manufactured by The Cuneo Press, Chicago. This is a waterproof reflecting material on paper backing which can be applied to a wood or metal sign by simply wetting the material, removing the paper and immediately applying to the sign with a roller. The letters are printed on the material before it is applied so that no sign painting is necessary. Visibility and legibility should be the same as Scotchlite or Permi-base. One of these signs was demonstrated to Committee 9 at Chicago in June. Two of them, on masonite base, were placed in service at 105th and Rockwell streets in Chicago on August 3, 1940, for test.

The sheet reflectorizing materials herein mentioned appear to have possibilities from a railroad standpoint.

Several crossbuck signs with sheet reflecting material have been tested in Minnesota and North Dakota. One installation has been in place for more than a year. Piers in the center of streets under 16 bridges in Minneapolis have had this material applied to increase their visibility at night. The committee understands that these installations have been entirely successful to date.

Scotch Flasher.—Manufactured by The Scotch Flasher Display Company, Wichita, Kan. This is a reflector button sign operated by a dry cell battery with a shutter so as to give a flashing effect. The visibility is claimed to be 2,250 ft. A hotel demonstration was viewed by Committee 9 in Chicago in June. Some experimental installations are being made in Illinois for approach warning signs for railroad grade crossings.

The report is presented as information with the recommendation that the subject be continued.

Report on Assignment 4

Prepare Drawings of Typical Location for Grade Crossing Signals, For Various Degrees of Crossing Angles

Collaborating with Signal Section, AAR

A. P. Button (chairman, subcommittee), A. F. Dorley, H. L. Engelhardt, H. W. Fenno, P. M. Gault, A. S. Haigh, H. A. Hampton, W. J. Hedley, Warren Henry, C. D. Horton, Maro Johnson, A. E. Korsell, W. C. Pinschmidt, L. J. Riegler, C. K. Smith, W. C. Swartout, C. A. Taylor.

The subcommittee has endeavored to carry out its assignment during the year and developed drawings for the location of flashing light signals. However, it is the consensus of Committee 9 that each case must be decided on its merits, and that requisites for the location, number and arrangement of automatic signals, automatic gates and auxiliary signs for rail-highway grade crossing protection should be developed rather than drawings.

Accordingly, your committee recommends that the assignment be changed to read as follows: "Requisites for the location, number and arrangement of automatic signals, automatic gates and auxiliary signs for highway grade crossing protection."

Report on Assignment 7

Recommend Methods of Protecting Highway Crossings and Flangeways Against Obstructions and Damage Caused by Use or Passage of Highway Work Equipment

Bernard Blum (chairman, subcommittee), F. D. Batchellor, H. D. Blake, A. R. Dewees, A. F. Dorley, G. N. Edmondson, C. F. Edwards, P. W. Elmore, H. L. Engelhardt, C. D. Horton, Maro Johnson, E. E. Mayo, G. P. Palmer, T. M. Pittman, Frank Ringer, W. C. Swartout.

Your committee has carried out its assignment by preparing the following instructions to highway department employees:

PROTECTING HIGHWAY-RAILROAD GRADE CROSSINGS AND FLANGEWAYS

Recommended Instructions to Highway Department Employees for Protecting Highway-Railroad Grade Crossings and Flangeways Against Obstructions and Damage Caused by Passage of Highway Work Equipment

To Highway Department Employees:

Your attention is called to the necessity for watchfulness and care in approaching, passing over, and leaving railroad grade crossings with highway equipment, in order to avoid accidents and resultant damage to equipment, injury to persons, or derailment of trains.

The following rules shall be strictly adhered to by all employees operating highway department equipment:

1. Stop all highway road-working equipment before crossing railroad tracks.

2. Do not depend on train schedules. Trains may be expected any time in either direction on any track. Keep a sharp lookout and do not cross tracks when trains are approaching.

3. Before reaching crossing, raise the nose and blade of snow plows and graders to clear rails and planks on crossing.

4. Stop all work equipment after passing over railroad crossings. Make a careful inspection of the crossing.

5. Clean flangeways and crossing of any material that might derail a train.

6. If equipment is stalled on crossing, highway employees shall do all in their power to prevent a train from hitting it.

It is recommended that the above material be adopted and printed in the Manual and the cooperation of the Executive Committee of the American Association of State Highway Officials be enlisted with the view of making it recommended practice for state highway departments.

Report of Committee 24—Cooperative Relations With Universities

E. T. Howson, *Chairman,*	R. H. Ford	F. A. Russell
Lem Adams	P. M. Gault	W. C. Sadler
W. J. Cunningham	E. M. Hastings	F. S. Schwinn
F. T. Darrow	Clark Hungerford	Barton Wheelwright
R. E. Dougherty	R. B. Kittredge	C. C. Williams
W. D. Faucette	B. R. Kulp	*Committee*

To the American Railway Engineering Association:

Your committee submits in its initial report a statement of the scope and purpose of its work .... page 156

It also reports on the following subjects:

1. Stimulate greater cooperation between railway officials and officers of universities and colleges in preparing the best courses of instruction to meet changing railway problems.

No report.

2. Call to the attention of universities and colleges such information and conclusions developed by the Association as thought to be of special interest or value to them.

No report.

3. Develop means of bringing to the attention of railway managements the value of a technical education as a qualifying factor for young men desiring to enter railway service with a view to advancement.

Progress report—submitted as information .... page 157

4. Stimulate a greater interest in the science of transportation among university and college students, and create thereby a greater appreciation of the place of transportation in our national economic structure.

Progress report—submitted as information .... page 169

5. Develop means whereby facilities of the universities may be made more directly available for research work of the Association and the railway industry by cooperative effort between the staffs of the universities and the committees of the Association.

Progress report—submitted as information .... page 170

6. Stimulate a greater appreciation among university and college authorities of the fundamental importance of instruction in transportation and economics, and of the necessity for assigning men of adequate ability, experience and fitness for such teaching.

No report.

7. Cooperate with organizations of university and college students engaged in study or discussion of engineering or transportation matters and contribute to their activities in such manner as may be mutually arranged.

Progress report—submitted as information .... page 171

The Committee on Cooperative Relations
With Universities,
E. T. Howson, *Chairman.*

Bulletin 421, December, 1940.

Statement of Scope and Purpose

Appointed shortly before the last convention of this Association, your committee on Cooperative Relations with Universities presents its first report. Its work during the year has been largely exploratory and has consisted primarily of the formulation of measures to gather the information called for in the assignments given it. The reports that the subcommittees present are, therefore, of progress. In its first report, the committee believes it desirable also to present a brief over-all statement of the purpose and scope of its work.

In a way, the work of this committee is less direct and immediate in its objectives than that of most of the other committees of this Association. It is not dealing with materials or detailed practices of working; neither is it concerned with the immediate present. Rather, it is dealing with a problem of management, the full impact of which will not be felt for some years. Its work is, however, of fundamental importance to the permanent well being of the railway industry.

The railways comprise one of our largest industries. They constitute a vital link in the industrial life of America, for America is a land of vast distances and the railways offer the only economical means for the transportation of the raw materials and food products from the mines and the farms of the Central West and the far West to the industrial centers of the East. Furthermore, as America enters more largely into world markets, it is forced to meet the competition of other countries with their lower wage scales. This requires maximum economy in transportation. Again, the railways are now meeting increasingly acute competition from new and alert agencies of transportation, a condition which creates still further problems of another character.

All these conditions place heavy demands upon those who bear the responsibility of management in the railway industry. These demands will become heavier in the days that are ahead. Will the railways be able to meet these demands adequately with the plans now in vogue?

A far larger proportion of the more promising young men are now enjoying the privileges of a college education than in any previous generation. It is pertinent to inquire whether as many of these college-trained young men, and especially those with greater promise of executive ability, are now being attracted to railway service as a career as was true a generation or two ago? And are the colleges and universities giving these men the education and the view point that best prepare them for progress in railway service?

In the early days of railway development in this country, the railways attracted many young engineers into their construction activities; in fact, they provided the major outlet for civil engineers and the bold nature of the work challenged men of initiative and resourcefulness, not a few of whom developed into executives of note. Today, the era of construction is closed, and this avenue of initial employment no longer exists.

The effect on the colleges has been immediate. Some have abandoned their courses in railway construction and have substituted no railway transportation instruction therefor. Within recent months one of our great universities has made public announcement of the abandonment of its long-maintained department of railway transportation and the scattering among other courses of the instruction previously offered there. Many colleges are openly discouraging their graduates from entering railway service.

It is true that the railways are no longer building long extensions into new and unsettled areas. On the contrary, they are actually taking up more miles of lines today than they are building. Their principal activities in the field of construction are the rebuilding of facilities to meet new and changing conditions and the reconstruction of lines and structures to effect greater economy or efficiency in transportation. But such activities require intensive study of present and possible practices, with relation to costs. both of construction and of operation, and call for the display of analytical ability as great as or even greater than that of the pioneer engineers who located our railways over the mountains and across the plains.

But it is ability of a different character and developed through education and training of widely differing purpose. It requires a more thorough appreciation and knowledge of economics, as applied to transportation—a greater willingness to work out refinements in practice to effect economies in costs and to increase effectiveness in service. In brief, it requires a far greater degree of exactness.

To the young man of engineering education who accepts this view, we know that the railways offer real opportunity. No industry so basically important in character, no industry whose business totals $3,000,000,000 to $5,000,000,000 annually or that employs a million to a million and a half persons, can fail to provide opportunity for analytical and executive ability of high order. The railways do offer such opportunities.

It is contended by the colleges that the railways fail to meet the competition of other industries for these young men. And it must be admitted that there is much evidence to support this view. On the other hand, not a few railway officers contend that the colleges have failed to revise their courses of instruction to keep pace with the changes in railway operation and that as a result the graduates of today are not prepared either in view point or training for their needs of today. It must be admitted also that a survey of college courses of instruction will provide much in support of this position.

Your committee understands that, in re-establishing this committee, the Board of Direction of this Association had in mind the importance of (a) bringing about the education of a capable group of young men in the railway problems of today and the days that are ahead and (b) providing for these men opportunities in the various branches of railway service comparable with those presented by other industries. Through the work that has been initiated by the subcommittees, it is hoped to bring about a recognition among college and university authorities that the railway industry does offer opportunities to a limited number of properly trained young men equal to or greater than those existing elsewhere and a corresponding recognition among railway managements that it is to their interest to give the same or even greater consideration to the selection and development of their personnel that they do to their physical plant and its use.

Report on Assignment 3

Develop Means of Bringing to the Attention of Railway Managements the Value of a Technical Education

As a Qualifying Factor for Young Men Desiring to Enter Railway Service with a View to Advancement

F. S. Schwinn (chairman, subcommittee), R. E. Dougherty, R. H. Ford, R. B. Kittredge, Barton Wheelwright, C. C. Williams.

In approaching this subject, your committee has attempted first to answer the question—why should railway managements be interested in employing technically educated men? This question has naturally led to another—why should technically educated men desire railway employment? It is quite evident that there must be a sufficiently attractive incentive in order to influence a desirable class of young men, with either a technical or non-technical college education, to seek employment on a railway. If the probability of ultimate reward is definitely present, there will be no difficulty in attracting the best of these young men into the railway industry.

In order that the answers to these two questions may be fully developed, the committee has first endeavored to show what the railway managements offer the young man with a technical or other college education and to present examples of what such young men have accomplished in the past when they associated themselves with railways, with, somewhat as a summary, the views of a few railway executives on this subject. In later reports it is proposed to explore additional phases of this subject, including the investigation of means employed by other industries to evaluate and absorb such men and the present activities of those railroads which now recognize the desirability of fostering the employment of men who have received desirable preliminary educational preparation.

What Can Railway Managements Offer?

After a boy has outgrown his desire to wear a policeman's uniform, he begins to envision himself as some kind of a manager or executive. This is but the natural result of the individualistic tendencies which come from and are a part of our democracy. Usually, the young man will tentatively select his career early during his college life, and his selection will be influenced to a large extent by the probable reward, either immediate or ultimate, following careful preparation, close application and sincere effort to succeed in such a career. The most accurate indication of what the future may hold for the properly equipped man who elects railroading is evidenced by the measure of success that has been attained in the railway field by technically educated men and other college graduates in the past.

In an address delivered last year before the New York section of the American Society of Civil Engineers, C. E. Smith, vice-president of the New York, New Haven and Hartford Railroad Company, pointed out that the chief executives of 180,458 miles of railway, comprising the larger and more important systems in the United States, were divided as follows: 36 percent of the mileage was headed by civil engineers; 40 percent of the mileage was directed by college graduates in other than civil engineering; and 24 percent of the mileage was administered by graduates of the school of hard knocks. This analysis covered 31 large railways and railway systems and 23 of the 31 chief executives were college graduates, while 8 were non-college graduates. Mr. Smith also furnished data concerning the heads of departments on these same railways which indicated that college graduates (both technical and non-technical) headed the several departments, based on the percent of the total mileage, as follows: accounting, 24 percent; purchases and stores, 26 percent; operating, 28 percent; traffic, 31 percent; mechanical, 47 percent; miscellaneous departments, 47 percent; engineering and maintenance, 84 percent; and law, 100 percent. On the 84 percent of the mileage whose engineering departments were headed by college graduates, these officers were naturally all civil engineers, but in addition, civil engineers headed the operating departments on 20 percent of the mileage, and headed miscellaneous departments on 29 percent of the mileage.

In furnishing this information, Mr. Smith writes: "Of course, the situation changes from time to time, but several times, when I have made these analyses, I have found that, of the important railroads, 35 percent are headed by civil engineers, 40 percent by other college graduates and 25 percent by men who merely graduated from the school of hard knocks and did not have a college training. I use the word 'merely' because . . . college graduates who made their way to the top also had to graduate from the school of hard knocks—a post graduate course as it were". Mr. Smith makes the further comment: "The astounding and amazing feature of the showing of civil engineers in railroading is that much less than 35 percent of the personnel on the railroads are civil engineers. While I have no statistics to support an estimate, I would say that 5 percent would be a very generous estimate of the proportion of civil engineers in railroading, which indicates that their chances of getting to the top have been seven times the chances of all others".

In an address delivered before the Transportation Section of the Society for the Promotion of Engineering Education at Berkeley, Cal., on June 24, 1940, M. C. Blanchard, chief engineer of the Coast Lines of the Atchison, Topeka and Santa Fe Railway Company, took as his subject "What the railways offer the engineering graduate". After listing the strictly technical opportunities confronting the engineering graduate, Mr. Blanchard said:

> In addition to opportunities for promotion along . . . technical lines . . . the way is open, as it has never been before, to advancement in other departments of the railways, such as operating, purchasing and traffic. In years past the railways . . . were generally inclined to look upon the engineer as a technical man qualified for advancement only along the line of his training. This attitude no longer prevails, the railways having come to the realization that the man educated in the fundamentals of mathematics and science has qualifications superior to those not so equipped, and if in addition to his education he possesses those other inherent qualities essential to advancement in any line of business, the railways are quite ready to give him an opportunity . . . to step out of his engineering environment into other departments.
>
> In making the above statement, I have in mind particularly the railroad on which I am employed . . . In the last twenty years . . . numbers of men from the engineering department have been . . . selected for service in other spheres of activity . . . These men are making good, as evidenced by the fact that two of them are now general managers, one is assistant to the operating vice-president and one is general purchasing agent for the system.

Mr. Blanchard concluded with the statement that ". . . I feel that to the engineering graduate who is transportation minded; who is alert, energetic, balanced; who is endowed with some native executive ability; who is willing to shoulder responsibilities and to undergo the hard work involved in each step of advancement; who is appreciative of the fact that he will be in competition with many other capable and ambitious men . . . a contest in which his engineering education should be of advantage; (to such a man) the railways offer an opportunity better than in the past, and on a par with the outlook in any other industry".

At the same meeting (of the S.P.E.E.), J. W. Williams, chief engineer of the Western Pacific Railroad Company, speaking in a somewhat similar vein on the subject "What a railway expects in the engineering graduate", said:

> The railway expects the engineering graduate to be equipped with a sound foundation of engineering education and trained thought processes, by means of which he can acquire, through experience, the judgment to estimate correctly the problems with which he will deal and arrive at reasonably accurate solutions.
>
> The graduate entering railway service, who is qualified by character and ability and who is equipped with a suitable education, has favorable opportunity for advancement, not only in engineering positions, but also in administrative positions.

> At no previous time have the railways had more urgent need for the services of highly intelligent and thoroughly educated young engineers. The quantity demand is, perhaps, not as great as in the days of railway expansion, but the quality requirement is higher than ever before. For the outstanding graduate, the railway field offers exceptional opportunity for success.

Also at this S.P.E.E. meeting, W. H. Kirkbride, chief engineer of the Southern Pacific Company, taking for his subject "After graduation—What?" referred to the new occupations that are coming forth in an ever-expanding world and said: "What better personnel could be found for such occupations than the men with engineering education? Note, I said engineering education, not engineers, and herein lies the important point of the theme I present: engineers should be educationally equipped to assume many positions in our complicated social economy that are far from pure engineering". In closing his address, Mr. Kirkbride remarked:

> Railroads have tried various schemes of selection of personnel with particular reference to advancement to the higher positions . . . The exact method of how a graduate of a university is to obtain employment with a railroad and acquire the experience that will enable him to advance to positions of greater responsibility is to my mind a matter of secondary importance. More important is to show that the opportunity exists.
>
> In concluding, may I state that I have endeavored to show that this opportunity does exist; that the railroads are not a thing of the past and that a large field of endeavor exists for those who wish to try; but paraphrasing, in part, the recent remarks of a world statesman, let us say we can only offer you labor and sweat . . .

From the 1940 report of the Transportation Committee, E. T. Howson, chairman, to the Civil Engineering Division of the Society for the Promotion of Engineering Education, the following is quoted:

> Their (the railways') principal activities in the field of construction are the rebuilding of facilities to meet new and changing conditions and the reconstruction of lines and structures to effect greater economy or efficiency in transportation. Such activities . . . call for the display of analytical ability as great as or even greater than that of the pioneer engineers . . .
>
> But it is ability of a different character and developed through education and training of widely differing purpose . . . In brief, it requires a far greater degree of exactness.
>
> To the young man of engineering education who accepts this view, the railways offer real opportunity. No industry so basically important in character . . . can fail to provide opportunity for analytical and executive ability of high order. The railways do offer such opportunities . . .

A limited number of railways have offered engineering graduates employment as student apprentices. In a few cases, this practice has been followed for many years and has been found generally successful. Outstanding in this effort to develop and use the technically educated man are the Pennsylvania Railroad and the Southern Railway System. A future report will describe, in some detail, the policy of these and other railways and their opinions of the results attained. Your committee has here reviewed the statements of several railway officers at some length to show affirmatively that the railways do offer opportunities to college graduates and that the college-educated man has frequently earned recognition beyond that which may be expected by the average individual without such education.

The Railway Executive's View

Little would be gained in "bringing to the attention of railway managements the value of a technical education as a qualifying factor for young men desiring to enter railway service with a view to advancement" if such men were not of the type desired. To develop this angle, your committee addressed a few railway executives, all of whom are technically educated and members of your Association. In addition to requesting their general views on the subject, these executives were requested to give specific answers to five questions. Their replies go far toward developing the true answer to our first question—why should railway managements be interested in employing technically educated men.

To the first of the five questions—do you favor employing this class of men (college graduates) and are they given recognition and opportunities for advancement?—all replied in the affirmative although four replies stressed the fact that educational qualifications alone were not paramount and that opportunities were offered to all employees, while two replies made reference to the difficulty of giving adequate recognition and opportunity because of restrictions imposed by agreements with other employees.

Replies to the second question—In what manner do you recommend that such men be selected?—were nearly uniform in suggesting that selections be made through personal contacts and interviews by department heads and that natural qualifications, as well as educational background, must be considered.

The third question—Coupled with practical experience, do you believe that these men fill the requirements of advanced positions more satisfactorily than men without either technical or general college education?—again brought generally affirmative answers, qualified, however, with repeated references to the fact that the requirements of advanced positions go beyond the basic college education.

To the fourth question—Do they progress more rapidly than men without a college education?—the replies were generally affirmative, although two executives here again stressed the importance of other factors without which the college man's progress would be slower.

The last question submitted by your committee was—Do they remain with the property as well as men without such education who may rise from the ranks? The experience of only one executive prompted an affirmative answer while four replies were definitely negative and one stressed the need that management advance the men selected with sufficient frequency to hold their enthusiasm.

Because of the important bearing of the comments and opinions expressed by these executives upon both the desirability of employing college graduates and on the type of college graduate to be employed, partial quotations from their letters are included:

From L. W. Baldwin, chief executive officer of the Missouri Pacific Lines:

> In employing new men we naturally favor selecting those giving the greatest promise of useful and helpful service and those considered capable of development which will fit them for promotion. While education is important, the traits of integrity, industry, loyalty and the ability for harmonious teamwork are fully as important. Natural ability to use one's head and good common sense, coupled with a pleasing personality, will go far towards overcoming any handicap due to lack of college training.

As to your third question, (regarding requirements for advanced positions) I would say that the answer is yes in general, but there are so many exceptions as to require the further statement that a college education is far from the most important factor, and a college man lacking in the ability to secure teamwork, for example, is unsuited for an advanced position. Probably a tabulation of men holding executive positions would show a preponderance of college-trained men out of proportion to the number of college men in service and this preponderance has no doubt increased through the years.

Do college men progress more rapidly? Again there are so many exceptions and so many other considerations as to require caution in a general statement. The non-college man usually has at least four years start over the college man of the same age. He is very apt to over-estimate the handicap of not having had the opportunity for college and if he is of the right kind, will dig in all the harder to overcome his assumed disability. Many college men, on the other hand, are similarly apt to over-estimate the advantages of college and in addition to being irked by the nature of their early assignments on the railroad, are apt to hold somewhat aloof from their fellow non-college employees. But the college man who can retain the correct perspective and who always gives his best to the tasks assigned, will, at least on the average, be able to progress more rapidly.

Answer to the last question (regarding speed of progress) is probably no, for several reasons. Those who leave railroad service early usually have been attracted by other lines of work where opportunities for rapid advancement seemed better and where living conditions were more desirable than at many of the scattered points on a railroad. It must be recognized that for many years the railroad industry has not been expanding, while newer industries have been growing rapidly, and these have, therefore, provided many more opportunities for service.

As to a technically trained college man compared to a non-technically trained one, it is my opinion that there is little choice although the former will be better fitted for an early start in some departments than the latter. If the engineer can retain a proper perspective and sense of proportion, his training in exactness will be helpful. But many engineers never seem to learn that a product is no more reliable than its least reliable factor, and they develop a hair-splitting attitude which becomes a serious hindrance.

From Ralph Budd, president of the Burlington Lines:

One of the most important duties of the railroad's supervisory forces is the careful selection of new employees. In the initial selection of employees, thought should be given to how well such persons may function, not only for the immediate position for which employed, but also for promotion to more responsible duties. In all branches of our organization are young men and women who have graduated from colleges in the last few years. They were not employed solely because of their college education but because, in addition to that, they had attributes which we felt would make them desirable employees and potential candidates for advancement.

There has existed, and probably still does exist with many, some prejudice against the employment of college graduates, principally due, I think, to the fact that up to a few years ago ordinarily only those from families of substantial means went to college and upon graduation some of them declined to accept employment except in preferred occupations and with a better than average starting salary. Many of them came out of school with the thought instilled into their minds that "the world was waiting for them with open arms" and that they should be given preference over those less fortunate who did not have the opportunity to acquire a higher education. Much of this prejudice has been dispelled in recent years. The picture has changed; now it is not only the favored few who attend college, but a cross section from our entire population. A majority of the college graduates nowadays realize, or should realize, that when they enter the business world, ordinarily they must start at the bottom and often in employment in which they can not, at first, if at all, make full use of all phases of their education.

Your inquiry was directed not only to the question of the value of a technical education as a qualifying factor for young men desiring to enter railroad service with a view to advancement, but also regarding college men who are not technically educated but who may be fitted for positions on the railroad not definitely requiring technical preparation. It is realized that certain branches of service, such as engineering, require for some of the positions those with a technical education, but there are many places in our service where a non-technical education, if it has taught a young man to think clearly and to carry his thoughts into action, should be of great benefit insofar as concerns making progress in railroad service.

Yes, we favor employing those who have acquired more than the ordinary grade or high school education, provided they have the other attributes considered necessary. They are given such opportunities for advancement, when they have demonstrated their ability, as the requirements of the service and the labor agreements permit. We all realize the difficulty, if not the impossibility, because of the seniority rules contained in the labor agreements, of giving special consideration, insofar as promotion is concerned, to those with unusual attainments, in jobs controlled by the provisions of such agreements; however, when an opportunity arises to promote a person from the ranks into what is referred to in railroad terminology as an "excepted position" the situation is different. From there on, ability governs rather than seniority and if a careful selection has been made in the initial employment of those with a college education, they should have an advantage when it comes to promotion. We recognize, however, that there are many with native ability who, for some reason or other, have not gone to college, and we do not favor closing the door to such persons, either for initial employment or for promotion.

While we realize the effectiveness of the formal training programs carried on by many of the larger industries, which programs call for the recruiting of college men who seem to be especially qualified in particular fields and the training of them over a period of months or years in various branches of the service, for several reasons it has not seemed to us feasible to install a training program of that pattern. The seniority agreements in the railroad industry would operate against the effectiveness of such a plan and would also entail a much higher cost because of the impossibility of realizing on any productive work done by such trainees during the early period of their employment. There is one exception, that being in departments not covered by labor agreements.

Because of these circumstances, I favor a different form of recruiting. It seems to me that our problem is to locate young men of ability whose general back ground education, and views appear to make them desirable for railroad service, looking to the possibility of their promotion to supervisory positions, and then absorb them into service as vacancies occur, promoting them as fast as their ability, the financial condition of the company, and the labor agreements will permit.

To function to the highest degree in supervisory jobs, more knowledge than that ordinarily gained through grade school and high school education is required, or at least is of great help. Of course, knowledge itself is not enough. Such positions also require the ability to secure the cooperation of others and to think clearly and make accurate decisions without prolonged deliberation.

Many young people with college education who enter the service in minor positions feel that promotion and increase in salary do not come quickly enough and they are on the alert for other opportunities carrying immediate salary increases and what appears to be greater opportunity for promotion.

Without raising any bar to the employment or promotion of those who do not have a college education, we have endeavored, in our traffic and other departments, to attract young men and women with exceptional education. So far as the traffic department is concerned, there seems to be no reason for distinguishing between those with a technical education and those with a liberal arts education, but in some branches of the service, such as the engineering and operating departments, the technical education is, of course, of more benefit, and in the accounting department a business education is of considerable help.

In a study made some years ago of two groups, one consisting of those who had college education and the other of those who did not have such education, it was found that they reached their first official position at the same average age, but that the group which did not have the advantage of a college education started work several years earlier than the college group. We have made no special study of this question in recent years, but I am inclined to think that one made now, or ten years hence, would show a different picture; in that those with a college education would, on the average, progress faster and reach higher positions than those lacking such education. I believe that in the future the majority of the top positions in railroad service will be filled by those who have prepared themselves for such positions by additional years in school, particularly in technical schools.

From J. R. Downes, vice-president of the Pennsylvania Railroad Company:

For many years we have placed in our service, and trained for supervisory positions, graduates from educational institutions, the courses of study at which provide the technical training we desire. Electrical engineers and mechanical engineers are usually placed in our motive power department and civil engineers in the maintenance of way department, although the latter department also employs some electrical engineers for training in the signal department. These courses cover a period of three years' work before the young men are placed in minor supervisory positions.

After review of applications by staff officers, and selection of the young men whom it is desired to interview, appointments are only made following a personal interview with the candidates so selected by our assistant vice-president—chief of motive power, the assistant chief engineer joining in the review of graduate civil engineers applying for the course in the maintenance of way department. From these personal interviews, judgment may be formed as to the general make-up of applicants and their interest in railroad careers.

During these special apprenticeship courses, reports are made each six months as to the application and ability of the young men and their probable advancement; this with the idea that if any cadet is unsuited for railroad work, or is not considered to be "officer material," he will be released before remaining too long with the railroad in order to have early opportunity to "find himself" in another line of industry.

Naturally, one of technical training, interested in railroad work, selected on the basis of his general make-up and attainments at college or other institution of higher education, should be better equipped to come along as a supervisory employee than one without such training. Of course, we bring along from time to time others who have not had either a technical or a general college education, but who display such qualities of practicability, general leadership, and administration as to warrant their advancement.

Technically educated men who come to the railroad after selecting a railroad career for their life-work have no less interest in remaining with us than men who come up from the ranks. From time to time, some men who are not engineers but who have a general college education or its equivalent are taken into our traffic and accounting departments. In such instances, the same general observations apply as have been outlined in the foregoing with reference to men of technical education.

From C. E. Denney, president of the Northern Pacific Railway Company:

I favor employing this class of men and giving them recognition and opportunities for advancement to the extent that it can be done in fairness to other qualified employees who have not had the advantage of a technical education.

Selection should be by the head of the department in which the individual is to be employed. A college education is helpful, but not necessary in meeting the requirements of advanced positions. An individual with a college education should advance more rapidly than he would without such an education.

Many college graduates are not willing to spend the time as apprentices in the railroad or any other business, that is necessary to learn the business and prepare themselves for advancement. Few realize that they are freshmen after graduation.

The first requisite of anyone entering the railroad business is industriousness. A college education is helpful, but not controlling. The college graduate who has worked or assisted in working his way through school is, generally speaking, the most likely candidate for railroad apprenticeship.

From E. M. Durham, Jr., chief executive officer of the Chicago, Rock Island and Pacific Railway Company:

As I know you realize, it is practically impossible to give a forthright answer to some of these questions. Based on my experience, I think I would say that an intelligent educated man is generally superior to an intelligent man without higher education. On the other hand, a technical education generally falls short of accomplishing what is desired if a man does not have this quality. Briefly stated, what the railroad seeks in employing young men is intelligence or "horse-sense".

From H. M. Lull, executive vice-president of the Southern Pacific Lines:

As a general proposition a college education should equip a person entering almost any kind of railroad service to handle his job better and give him some advantage over other persons similarly employed who do not have the advantage of a college education. However, the rules, and particularly the seniority practices established in contracts with the railway employee organizations, prevent managements from selective choice in advancing employees who have superior qualifications, ability and ambition—at least until advancement by means of seniority has gained for the employee a sufficient amount of experience for the employee to qualify for a supervisory position where the organization rules and seniority practices do not apply.

Under these circumstances it is difficult for railroad management to give recognition and opportunity for advancement to those who by reason of superior educational attainments, natural ability, or outstanding work performance, are entitled to preferred consideration. I do not know of any means whereby this situation can be overcome in a way to encourage college men to take railway employment, except in the limited field of technical work where contract organization rules and seniority practices do not apply.

On our road, and I think this is probably true on most roads, there are relatively few college trained men in service, other than those doing more or less strictly technical work, such as construction and maintenance of way department engineers, architects, draftsmen, and mechanical department engineers, designers, draftsmen, metallurgists, chemists, etc.

Obviously, it is highly desirable that men employed in these classifications be qualified by having had a complete technical education in the field of their employment and as a rule new employees are selected having such qualifications.

I think it is generally true, particularly in recent years, that the proportion of men selected for advanced positions from railroad services made up largely of men with college and technical education represents relatively a much higher proportion than the selection of men for such advanced positions taken from other classifications of railway employees. If there were more college trained men in other branches of railway service, such as train service, station service, accounting and clerical service, etc., the chances are that relatively a larger proportion from these other departments would attain advanced positions.

Looking to the future, the difficulty of college trained men finding employment may and likely will result in a gradual infiltration of college trained men in employee classifications other than the technical classifications. With the situation as it now exists with respect to advancement being governed largely by seniority, their advancement opportunity will be no greater than their fellow employees not having the advantage of college education, at least during the early years of their employment. Whether college trained men are likely to be satisfied and remain in railroad work under such circumstances cannot be answered from any experience that we have had. The chances are that this will depend largely upon the employment situation generally and the opportunities that may be afforded to obtain employment in other industries offering greater opportunity for advancement in recognition of superior capacity and ambitious effort.

From H. R. Safford, senior executive assistant of the Missouri Pacific Lines:

I believe such men fill the requirements of advanced positions more satisfactorily than men without either technical or college education because such education gives the men some advantage that is beyond mere technical knowledge and gives broader opportunities for research and analysis. It is expected also that everybody who has a technical education is better than the average of those who have not had it and while there are defections and failures among such people in the application of the ground work of education, I think on the whole the answer to this is "yes".

I think it is rather hard to make a definite reply to this question (as to remaining with a railway). My opinion is, however, that they will stay longer with the property, except insofar as better opportunities may be offered in fields for which they are trained beyond the scope of railroad service.

From Robert E. Woodruff, trustee and chief executive officer of the Erie Railroad Company:

We regularly employ a few each year for our operating department; some civil engineers for the maintenance of way department; and some mechanical and electrical graduates for the mechanical department. Those in the mechanical department are given a special apprenticeship, followed by opportunities for advancement. Those in the maintenance of way department are given employment in whatever branch vacancies occur, getting some experience as trackmen, signalmen, foremen, rodmen, transitmen, etc.

One cannot generalize on this question. Half of our higher officers are college trained, and an investigation of a highly technical manufacturing concern developed that half of its higher officers were college men. To be a good manager, a man should be able to analyze and plan and also to organize and be able to get along with men. A college education, with a knowledge of mathematics and engineering, helps to train a man to analyze and plan, but does little to help him to organize or to get along with men. Some college men have this latter ability. They are, in general, the men who have taken part in college activities, been elected by the student body to elective positions, have had experience in managing clubs and organizations, and stand out definitely as managerial material. Many boys spend their four years in college doing nothing but studying and, therefore, miss a considerable part of a true college education. In other words, college trained men are not necessarily good managers or good organizers. Some men who have never been to college, but who come up through the ranks, have a better knowledge of men, of labor conditions, of how to get work done, of how to arouse enthusiasm, and accordingly are selected for managerial positions in competition with college graduates.

The college training is not the principal factor, as outlined above. A college graduate who has managerial ability and who is willing to study after leaving college should progress satisfactorily. It is up to the employing officer to be careful in hiring such men to pick only those who really want to take up railroad work as their life work, and not to hire those who just want any job at all. Then it is up to the management to see that these men who are employed receive proper training and are moved often enough to retain their enthusiasm and interest.

From F. E. Williamson, president of the New York Central System:

In approaching consideration of the advantages of a college education to men entering railroad service, it must be remembered that there are certain fundamentals that must first be considered. These fundamentals primarily relate to the fact that there are certain natural elements for success granted to some men and denied to others, regardless of education or any other acquired experience. For example, character, personality, tact, perseverance, inherent executive ability, acceptibility of the doctrine of hard work, and all-around intelligence would give a man fortunate to possess these attributes a distinct advantage over some men without them. The only reasonable comparison that can be made is the one that starts with the assumption that these innate characteristics are common to both, and if that is assumed, it would seem to be absolutely futile for anyone to argue that an education is not an advantage to a young man entering railroad service, particularly the branches where technical training cannot help but be an asset. No one can possibly argue that education is a panacea and a complete answer for the success of a young man in any walk of life or that college education can be a substitute for brains and native intelligence. It would seem axiomatic that, with equal natural characteristics, the well-trained educated man has a distinct advantage.

The New York Central has employed many men with a college education who have received recognition and opportunity for advancement. We have no fixed method of engaging men of this calibre, but it would seem that that is a question to which all railroads might to advantage give further consideration.

The two questions as to past rates of progress and remaining with the property are difficult to answer, inasmuch as they have been dependent so much upon the various individuals and the opportunities that have been opened to them through various changes in organization. It is probably difficult in any large organization to retain ambitious young college men seeking more rapid advancemen than opportunity has permitted. Some in later years, however, have expressed regrets over their earlier impatience.

In Review

Your committee is attempting to prepare its presentation of this assignment in such a manner that it will forcefully direct the attention of railway managements to the value of employing young men with college educations and particularly those with technical qualifications. Considerable information already has been collected regarding the practices followed by other industries and this indicates a surprisingly strong interest in, and desire to employ, qualified college men. A more exhaustive investigation of this angle of the subject will be attempted in the next report. The committee feels that certain worth-while preliminary observations may be drawn from the informative matter here presented and that such observations can be stated briefly as follows:

(1) Railway managements should be interested in giving employment, training, encouragement and opportunity to desirable college men in order to provide a reserve from which to draw the future supervising officers, managers and executives, and in that manner enable the railways to meet the competition of other transportation agencies and keep abreast of industry in general.

(2) A desirable college man is a young man who, in addition to his educational qualifications, has character and loyalty, has initiative and analytical ability, is a natural leader and organizer, is aggressive, is willing to take and execute orders and, finally but of major importance, is not above starting at the bottom of the ladder or afraid of hard work.

There are several phases of this assignment which deserve more detailed study and analysis and your committee plans to develop these in future reports.

Report on Assignment 4

Stimulate a Greater Interest in the Science of Transportation Among University and College Students

And Create Thereby a Greater Appreciation of the Place of Transportation in Our National Economic Structure

W. C. Sadler (chairman, subcommittee), Lem Adams, W. J. Cunningham, R. B. Kittredge, F. S. Schwinn, C. C. Williams.

The modern railroad is part of a highly competitive industry, which fact in itself necessitates a superior organization. Therefore, it would seem most desirable that there should be a steady influx into railroad service of young men, whether collegiate or not, of that high quality and promise consistent with the attractions of the railroad industry.

Young men of today are very cognizant of the problems of life, and many of them should be given credit for careful thought and deliberation in the selection of their life's work. The best young men do not follow some particular vocation accidentally. Their decision will be based in part on the probability of steady employment, and the wages available. But of no small influence will be the attractiveness of the work, and the interest which it arouses. Above all, the student desires to be engaged in a strong, virile industry which will offer a challenge to his fullest abilities. He has found his education long and arduous, quite expensive, but usually fascinating. He is eager for the arrival of that time when he can apply his academic training; and incidentally, he wants to realize a return on his college investment. The railroad industry has a very personal interest in these college men.

Cooperation between the railroads and the universities may well take that active, energetic form which will ultimately render a public service, in addition to any incidental mutual benefits.

Campus meetings, with informal addresses on problems of the railroads and other transportation agencies, are important because of the personal contacts they offer, as well as the subject matter of the talks. Student inspection trips to railroad operations also develop personal contacts, as well as coordinating the academic and practical phases of railroading. A properly-equipped library, of a size appropriate to the circumstances, is indispensable; and where possible it might well be augmented with museum pieces. Even the opportunity of student summer employment at common labor will awaken a fuller appreciation of the true significance of a large railroad in operation.

The committee proposes to develop this subject further during the next year to determine specific means and methods of obtaining a fuller appreciation among all college students of the basic importance of the transportation industry in our economic order.

Report on Assignment 5

Develop Means Whereby Facilities of the Universities May Be Made More Directly Available for Research Work of the Association and the Railway Industry

By Cooperative Effort Between the Staffs of the Universities and the Committees of the Association

F. A. Russell (chairman, subcommittee), Lem Adams, W. J. Cunningham, R. E. Dougherty, R. H. Ford, Barton Wheelwright.

It is the thought of the committee that its first activity should be to develop by means of a questionnaire as complete information as possible regarding the present facilities, personnel, activities, and interests of the various schools bearing on railway problems, as well as a compilation of the subjects already investigated and the reports that are available for distribution.

Information of this character can be collected most readily from the colleges giving engineering degrees, of which there are about 145 in the United States. A questionnaire was sent to 125 of these schools as it was thought best not to contact similar schools in Canada at this time because of the unsettled conditions now prevailing in the country by reason of the war. This questionnaire included the following questions:

1. What facilities do you have available for research?
2. In what fields are you best equipped in personnel, experience and equipment?
3. What projects do you now have under way or recently completed?
4. What work have you done in recent years for or of special interest to the railroads?
5. Would you be interested in doing more work along lines which have a bearing on railway activities?

Because of a late start in sending out the questionnaire and because the early fall months comprise an extremely busy period for schools in getting the new year's program under way, response to the questionnaire has not been complete, but the answers are coming in slowly. As of November 1, about 40 of the 125 schools solicited had replied, submitting a large amount of information of a diversified character, much of which will be interesting and valuable to the railways when made available to them in future reports of this committee.

Report on Assignment 7

Cooperate with Organizations of University and College Students Engaged in Study or Discussion of Engineering or Transportation Matters

And Contribute to Their Activities in Such Manner as May Be Mutually Arranged

P. M. Gault (chairman, subcommittee), F. T. Darrow, W. D. Faucette, Clark Hungerford, F. A. Russell, C. C. Williams.

The deans of 17 colleges located in various sections of the United States and Canada were invited to submit suggestions pertinent to the assignment of the subcommittee. None of those contacted is represented on the committee.

Replies were received from 14 of those to whom the inquiry was addressed, each of whom expressed a desire to cooperate with the railroads in any way that would be mutually helpful to the railroads and the students. Following is a brief digest of the suggestions received.

1. Lectures before student gatherings by railroad men engaged in various branches of service, these lectures to be given by specialists before small groups of students who are interested in specialized subjects or by speakers who may be able to bring a message of interest to the student body as a whole.

2. Employment of students:

(a) Summer work, looking to permanent employment after graduation.

(b) Graduates who are especially interested in, or adapted to, railroad work.

(c) Part time employment of students while still in school. Generally speaking, this would mean that two students would be filling one railroad job, one being in school while the other is working and alternating at definite pre-arranged times such as every four or six weeks.

3. Conducting research work on railway problems through college laboratories by and with students.

4. Distribution of railroad publications and literature bearing on transportation to college libraries.

5. English composition assignments covering certain features of railroad transportation. The AREA might establish either cash prizes or medal awards to encourage competition.

Report of Committee 27—Maintenance of Way Work Equipment

G. R. Westcott, *Chairman,*	E. C. Jackson	C. H. R. Howe, *Vice-Chairman,*
C. M. Angel	R. K. Johnson	A. J. Neff
R. M. Baldock	W. G. Kemmerer	E. H. Ness
Edgar Bennett	C. R. Knowles	C. H. Ordas
W. H. Bettis	Jack Largent	P. G. Petri
G. E. Boyd	R. M. Leeds	T. M. Pittman
C. R. Edwards	R. W. Marye	W. D. Rhoads
G. J. Ermentrout	F. H. McKenney	F. H. Rothe
C. L. Fero	E. L. Mead	J. C. Ryan
J. G. Hartley	E. H. Mills	R. R. Smith
C. E. Herth	C. E. Morgan	Roy Wade
L. B. Holt	C. H. Morse	F. F. Zavatkay
N. W. Hutchison	R. A. Morrison	

Committee

To the American Railway Engineering Association:

Your committee reports as follows on its assignments:

1. Revision of Manual.

No report except one recommendation for additional material offered under Assignment 2.

2. Standardization of parts and accessories for railway maintenance motor cars.

Progress report—submitted as information—also one plan recommended for inclusion in the Manual .... page 174

3. Lubrication of roadway machines.

No report.

4. Self-contained direct-blow gasoline tampers.

No report.

5. Devices for applying metal preservative to rail and track fastenings.

Final report—submitted as information .... page 177

6. Methods of keeping data on work equipment.

Final report—submitted as information .... page 183

7. Pneumatic-tired tractor equipment.

Progress report—submitted as information .... page 194

8. Impact wrenches.

Final report—submitted as information .... page 199

9. Track welding equipment:

(a) Oxy-acetylene;

No report.

(b) Electric arc, collaborating with Committee 5—Track, and with Committee 5, Electrical Section, Engineering Division.

Final report—submitted as information .... page 200

10. Railway owned automotive equipment.

No report.

11. Off-track grading equipment.

Final report—submitted as information .... page 206

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12. Weed burners and extinguisher cars.

No report.

13. Safety devices for work equipment, collaborating with Committee 22—Economics of Railway Labor, and with Safety Section, AAR.

No report.

THE COMMITTEE ON MAINTENANCE OF WAY WORK EQUIPMENT,
G. R. WESTCOTT, *Chairman.*

Report on Assignment 2

Standardization of Parts and Accessories for Railway Maintenance Motor Cars

R. K. Johnston (chairman, subcommittee), G. J. Ermentrout, C. L. Fero, Jack Largent, R. A. Morrison, E. H. Ness, C. H. Ordas, P. G. Petri, Roy Wade.

During this year your committee has given consideration to, and offers to the Association:

1. Designs of receptacle to be mounted on motor cars for the purpose of carrying fusees and torpedoes, Figures 1, 2, 3 and 4.

Both the design shown in Figures 2 and 3, and that shown in Figures 1 and 4, make provision for a first-aid kit in the same container. No recommendation is made at this time as to the desirability of including a first-aid kit, nor as to the number of flags, fusees, and torpedoes to be carried, as these matters depend on the rules in effect on individual railroads. For this reason no dimensions are shown, as the size required depends on the amount and character of material to be carried.

In both designs the boxes will be constructed of 26-gage to 20-gage iron with welded joints and a weather-tight hinged lid.

A variation of design shown in Figures 1 and 4, provides space for fusees and torpedoes only. In connection with the use of this box, flags are carried in sections of second-hand air hose fastened in a vertical position on the front safety rail.

2. Design of safety rail for light inspection motor cars, Fig. 5.

A recommended design for safety rail for section duty motor car is now shown in Fig. 2703 on page 27–5 of the Manual. The design presented in Fig. 5 is submitted for use on light inspection cars.

Recommendation

Fig. 5 is submitted for adoption and publication in the Manual. The remainder of the report is offered as information, with the recommendation that the subject be continued.

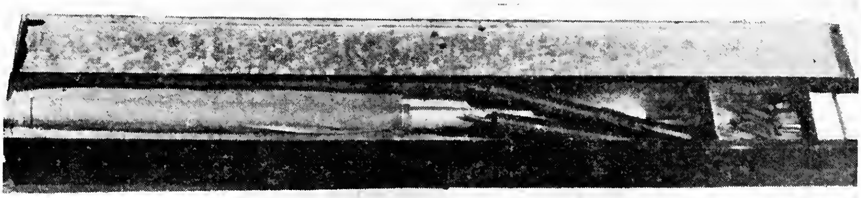


Fig. 1.

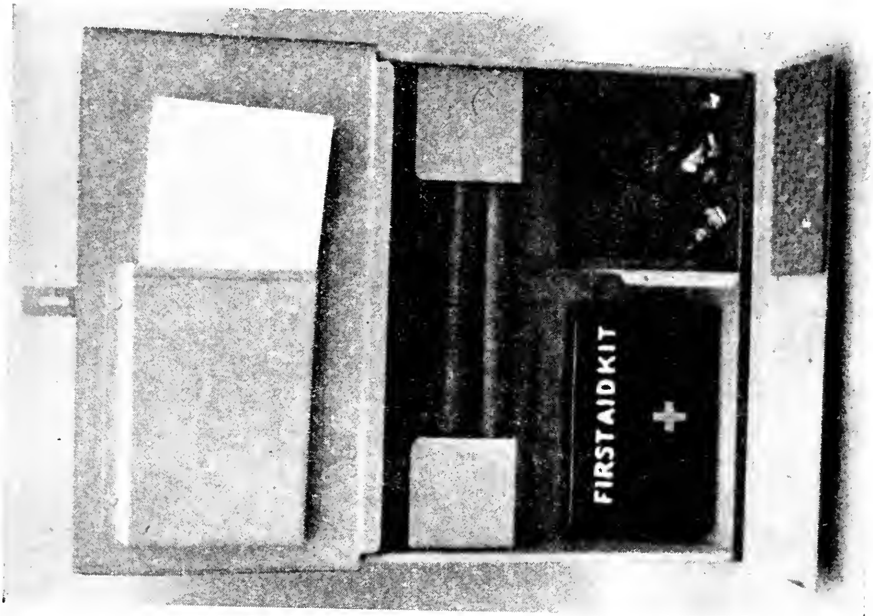


Fig. 3.

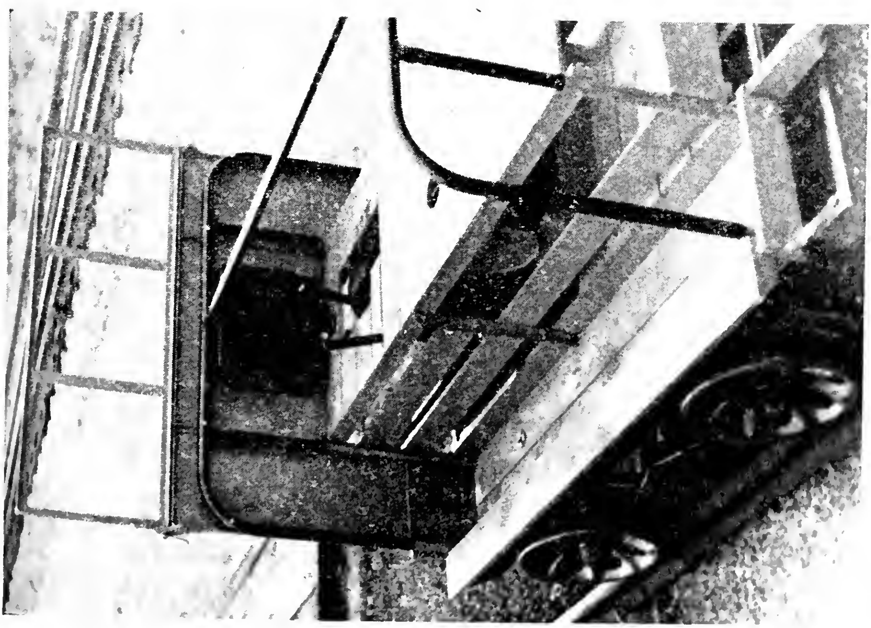


Fig. 2.

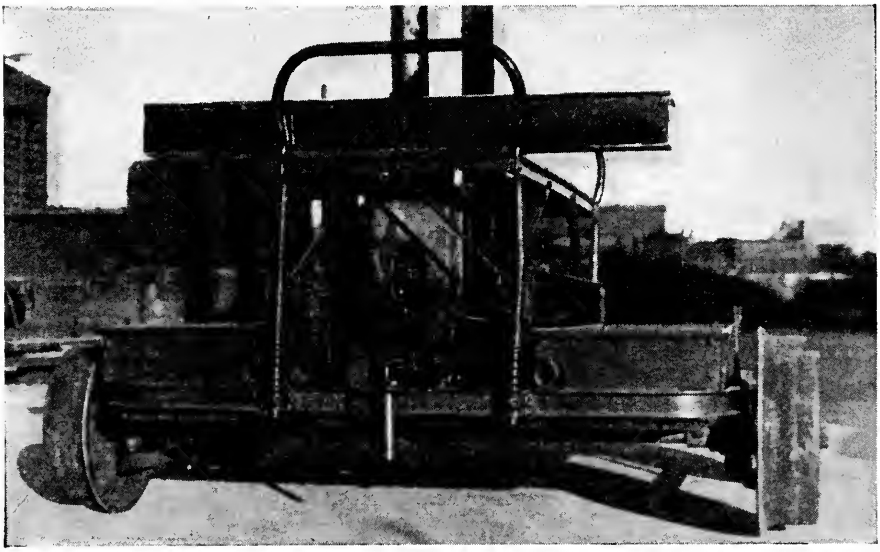
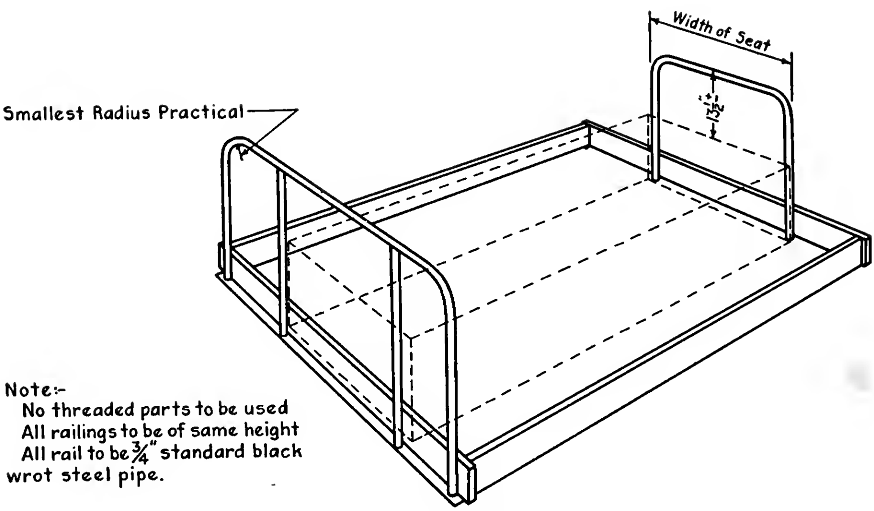


Fig. 4.



Safety Rails for Light Inspection Motor Car.

Report on Assignment 5

Devices for Applying Metal Preservatives to Rail and Fastenings

R. R. Smith (chairman, subcommittee), Edgar Bennett, C. L. Fero, E. C. Jackson, W. G. Kemmerer, Jack Largent, F. H. McKenney, E. L. Mead, A. J. Neff, C. H. Ordas.

In general, the causes of corrosion to rail and track fastenings are:

1. Refrigerator car brine drippings
2. Locomotive exhaust gases combined with moisture
3. Fumes from nearby manufacturing plants
4. Drippings from locomotives and coal cars
5. Sea water and sea air
6. Electrolysis

The prevention or control of corrosion is achieved by the simple expedient of placing a protective coating on the surface of the metal. The most commonly employed material is an asphalt base oil usually containing 45 to 55 percent asphalt. Viscosity or density of the oil is often varied by the addition of light solvents or by heating to make it more adaptable to the method of application.

Appliances for placing the oil are divided into two general classifications; namely, hand operated and power sprayers.

Hand Operated Appliances

Hand operations may be sub-divided into the three following groups:

(a) Brushing or painting

(b) Hand operated one-man sprayers

(c) Application of joint packing

(a) The method of applying preservatives by brushing or painting is too readily perceived or generally understood to require description.

(b) Various types of hand sprayers are available, but all are basically the same. In general, they consist of a container for the liquid to be sprayed, to which pneumatic pressure is applied by means of a hand operated pump. Nozzles of various designs, depending upon the nature of the work to be performed and also upon the characteristics of the material to be sprayed, are connected to the tank with a short hose.

Nozzles used with hand sprayers for applying the preservative behind joint bars are ordinarily long metal tubes, offset for easy insertion, and having one or more small orifices for drenching the rail ends and back surfaces of the joint bars. The same nozzle may be used for coating the outside of the joint or a spray type may be substituted. The latter will give more uniform and more positive coverage with less oil consumption. However, due to the smaller orifice in a spray type nozzle it may be necessary to use oil of a lower viscosity or add kerosene or some other light solvent to the material used with the tubular type.

(c) It has become the practice on some roads, usually when laying rail or renewing splice bars, to fill the void between the bars and rail with a plastic filler composed of finely divided wood flour, metal preservative oil and lubricating oil. The proportion currently used amounts to approximately 2½ lb. of oil to 1 lb. of wood flour. The oil is 70 percent asphalt base metal preservative and 30 percent lubricating oil.

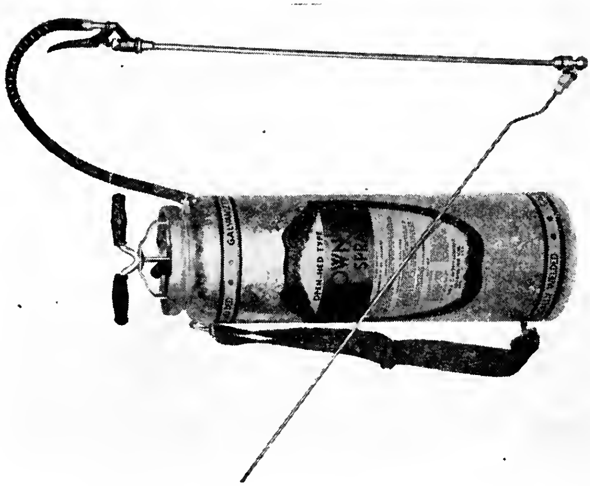


Fig. 1.—Hand Sprayer With Tubular Nozzle.

Fig. 2.—Plastic Blocks Placed Back of Splice Bars.

In present practice the plastic filler is formed into blocks 12 in. long, the cross-section varying with the size of the void to be filled. The blocks are wrapped in wax paper, a sufficient number of blocks for one joint being packed in a carton.

Application consists of placing the blocks of plastic (without removing the wax paper) on the back surfaces of the splice bars as they lie face downward at their point of application to the rail. The splice bars are then revolved quickly into place. The action of bolt tightening or pulling the bars into position causes the plastic to be squeezed or forced into all parts of the void.

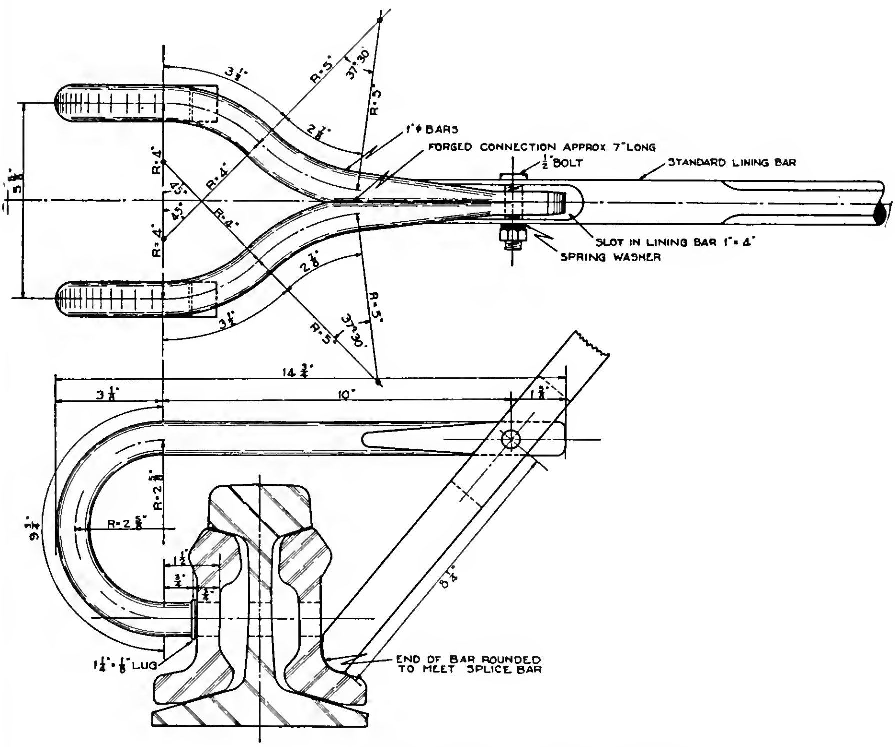


Fig. 3.—Lever For Applying Splice Bars Over Plastic Blocks.

With rail sections having large void areas between the splice bars and the rail and requiring correspondingly heavier plastic blocks, it is often difficult or impossible to force the splice bars far enough into position by hand to apply the nut to the track bolts. Hooks or levers for pulling the bars into position for bolt application have been devised by some roads. A typical device for this purpose is shown in Fig. 3.

Power Operated Sprayers

For an extensive oiling program power operated sprayers are advisable. This type of equipment employs mechanically operated pumps for forcing the preservative through spray nozzles under high pressure.

The equipment used falls into three general classifications:

(a) Small power sprayers hauled by motor cars

(b) Gasoline powered self propelled units

(c) Large spray cars handled by work train

(a) One railroad has developed a small car, hauled by a track motor car, primarily designed for automatically spraying the external surfaces of rail joints.

The unit, about the size of a regular track push car, carries two standard 55-gal. drums of preservative, together with a single cylinder air-cooled gasoline engine driving a small centrifugal pump for applying the preservative under approximately 70 lb. pressure. Before spraying operations begin, the oil is heated by pumping it through a manifold surrounding the motor exhaust line. Oil enters the manifold at the engine end, passes along the exhaust line for a distance of about four feet and is discharged back into the drum. Approximately 15 to 20 min. are required to adequately heat a 55-gal. drum of preservative.

During spraying operations valves controlling the flow of oil to the spray nozzles are automatically opened as "kick rods" come in contact with the splice bars and close as soon as the contact is released. The machine is equipped with an arrangement to by-pass the oil back into the drum when spray valves are closed.

Obviously, it is feasible to use the unit for continuous spraying by simply removing the devices used for automatically opening and closing the valve in the supply line, or by arranging to hold the valves open for as long a period as desired.

(b) There is available through a manufacturer a self-propelled track oiler of rather large capacity designed to accomplish all of the oiling on track or roadway. The machine consisting of two units, the track oiler and the trailer tank car, is powered with a 72-hp. gasoline motor for propulsion and the operation of all the mechanical equipment, such as air pump, oil pumps, etc.

This appliance will automatically oil rail joints at a speed of 8 to 12 miles per hour, the entire rail and the fastenings at from 15 to 20 miles per hour and the roadbed at a rate of 6 to 8 miles per hour. The spray car is equipped with two auxiliary hand spray lines for use in oiling switches, frogs and other appurtenances within 25 ft. of the machine.

The oil is heated by the motor exhaust in the course of its flow from the supply tanks to the spray nozzles and is applied to the track under high pressure. The oiler and trailer tank have a total capacity of approximately 3,000 gal., and this supply can be replenished from railway tank cars by means of a power-operated pump in about 30 min.

(c) For extensive track oiling some roads have developed large spray cars designed exclusively for train operation. These consist essentially of a box car in which there is mounted a rotary pump having a capacity of 200 gal. per min., with a 4-in. intake and a 3-in. discharge, driven by a 20-hp. gasoline engine. The car is piped to permit pumping oil direct from the tank cars in which it is received through a flexible hose suction line between the oil car and the tank car. On the suction side of the pump there is a valve by which the intake of oil can be controlled so as to maintain a fixed pressure of about 45 lb. in the discharge line. There is also a strainer installed in the suction line to prevent anything from getting into the pump that might injure or clog it. Both pump and strainer are steam jacketed.

The discharge line from the pump delivers the oil to oiling heads at the end of the car. There is an oiling head over each rail, each head having spray nozzles on each side of the rail so arranged that they can be adjusted to fit the rail and fastenings to be oiled. The spray nozzles for one rail are mounted on the body of a quick-acting valve, the stem of which is secured in a fixed position on the bracket supporting the oiling head. By means of a lever just inside the car, both oiling heads at that end of the car can be

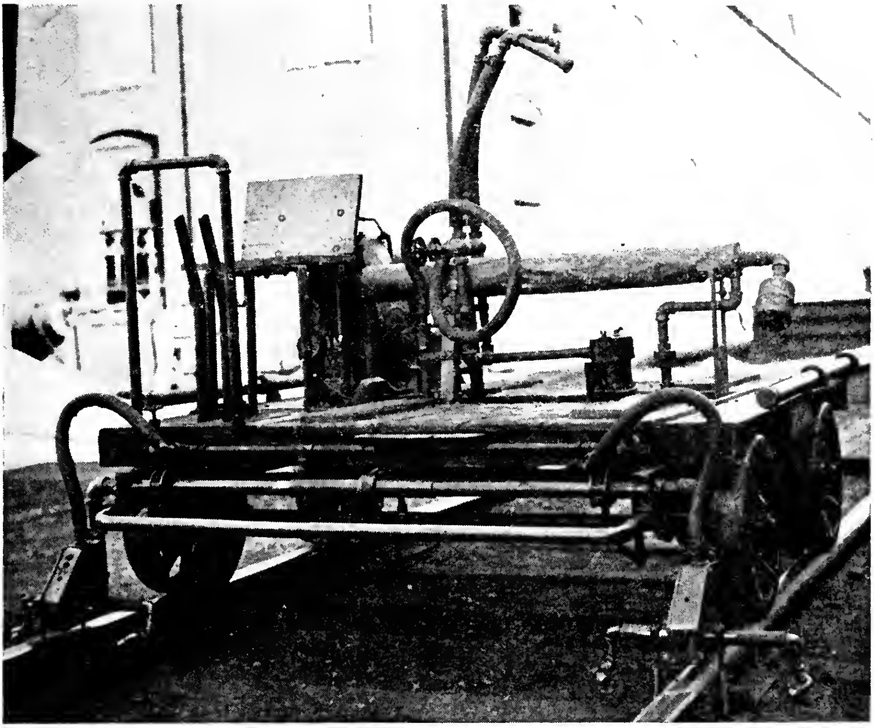


Fig. 4.—Rail Joint Spray Car—Nozzle in Spraying Position.

Fig. 5.—Self-Propelled Rail Oiling Car.

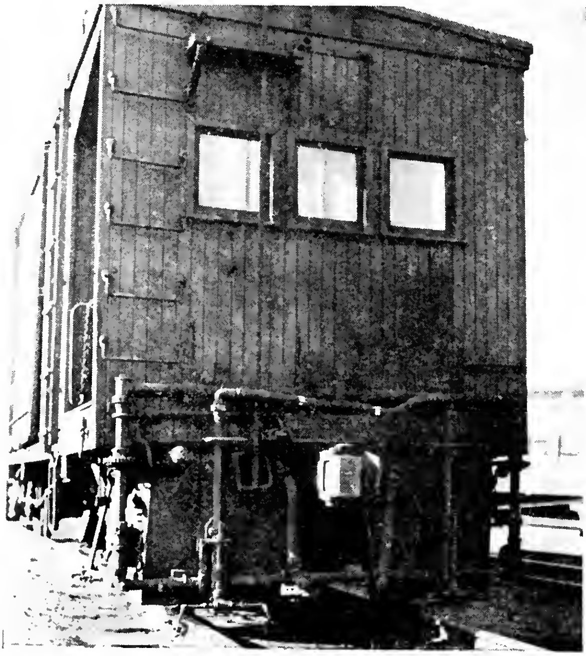


Fig. 6.—Train-Operated Rail Oiling Car.

raised so that the spray nozzles, which in operation extend somewhat below the top of the rail, will clear such obstructions as crossing plank or turnout rails. When the heads, including the valve bodies, are so raised against the fixed position of the stems, the valves are automatically closed.

As the flow of oil is cut off in this way, it is necessary to have a relief by-pass at the pump. Other accessories at the pump are a pressure gage in the discharge line to facilitate the maintenance of the desired pressure, and a thermometer to indicate the temperature of the oil.

The steam piping in the car supplies steam for maintaining proper temperature at the pump and strainer, and is arranged also for blowing out the discharge lines and oiling heads with steam at the end of the run. It is desirable to apply the oil at a temperature of about 175 deg. F. To this end, oil must be received in tank cars having steam heating coils in good condition.

In use, the oiling car is pushed ahead of the work train, with the oiling end forward. This permits the operator to see obstructions requiring the oiling heads to be raised. The consist of the train back of the oiling car includes one or two tanks of oil under heat, an engine with steam connection on the front end, other tank cars of oil, if any, and finally, the caboose. In operation, a considerable amount of oil vapor will collect on the oiling car and other equipment in the train and finally on the rails. It is necessary, therefore, that the oiling car be equipped with sanders in good condition and sand hoppers of 100 to 200-cu. ft. capacity.

The car is operated at about 20 miles per hour, and at this speed it is not practicable to stop to oil switches and frogs, and turnout rails and fixtures.

Several roads have used equipment as described above very successfully, although work-train service is required; the work is done with such speed that the total cost is comparatively low, often running less than $3 per mile. It has the additional advantage that the oil is applied hot and therefore penetrates the rust and seals better than cold oil. Also, as the oil is taken directly from the tank car, there is no loss of time transferring the load, as is the case of rail oilers having a tank built into the car. In operation, only two men, other than the train crew, are required, namely, the operator, who is stationed at the oiling end and raises the oiling heads when necessary, and a helper who sees that the pump is operating properly and that pressure and temperature are correct.

Tie-tamping air compressors equipped with hose and spray nozzles are often used for spraying facilities that are either too extensive to be sprayed economically with hand operated appliances, or consume too much time to be economically handled with train operated spray cars. Typical of such facilities are turnouts and crossovers at interlocking plants.

When using compressed air a vacuum type nozzle may be employed. A vacuum nozzle using a relatively large volume of air has the advantage of blowing the metal free of dirt and scale as well as coating it with preservative. However, its disadvantage lies in the fact that a short suction hose must be used and consequently the oil container must be frequently moved as the work progresses.

Direct pneumatic pressure may be applied to the preservative oil container and an ordinary spray nozzle used in place of the vacuum type. By using this method it is possible to force the oil a considerable distance and thus it is feasible to mount the container on the compressor and obtain the advantage of heating the preservative with the motor exhaust.

The intent of this report as defined by its title is solely to describe devices used or available for applying metal preservatives to rail and fastenings. Therefore, the economic value of any device or method has not been discussed.

Your committee presents this report as information and recommends that the subject be discontinued.

Report on Assignment 6

Methods of Keeping Data on Work Equipment

N. W. Hutchison (chairman, subcommittee), C. R. Edwards, G. J. Ermentrout, C. E. Herth, W. G. Kemmerer, R. W. Marye, E. L. Mead, C. H. Morse.

Every railroad that invests in work equipment expects at least a normal return on the money invested; otherwise it would be illogical to make the expenditure. The ultimate objective, however, is to secure the maximum return, which can only be determined where reliable data are available relative to the operating and financial costs of the work equipment purchased.

Although data relative to the ownership, operation, and maintenance of work equipment are not vitally essential, they are highly desirable for the following purposes:

1. To determine the rate of return on the investment
2. To compare the cost of machine work with work done manually or by other machines
3. To permit proper coordination of work programs with the work equipment schedule
4. To forecast maintenance allowances necessary for machine work

5. To control, within limits, the operating and repair costs of work equipment
6. To provide information promptly regarding the location and condition of each machine
7. To permit intelligent supervision of work equipment
8. To provide a basis on which to predicate future purchases of similar equipment

Data of any description are valueless unless accurate, and their collection should be effectively supervised. Too much detail adds "paper work" to the duties of the foremen and machine operators and defeats its own purpose. In specific cases test data only may be sufficient, but where complete operating and repair costs are desirable, data should be collected and recorded for the entire life of a unit of equipment.

To your committee was assigned the task of studying various methods of keeping data on work equipment. Studies conducted clearly indicate that there are not now, nor can there be, from a practical standpoint, standardized methods of keeping such data. However, standardization of forms for the purpose is considered practical and desirable, which forms can be utilized as necessary. Your committee has, therefore, designed forms for collecting and recording work equipment data, which represent a cross-section of the forms in use on various railroads that have heavy investments in work equipment.

The forms, shown on following pages with illustrative data, are classified and used as follows:

1. Ownership, Location and Condition

Form A—Report of Inspection of New Work Equipment

Upon receipt of a new unit of work equipment it should be inspected for visible defects, the data inserted on Form A and the form forwarded to the supervisor of work equipment, who shall assign a railroad number to the equipment.

Form B-1—Record of Work Equipment

Data for the upper portion of this form are taken from Form A, from invoices and from other available sources, and when inserted on the form, serve as a permanent record. The form should be made of stiff cardboard and kept in a file drawer, grouped with cards for other equipment of the same type. Data for the lower half of this form are supplied by Form C.

Form C—Report of Transfers of Work Equipment

This form should be filled out and forwarded to the supervisor of work equipment each time a machine is transferred to or from a division.

Form D—Report of Failure of Work Equipment

This form should be submitted to the division engineer immediately, when a unit of work equipment breaks down.

Form E—Work Equipment Inspection Report

This form should be forwarded to the supervisor of work equipment immediately following a regular or emergency inspection of any unit of work equipment.

Form F—Report of Location of Work Equipment

These data should be submitted to the supervisor of work equipment periodically by the division engineer covering all equipment on his territory.

Form G—Report of Work Equipment Used for AFE Work

Data on this form should be forwarded at the end of each month or at the conclusion of an AFE project to the supervisor of work equipment by the engineer or foreman in charge of the work.

Text continued on page 194

THE NORTH AND SOUTH RAILROAD

REPORT OF INSPECTION OF NEW WORK EQUIPMENT

ITEM OF EQUIPMENT *Tie Tamping Compressor*

MANUFACTURER *Black Mfg Co* MFRS. SERIAL NO. *63822*

TYPE *Single Stage* MODEL *Z* SIZE *7X6* WEIGHT ______

MANUFACTURER OF BOILER ______ BOILER NO *–*

SIZE OF BOILER ______ KIND OF BOILER *–*

MANUFACTURER OF ENGINE OR MOTOR *Jones Engine Co*

ENGINE OR MOTOR SERIAL NO. *4K-16392* SIZE OF ENGINE OR MOTOR *5×6*

MODEL OF ENGINE OR MOTOR *R-16-KM* TYPE OF ENGINE OR MOTOR ______

NO. OF CYLINDERS *4* CYCLES *4* R.P.M. *650* VOLTS ______

AMPS. ______ K.V.A. RATING ______ H.P. ______ CAPACITY ______

OTHER INFORMATION ______

DATE INSPECTED ______ CONDITION WHEN INSPECTED ______

LIST BELOW DEFECTS IF ANY:

ASSIGNED TO *John Doe's Extra Force* PUT IN SERVICE ON *Feb 1* 19*32*

AT *M.P. 680* R.R. NUMBER ASSIGNED *AC-128*

John Black Inspector
NAME & TITLE

FORM A — SIZE 8½" X 11"

ITEM Tie Tamping Compressor

THE NORTH AND SOUTH RAILROAD

RECORD OF WORK EQUIPMENT

R.R. NO. AC-128

SERIAL NO. 63822 MANUFACTURER Blank Mfg Co TRADE NAME ____

TYPE Single Stage MODEL Z SIZE 7x6 WEIGHT ____ CAPACITY ____

SELF-PROPELLED Yes ON OR OFF RAILS On PURPOSE FOR WHICH DESIGNED Tamping Ties

POWER USED Gasoline Engine DATE PURCHASED Jan 1, 1939 PURCHASE PRICE $8100.00 A.F.E. NO. 16982 REQN. NO. 39-48

ESTIMATED LIFE 15 years ASSIGNED TO John Doe's Extra Force DATE PUT IN SERVICE Feb 1, 1939

MAKE OF ENG. OR MOTOR Jones Engine Co SERIAL NO. 4K-16392 MODEL R-16-KM R.P.M. 650 H.P. 35

SIZE 5x6 CYCLES 4 NO. OF CYLINDERS 4 VOLTS ____ AMPERES ____ PHASES ____ K.V.A. RATING ____

MAKE OF BOILER ____ BOILER NO. ____ BOILER TYPE ____ BOILER SIZE ____

OTHER INFORMATION ____

____ DATE RETIRED OR REPLACED ____ 19__

TRANSFERS

From	To	Date	Reason	From	To	Date	Reason
N.Y. Divn	Springfield Shop	11/1/39	Inspection and repairs				
Springfield Shop	N.Y. Divn	11/24/39	Repairs completed				

FORM B-1 – SIZE 8½" X 11"

THE NORTH AND SOUTH RAILROAD

REPORT OF TRANSFERS OF WORK EQUIPMENT

ITEM OF EQUIPMENT	R.R. NO.	MFRS. SER.NO.	ENG. NO.	RECEIVED FROM	DATE REC'D.	SHIPPED TO	DATE SHIPPED
Tie Tamping Compressor	AC-128	63822	4K-16392	Springfield Shop	11/25/39		

PURPOSE OF TRANSFER Return from shop following repairs

AUTHORITY FOR TRANSFER Instructions of Supervisor of Work Equipment

SIGNED H Smith TITLE Div Engr

FORM C-SIZE 8½X11"

THE NORTH AND SOUTH RAILROAD

REPORT OF FAILURE OF WORK EQUIPMENT

DATE 5/14/39 LOCATION MP 684 DATE & TIME FAILED 5/14 - 9:15 a.m.

ITEM OF EQUIPMENT Tie Tamping Compressor R.R. NO. AC-128

CAUSE OF FAILURE Broken water pump

ESTIMATED TIME WILL BE OUT OF SERVICE 5 hours

ACTION TAKEN TO RETURN IT TO SERVICE Immediate repairs

IF NOW BACK IN SERVICE SHOW DAY & HOUR RETURNED TO SERVICE 5/14 - 2.00 p.m.

SIGNED J Henry, Road Mechanic
OPERATOR OR MECHANIC

FORM D- SIZE 9"X6"

THE NORTH AND SOUTH RAILROAD

WORK EQUIPMENT INSPECTION REPORT

ITEM OF EQUIPMENT *Tie Tamping Compressor* DATE *Nov 15, 1939* R.R. NUMBER *AC-128*
MANUFACTURER *Black Mfg Co* SERIAL NUMBER *63822* ENGINE MAKE *Jones Engine Co*
ENGINE SERIAL NUMBER *4K-16992* MAKE OF BOILER ______ BOILER NUMBER ______
TYPE OF FUEL USED *Gasoline* DATE OF LAST PREVIOUS INSPECTION *July 1, 1939*
DATE OF LAST PREVIOUS ENGINE OVERHAUL *Never Overhauled* DATE BOILER LAST WASHED ______
DATE RADIATOR LAST FLUSHED *Apr 15, 1939* DATE OIL LAST CHANGED *Oct 20, 1939*

PARTS OF MACHINE INSPECTED (INSPECTION TO BE MADE OF ALL MAJOR PARTS AND CONDITION NOTED)	CONDITION: GOOD	FAIR	POOR	BROKEN
COMPRESSION			✓	
IGNITION	✓			
COOLING SYSTEM	✓			
LUBRICATION	✓			
COMPRESSOR END	✓			

RECOMMENDATION *That compressor be sent to Springfield shop for complete inspection*
INSPECTED BY *J. Henry, Road Mechanic* OPERATOR ______

FORM E - SIZE 8½" X 11"

THE NORTH AND SOUTH RAILROAD

REPORT OF LOCATION OF WORK EQUIPMENT

DIVISION *New York* FOR *Month* ENDING *Sept 30* 1939

ITEM OF EQUIPMENT	R.R. NO.	LOCATION	IN STORAGE, WORKING, OR IDLE	GENERAL CONDITION	REMARKS
Tie Tamping Compressor	*AC-128*	*MP 715*	*Working*	*Fair*	
Rail Layer	*RL-15*	*Pine Creek*	*Idle*	*Good*	

DIVISION ENGINEER *H Smith*

FORM F-SIZE 8½" X 11"

THE NORTH AND SOUTH RAILROAD

REPORT OF WORK EQUIPMENT USED FOR A.F.E WORK

LOCATION OF WORK *Extension of Smithville Passing Siding* FOR PERIOD ENDING *Aug 31* 1939

ITEM OF EQUIPMENT	R.R. NO.	A.F.E. NO.	NO. OF DAYS USED	NO. OF HOURS USED	BEGINNING OF PERIOD (CHECK)	END OF PERIOD (CHECK)	REMARKS
Tie Tamping Compressor	*AC-128*	*13219*	*14*	*98*	*No*	✓	*Put on job Aug 15*

SIGNED *W H Gray, Res Engr*

FORM G-SIZE 8½" X 11"

THE NORTH AND SOUTH RAILROAD

RECOMMENDATION FOR RETIREMENT OF WORK EQUIPMENT

ITEM OF EQUIPMENT *Concrete Mixer* R.R. NO. *CM-322* DATE *Sept 14* 19*39*

MANUFACTURER *Engineering Corp* MFRS. SERIAL NO. *22913*

MAKE OF ENGINE *Brown Engine Co* ENGINE NO. *355872* BOILER NO. _____

THIS MACHINE WAS RECEIVED ON *Sept 1* 19*39* FROM *New York* DIVISION FOR REPAIRS, COVERED BY REQUISITION NUMBER *X-14375* IT IS ESTIMATED THAT THE REPAIRS WILL COST *$250.00*. IF DISMANTLED, IT IS ESTIMATED THAT THE CHARGE FOR DISMANTLING WILL BE *$50.00*. THE VALUE OF THE SECOND HAND PARTS WILL BE *$15.00* AND THE VALUE OF THE SCRAP PARTS WILL BE *$10.00*

SHOP SUPT. *J E Brown*

THIS MACHINE WAS PURCHASED *June 16* 19*27* ON A.F.E. NUMBER *42619*, REQUISITION NUMBER *B-985* AT A COST OF *$750.00*

DURING THE *12* YEARS IT HAS BEEN IN SERVICE IT WAS USED FOR AN AVERAGE OF *115* DAYS PER YEAR, *5* HOURS PER DAY, AT A TOTAL OPERATING COST TO DATE OF *$2484.62* INCLUDING FUEL, LUBRICATION, AND REPAIRS.

REMARKS _____

IT IS MY RECOMMENDATION THAT THIS MACHINE BE *Retired*

SUPERVISOR OF WORK EQUIPMENT *A B Green*

FORM H—SIZE 8½"X11"

THE NORTH AND SOUTH RAILROAD

DAILY REPORT OF OPERATION OF WORK EQUIPMENT

DIVISION *New York* SUB-DIVN. *Western* DATE *6/7* 19*29* R.R. MACHINE NO. *AC-128*
KIND OF MACHINE *Tie Tamping Outfit* KIND OF WORK *Tamping Ties* PROGRAMMED? *yes*
MACHINE WORKING *6* HRS. *45* MINS; IDLE *1* HRS. *15* MINS. REASON IDLE *Traffic delays*

A. DELAYS
WEATHER ____
TRAFFIC *1 Hr 15 Min*
REPAIRS ____
MOVING ____
OTHER ____
TOTAL DELAYS ____

B. PRODUCTION
LOCATION ____
WORKING *1620* FEET E.W.N. OR S. OF M.P. *692*
WORKING ON TRACK NO. *Eastbound*
WORKING BETWEEN TRACKS NO. ____ AND ____
WORKING BORDER ALONG TRACK NO. ____

NUMBER OF TOOLS WITH OUTFIT *8*

CAPACITY OF UNIT *8 Tools*

WORK IN DETAIL	QUANTITY	UNITS	WORK IN DETAIL	QUANTITY	UNITS
Tamping Ties	*608*	*Feet*			

C. LABOR (EXCLUSIVE OF REPAIRS)

OCCUPATION	RATE	NO. MEN	TIME STR.	TIME PRO.	TIME PUN.	TOTAL EARNED
Foreman	$ *150.00*	*1*	$ *6 82*	$	$	$ *6 82*
Laborers	$ *.35*	*12*	$ *33 60*	$	$	$ *33 60*
	$		$	$	$	$
	$		$	$	$	$
	$		$	$	$	$

REPAIRS

OCCUPATION	RATE	NO. MEN	TIME STR.	TIME PRO.	TIME PUN.	TOTAL EARNED
	$		$	$	$	$
None	$		$	$	$	$
	$		$	$	$	$
	$		$	$	$	$
	$		$	$	$	$

D. WORK TRAIN (MOVE & SERVICE EQUIPMENT)

TRAIN ____ HOURS @ $ ____ PER HR. = ____
FOREMAN ____ " @ $ ____ " " = ____
LABORERS ____ " @ $ ____ " " = ____ *None*
OTHER ____ " @ $ ____ " " = ____
____ " @ $ ____ " " = ____
TRUCK ____ " @ $ ____ " " = ____
TIME CALLED ____ TIME RELEASED ____

E. SUPPLIES

27 GALS. GAS @ $ *.15* PER GAL. = $ *4 05*
2 QTS. OIL @ $ *.20* PER QT. = $ *.40*
1 LBS. GREASE @ $ *.05* PER LB. = $ *.05*
____ LBS. GREASE @ $ ____ " " = $ ____
____ GALS. FUEL OIL @ $ ____ PER GAL. = $ ____
____ TONS COAL @ $ ____ PER TON = $ ____
____ @ $ ____ PER = $ ____
____ @ $ ____ PER = $ ____

F. REPAIR PARTS

PIECES	DESCRIPTION OF PART	CAT. NO.	COST
			$
	None		$
			$
			$
			$

G. SUMMARY OF OPERATING COST

ITEM C - LABOR OPERATING $ *40 42*
" " - LABOR REPAIRS $ *-*
ITEM D - WORK TRAIN $ *-*
ITEM E - SUPPLIES $ *4 50*
ITEM F - REPAIR PARTS $ *-*
TOTAL COST OF OPERATION $ *44 92*

CONDITION OF THE MACHINE AT THE CLOSE OF THE DAY'S WORK *Good*
DATE REPAIR PARTS ORDERED ____ 19__

MACHINE FORWARDED TO SUPERVISOR ____ AT ____ DATE ____ 19__

MACHINE RECEIVED BY SUPERVISOR ____ AT ____ DATE ____ 19__

REMARKS ____

SIGNED *John Doe, Extra Force Foreman*
NAME & TITLE

FORM 1 - SIZE 8½" X 11"

DIVISION *New York.* THE NORTH AND SOUTH RAILROAD MONTH *June* YEAR 19*39*

MONTHLY REPORT OF OPERATION OF WORK EQUIPMENT

TYPE OF MACHINE	R.R. NO.	ACT. HRS. USED	ACT. DAYS USED	GALS GASO LINE	PTS. OIL	MISCEL. SUPPLIES IN MONEY	KIND OF WORK	MAN HRS.	LOCATION OF WORK M.P.	TO M.P.	UNIT USED	NUMBER OF UNITS	MACHINE DELAYS HOURS	REMARKS
Tie Tamping Compressor	*[illegible]-125*	*148*	*21*	*592*	*32*	*$2 16*	*Tamping Ties*	*2184*	*691.5*	*694.2*	*Lin. Ft. Track*	*14280*	*20*	

DIVISION ENGINEER *H. Smith*

FORM J-SIZE 11" X 16"

THE NORTH AND SOUTH RAILROAD

REPORT OF FIELD REPAIRS TO WORK EQUIPMENT

DIVISION *New York.* FOR *Month* ENDING *May 30* 19*39*

ITEM OF EQUIPMENT	R.R. NO.	REPAIRS MADE AT	DATE REPAIRED	REPAIRS MADE BY	COST OF REPAIRS LABOR	MATERIAL	TOTAL	HRS. DELAY DURING REPAIRS
Tie Tamping Compressor	*[illegible]-128*	*On R/W*	*5/12/39*	*J. Henry, Road Mechanic*	*$3 25*	*$6 75*	*$10.00*	*5*

DIVISION ENGINEER *H. Smith*

FORM K-SIZE 8½" X 11"

The North and South Railroad

Report of Shop Repairs to Work Equipment

Location of Shop *Springfield* For *Month* Ending *Nov 30* 19*39*

Item of Equipment	R.R. No.	Date Rec'd.	Received From	Shop Order Number	Completion Date	Cost of Repairs: Labor	Mat'l	Other	Total	Date Shipped	Shipped To
Tie Tamping Compressor	*AC-128*	*11/2/39*	*New York Div.*	*N-314*	*11/22/39*	*$116.22*	*$45 19*	*$3 85*	*$165.26*	*11/24/39*	*New York Div.*

Shop Supt. *J. E. Brown*

FORM L - SIZE 8½" X 11"

Service Record

Item *Tie Tamping Compressor* R.R. No. *AC-128*

Year	In Service: Hrs.	In Service: Da.	Fuel & Lubrication Cost: Gasoline: Gals.	Gasoline: Gal. Cost	Gasoline: Total Cost	Oil: Pts.	Oil: Pt. Cost	Oil: Total Cost	Grease: Lbs.	Grease: Lb. Cost	Grease: Total Cost	Total Cost	Cost Misc. Supplies	Repair Cost: Field: Mat'l	Field: Labor	Shop: Mat'l	Shop: Labor	Shop: Overhead	Total Cost	Total Cost of Operation
19*39*	*1132*	*150*	*4685*	*$ 15*	*$702 75*	*303*	*$ .10*	*$30 30*	*160*	*$ .05*	*$8 00*	*$741 05*	*$12 19*	*$8 15*	*$18.70*	*$45 19*	*$116.22*	*$3 85*	*$192 11*	*$945.35*
19*40*																				
Total to Date																				
19*41*																				
Total to Date																				
19[illegible]																				
Total to Date																				
19*59*																				
Total to Date																				

FORM B-2 - SIZE 8½" X 11"

Form H—Recommendation for Retirement of Work Equipment
Following a complete inspection by the shop superintendent or road mechanic, this form should be forwarded to the supervisor of work equipment who supplies additional information with his recommendation and forwards the completed form to his superior.

2. Cost of Operating and Maintaining Work Equipment

Form I—Daily Report of Operation of Work Equipment
This form should be forwarded daily by the machine operator or foreman to the supervisor of work equipment, with a copy to the supervisor of track and the division engineer.

Form J—Monthly Report of Operation of Work Equipment
This form should be prepared monthly by the division engineer, from data supplied on Form I and forwarded to the supervisor of work equipment.

Form K—Report of Field Repairs to Work Equipment
Data on this form should be supplied by the road mechanic or division engineer and forwarded to the supervisor of work equipment.

Form L—Report of Shop Repairs to Work Equipment
Data on this form should be furnished by the shop superintendent and forwarded to the supervisor of work equipment.

Form B–2—Service Record
This form is the reverse side of Form B–1 and on it should be posted data supplied on Forms G, I or J, K and L.

No forms have been designed nor are any illustrations submitted in this report to indicate the manner in which final data are submitted to the management. It is felt that, with all the data at his command, the supervisor of work equipment or other responsible officer should be in a position to furnish any information desired by the management.

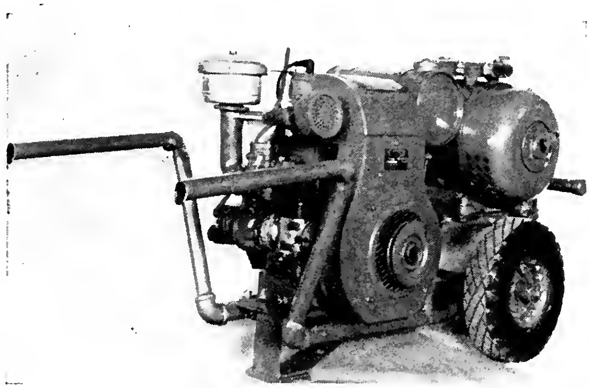
The report is presented as information with the recommendation that the subject be discontinued.

Report on Assignment 7

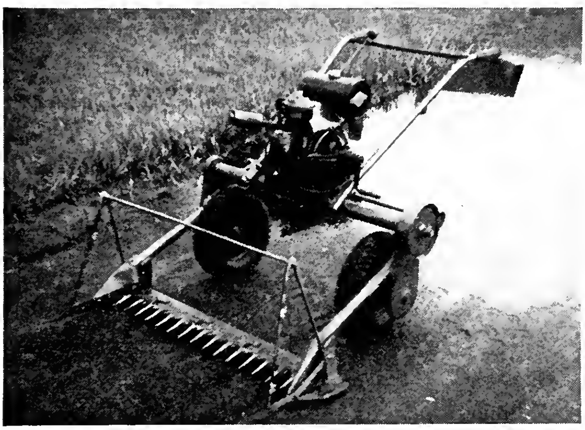
Report on Pneumatic Tired Tractor Equipment

R. M. Leeds (chairman, subcommittee), Edgar Bennett, C. E. Herth, F. H. McKenney, C. E. Morgan, A. J. Neff, T. M. Pittman, F. H. Rothe.

The committee finds the use of pneumatic tired tractor equipment by farmers, contractors, state and county highway departments has increased greatly during recent years. This is also true of railroads, but to a lesser degree. The failure of the railways to make use of more pneumatic mounted equipment has been due to the fact that equipment of a character suitable for railroad service, has not been available. One reason for the trend from the steel tired equipment, as well as from the crawler-mounted tractors, is no doubt the increased mileage of paved highways over which such equipment is moved, it being possible to operate pneumatic tired equipment much more quickly from one point to another with less damage to the highways, and to the equip-

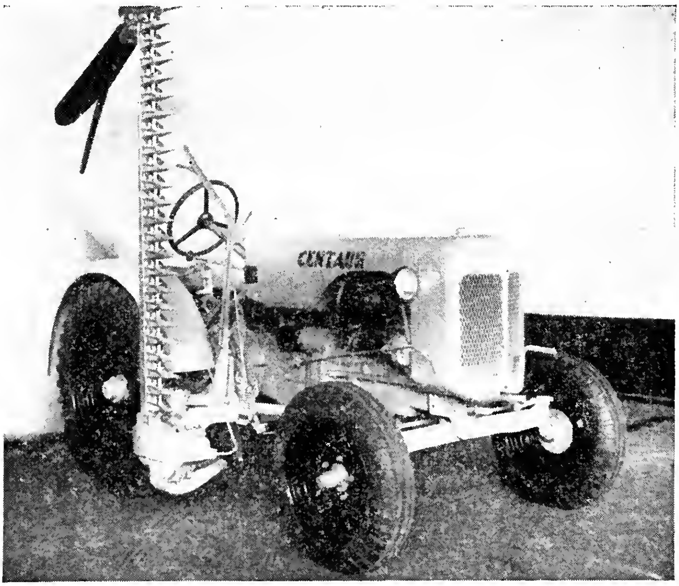


Portable Generator Mounted on Pneumatic Tires.



Power-Operated Mowing Machine Mounted on Pneumatic Tires.

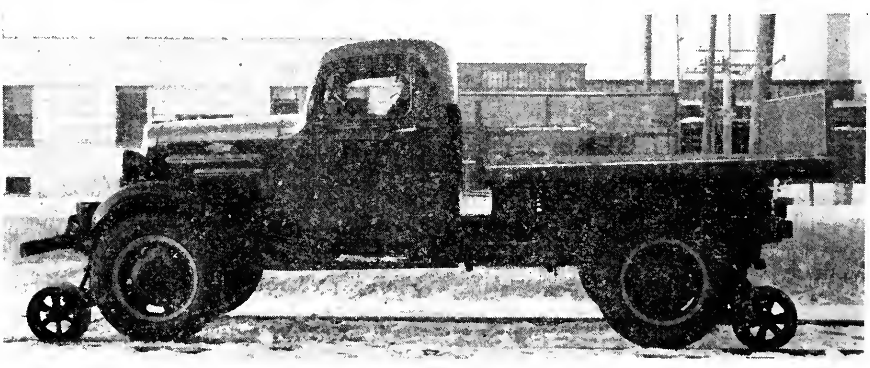
Small Wheel Tractor With Trailers Used by Purchases and Stores Department.



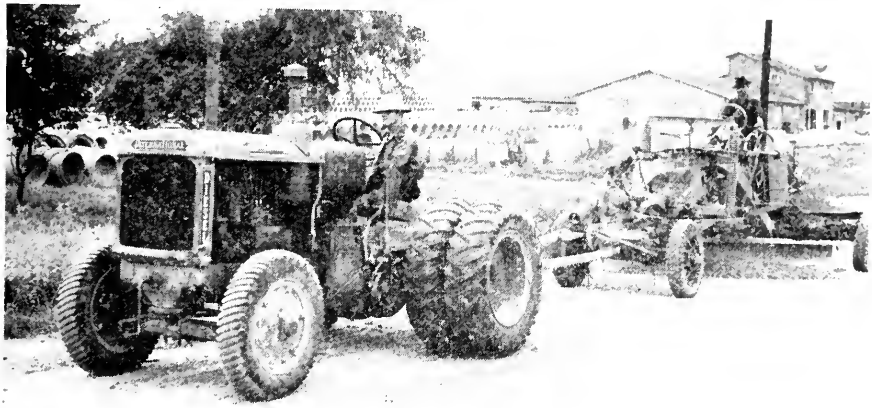
Pneumatic Tired Tractor Mowing Machine.

ment so handled. This applies to railroads in moving such equipment as truck-mounted cranes and welding outfits, mowing machines and tractors from one job to another quickly on adjacent highways, thus saving delays in loading, unloading, and delays to rolling stock and trains when making such moves.

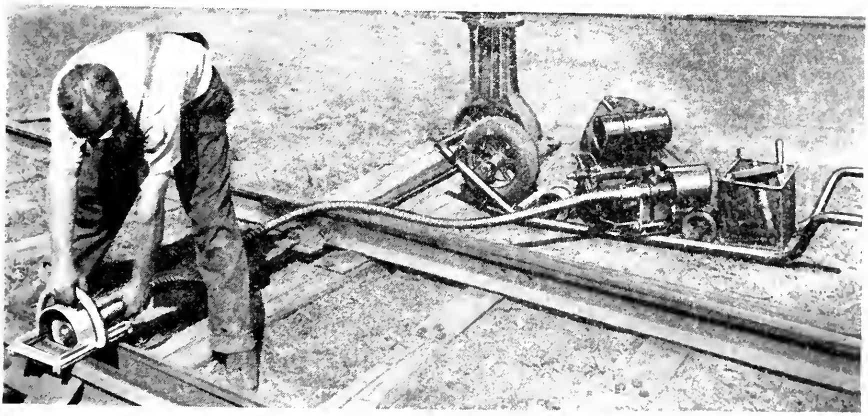
Another inducement accountable for the increased use of pneumatic tired tractor equipment is the lower cost and better quality of pneumatic tires now available. Other reasons for this transition are lower first cost, lighter weight and portability. Such machines, especially those formerly operated on the rails, were not capable of as extensive and diversified use as the pneumatic tired machines, as their usefulness was confined to the distances they could reach from the track. Delays caused by traffic were also encountered by this type of equipment.



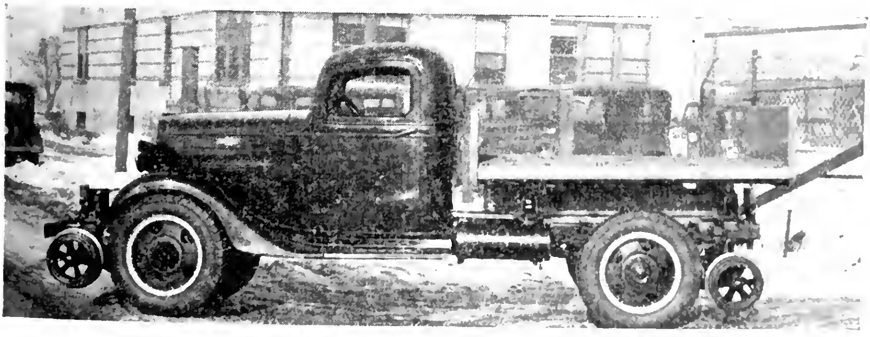
Auto Railer—Traction is Obtained Through Friction of Pneumatic Tires on Rails.



Pneumatic Tired Diesel-Powered Tractor With Road Grader.



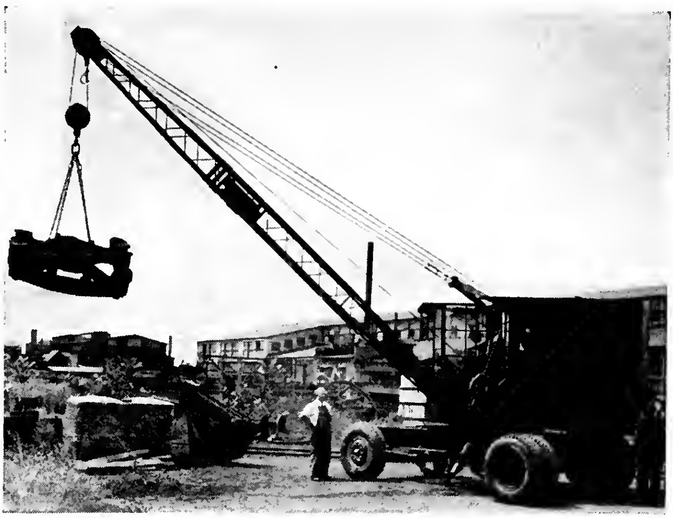
Portable Pneumatic Tired Utility Grinder.



Auto Railer in Position for Offtrack Operation.

As compared with similar crawler-mounted equipment, the pneumatic tired equipment has the advantages, as stated, of lower cost per rated horsepower, lighter weight and greater portability in moving, but they have the disadvantage of having less tractive power.

Other items of pneumatic tired equipment not classified as tractors are being used to advantage by railroads, mostly because they are more portable and easier to handle, thus effecting savings in time. These include rail grinders, compressors, generators, welding outfits, wheel scrapers, carryalls, lawn mowers and wheelbarrows. Others, such as trailers, lift trucks and small cranes used around store rooms, freight houses and roundhouses, not only save time in handling, but also eliminate to a large extent the wear on platforms and floors and reduce damage to lading carried by them.



Crane Mounted on Pneumatic Tired Truck Frame.

While pneumatic tired equipment is being used advantageously by the railroads to a limited extent, it is the consensus of your committee that cooperation between the railroads and the manufacturers in developing units suitable for railroad service will largely increase the use of such equipment.

This report is submitted as information with the recommendation that the subject be continued.

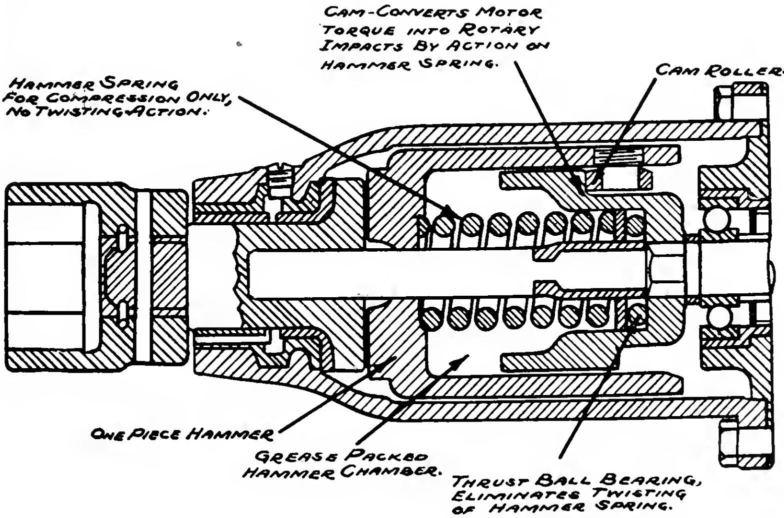
Report on Assignment 8

Impact Wrenches

R. A. Morrison (chairman, subcommittee), G. J. Ermentrout, R. K. Johnson, W. G. Kemmerer, Jack Largent, E. H. Mills, P. G. Petri, J. C. Ryan, Roy Wade.

An impact wrench is a tool in which the twisting strain exerted in turning bolts, nuts, screw taps, etc., is applied in a rapid series of instantaneous blows. Compressed air furnishes the power in the two wrenches of this type on the market at the present time.

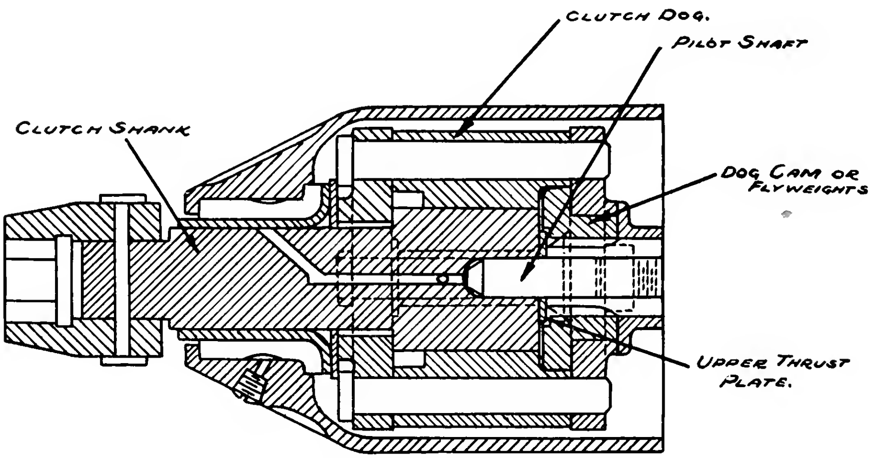
In one type, the impact wrench consists of a "Multi Vane" air motor, cam, hammer spring, hammer anvil (enclosed in hammer case), and chuck, or socket. The specially designed cam converts air motor torque into rotary impacts by action on the hammer spring. These rotary or torsional impacts occur at the rate of 1,200 or more per minute. Impacting begins when resistance to turning reaches a value determined by the strength of the spring and continues until the air is shut off or the torque required to turn the nut falls below this point.



Spring and Cam Type Impact Unit.

In the second type—called Power Vane wrenches—there are no springs, gears, or resilient member in their construction. The impactive effort is built up through a pair of fly weights, similar in operation to a fly-ball governor, except that rotation is interrupted each half revolution, at which point the impact is delivered to the socket through a shank. A slow speed rotor motor is used.

Reversible (applying and removing) and non-reversible (applying only) models can be purchased. Various models for maintenance of way work have an overall length of 16¼ in. to 19¼ in., weighing 13 to 27½ lb., and handle bolts, nuts, etc., ¾ to 1¼ in. in size. However, larger and heavier models are made and used by the mechanical departments of railroads in their boiler and car repair work. On the maintenance of way models 90-lb. air pressure is used at average working speeds, and 40 cu. ft. of air is consumed per minute.



Power Vane Wrench.

These hammers are being used for nut running for fitting up operations on steel structures, on cover-plate jobs, the dismantling and assembling of frogs and switches, driving screw spikes, and track bolting.

The low torque reaction (recoil) on the operator reduces scaffold requirements and makes it possible to use these wrenches safely at overhead or arms-length operations. However, care must be exercised to avoid overstressing, as the only safeguard is the judgment and skill of the operator as to the amount of twisting strain exerted.

This report is submitted as information. It is recommended that the subject be discontinued.

Report on Assignment 9-b

Arc Welding Equipment

Collaborating with Committee 5—Track, and with Electrical Section, Engineering Division

C. E. Morgan (chairman, subcommittee), C. M. Angel, R. M. Baldock, C. L. Fero, L. B. Holt, C. H. R. Howe, R. K. Johnson, E. H. Ness, J. C. Ryan, R. R. Smith.

The report on arc welding will be confined to the mounting of machines for maintenance work. Because of interest in the manner in which arc-welding machines may be adapted to suit the users' purpose, illustrations of each of many types in use today are presented in the hope that they may help someone to solve his particular problems.

Fig. 1 shows a unit with standard skid-mounted track wheels with an adapted undercarriage of motor car axle, wheel, and bearing assembly and with transverse wheels to move the machine in a horizontal plane out to the side of track where the unit comes to rest on its adjustable-leg stand at proper track clearance. It can be used on or off the track depending on frequency of traffic. One advantage is the ease with which the unit may be moved by towing it with a motor car. Some such units have been made self propelling.

Fig. 1.—Skid-Mounted Track Wheels.

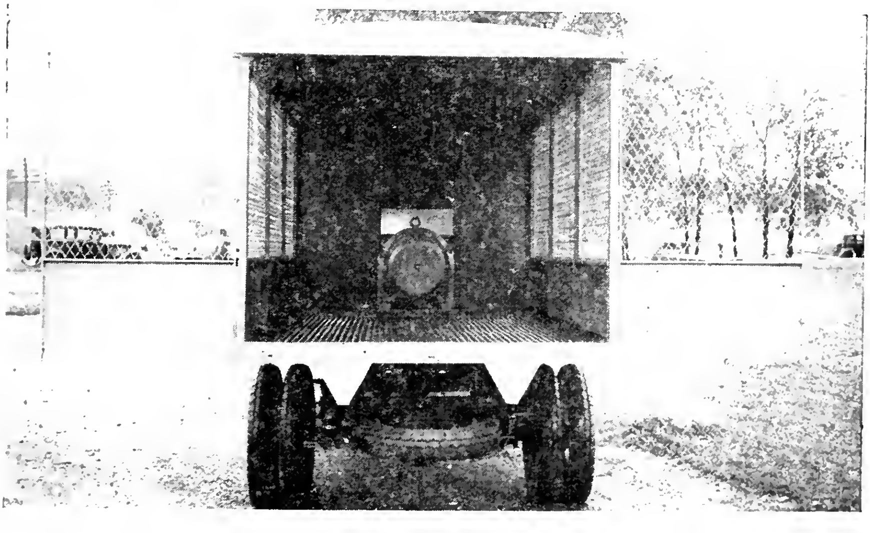


Fig. 2.—Truck-Mounted Power Take-off.

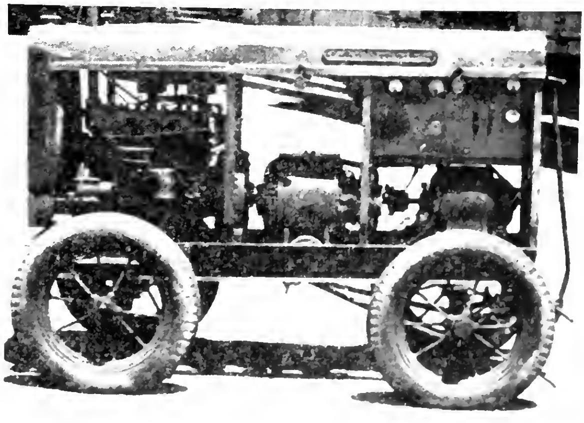


Fig. 3.—Pneumatic Tire Wheel Mounted.

Fig. 4.—Track-Mounted Power Unit.

Fig. 5.—Track-Mounted Power Unit, Removed from Track.

Fig. 2 shows a truck-mounted power take-off. These units make use of the truck engine for power, through a "V" belt drive and a power take-off hooked up from the transmission or drive shaft. They are used for crossing and frog work and offer the welder a means for hauling his grinding machine, welding rods and other materials from one job to another independent of train service. This type of unit, with panel sides or wire mesh sides, enables the welder to keep all his equipment locked up and ready to go. Truck units are used in terminal service or where considerable work is concentrated in a small area.

Standard engine-driven skid units mounted on pneumatic tires, like the one shown in Fig. 3, are used where it is possible to pull a machine around in a yard for frog or crossing work. These units are also used on steel structures such as bridges or buildings. They are widely used by welding shops, contractors and other industries outside of the railroad group.

Fig. 6. — Combination Pneumatic Tired Unit Set on Underslung Push Car.

Fig. 7.—Underslung Push Car.

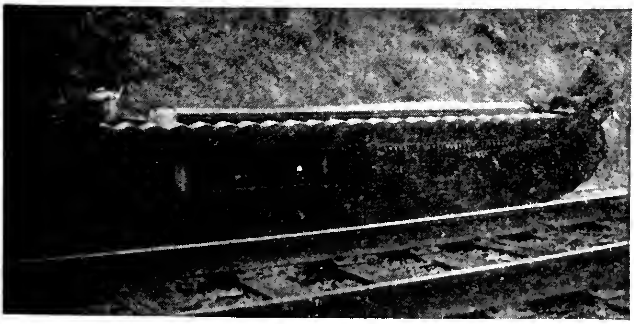


Fig. 8.—Side View of Special Crawler.

Fig. 9.—End View.

Figures 4 and 5 illustrate another type of track-mounted machine with take-off. This unit moves on the rails with flanged wheels and has a device for removing it from the track. The welder is pushed horizontally from the track, leaving the underframe and wheels on the track. Then, after the unit gets to the proper clearance position, the frame with track wheels folds up against the unit itself.

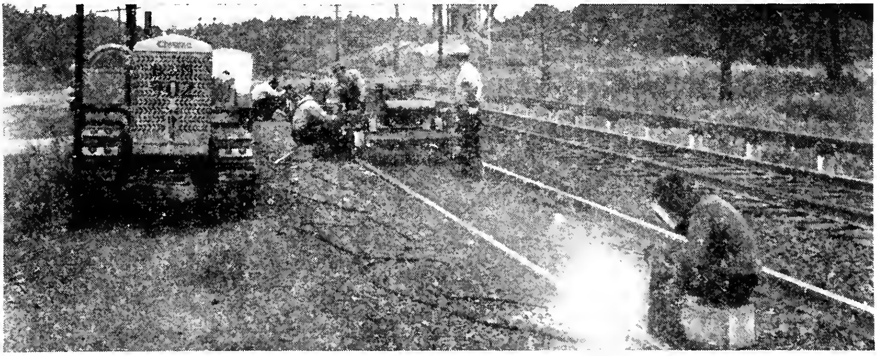


Fig. 10.—Standard Tractor With One Arc.

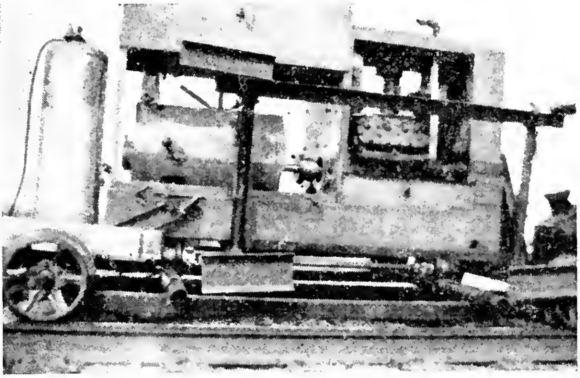


Fig. 11.—Track-Mounted Quick Take-off.

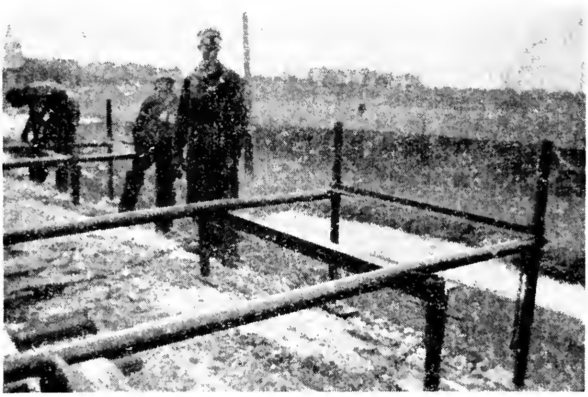


Fig. 12.—Track-Mounted Quick Take-off Set Up on Shoulder.

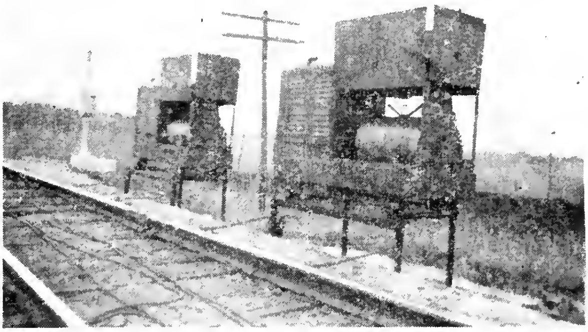


Fig. 13.—Track-Mounted Quick Take-off Machines For Train Passage.

Figures 6 and 7 show a combination pneumatic tired unit and track-mounted underslung push car. This unit has the added flexibility of being readily moved about in yards or at a crossing, out on a highway, on city streets, or along the shoulder off the rails, and can also be readily moved on the rails by being towed by a motor car after it is loaded on its underslung carriage.

Figures 8 and 9 show crawler-mounted self-propelled units. Some machines are in use where traffic is dense and the units must be kept off the track at all times. These units have one or two arcs.

Standard tractors of the crawler type are sometimes used with one or two welding generators mounted on them, as illustrated in Fig. 10. They can be kept off the track except when crossing bridges or trestles.

Figures 11, 12 and 13 illustrate a track-mounted machine with a quick take-off device. These units are mounted on an underslung track-mounted carriage. They rest on large pipes out of which telescope smaller pipes, which in turn rest on still smaller pipes forming the support for an adjustable-height, four-legged stand. These machines are so made that the stand on which they rest when off the track is carried along with the machine when being employed on the track at such work as building up rail ends. These machines can be moved from the track in two minutes, which includes the time for setting up the stand off track at the proper height. All means of fastening are made for quick operation, such as chains and hooks, pointed pins and holes for the legs of the stand. These machines are used on the track for rail-end work, and off the track for work on bridges, crossings and frogs.

Conclusions

It is contended by many that the use to which welding is put in the maintenance work depends on the mobility of the equipment associated with it. To this end, the mountings described have been designed for a broad field of application.

The report is submitted as information and it is recommended that the subject be discontinued.

Report on Assignment 11

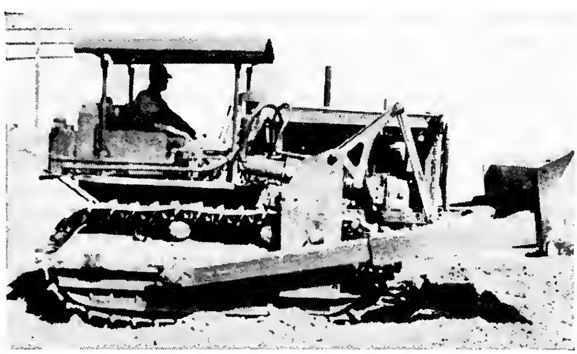
Off-Track Grading Equipment

A. J. Neff (chairman, subcommittee), Edgar Bennett, G. E. Boyd, J. G. Hartley, N. W. Hutchison, R. M. Leeds, T. M. Pittman, F. H. Rothe, F. F. Zavatkay.

The present tendency of railroads to replace expensive on-track equipment with the latest off-track machines indicates that great advantages are being found in the use of crawler machines. Questionnaires sent to 15 railroads revealed that the following off-track equipment had been purchased or was being given serious consideration: 20 Bulldozers; 9 bullgraders (trailbuilders); 9 crawler-mounted loaders with bulldozer blades; 7 crawler-mounted loaders without bulldozer blades; 3 scrapers or carryalls (wheel-mounted); 5 scrapers or carryalls (not wheel-mounted); 35 shovels; 66 draglines; and 18 combination dragline-shovels.

Bulldozers and Bullgraders (Trailbuilders)

As bulldozers, angledozers, bullgraders, and trailbuilders are merely trade names used by all manufacturers of this type of equipment, very little difference in general design of the machines is encountered. The bulldozer has a large, slightly curved rigid blade; the angledozer has a similar type of blade, the difference being that it can be angled to throw material to either side, which is one of the features of the trailbuilder. These machines are operated either by hydraulic or cable control. Cable-operated blades



Hydraulic Operated Trailbuilder on Crawler-Mounted Tractor.

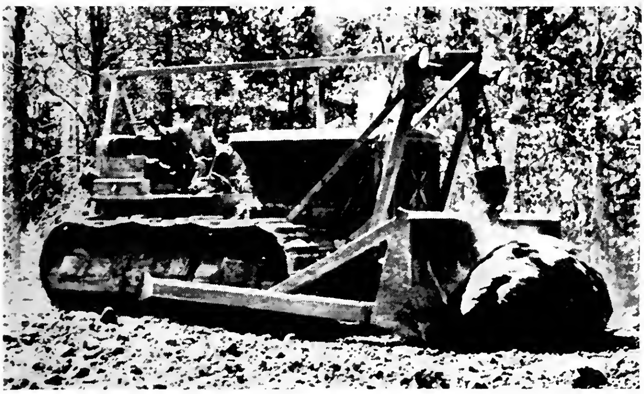
can only be lifted up and must depend on their own weight to force themselves into the material, while hydraulic-operated blades exert both up and down pressure. Bulldozers or angledozers are generally used in leveling off or spreading loose materials.

The trailbuilder and bullgrader, which are identical, have a smaller curved blade with heavy cutting shoes. These blades can be angled to throw material to either side or to cut more on one side than on the other, and are used in harder materials. They are usually operated by hydraulic control, which gives them both up and down pressure.

These machines, being very flexible units, are capable of performing a wide variety of off-track work, such as bank widening, cutting drainage ditches, riprapping, eliminating banks for drainage or vision purposes, filling small bridges, shifting tracks, grading for team tracks, cleaning up stock coal storage piles, dismantling branch lines, leveling off rubbish at dumps, plowing snow, clearing snow and rock slides, spreading cinders and ballast, etc. It is the consensus that machines of this type are invaluable in railroad work, and the savings effected through their use, in many cases, have paid for the original investment during the first few months they were used. The fact that most of the railroads report this type of machine in service 100 percent of their available time is indicative of their adaptability.

Crawler-mounted Front-End Loaders

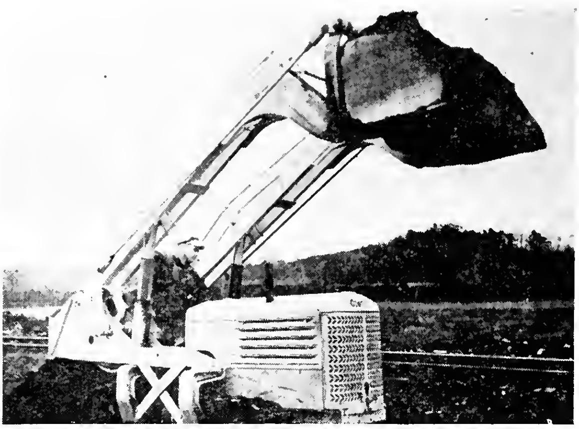
This type of machine is mounted on a 35 or 40-hp. crawler tractor and has either a ⅝ or ¾-cu. yd. bucket mounted on the front end. There are both cable and hydraulic-operated machines, acting on the same principle as a bulldozer, except that the bucket is shoved into the material that is to be moved until it is full and then raised and carried to the place where the material is to be deposited. This type of machine can also be



Straight Bulldozer, Cable Operated.

Cable-Operated Angledozer with Same Type of Blade as Bulldozer.

Front-End Loader—Cable Operated ¾ Cu. Yd. Bucket Mounted on 40-Hp. Crawler Tractor.



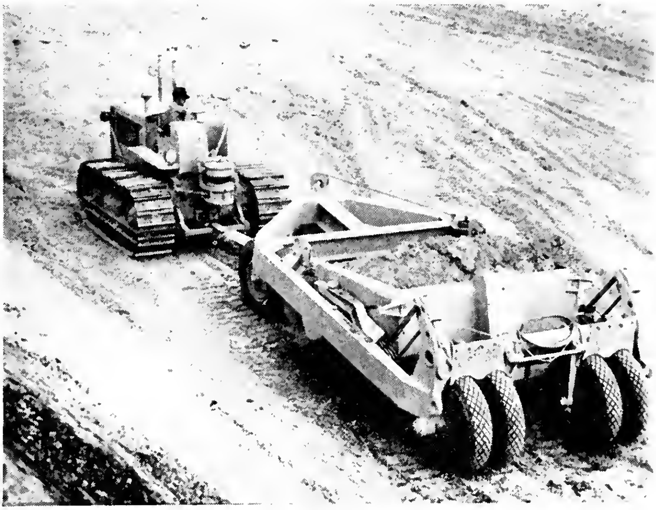
Front-End Loader—Hydraulic Operated ¾-Cu. Yd. Bucket—Mounted on 40-Hp. Crawler.

equipped with bulldozer or angledozer blades instead of the bucket, and the change can be made in a very short time.

These machines, equipped with buckets, have proved very successful in ditching cuts of moderate length, and have been used with a large measure of success in restoring embankments, widening banks, surface ditching, building roads, grading, loading trucks, lining tracks, cleaning up coal storage piles, and plowing and loading snow, and cleaning under bridges. The hydraulic-operated machine shown is more desirable for cleaning under low bridges than the cable-operated machine because of the high frame on the latter.

Certain changes might be desirable in this type of equipment, i.e., the bucket should be as wide as the tread of the crawlers in order that successive cuts can be made in the same ditch, each pass being progressively deeper; hydraulic-operated machines should

Four - Wheel Scraper — Capacity 20 Cu. Yd.



Two-Wheel Scraper—Capacity 4 Cu. Yd., Loading.

have a pump attached to the front of the motor; and smaller and narrower machines should be made for cuts of very close clearance.

Scrapers or Carryalls

So few carryalls are in use on railroads that very little information is available regarding them. Some railroads are towing small scrapers behind their crawler-mounted loaders. Manufacturers of scrapers are offering 3 and 4-cu. yd. scrapers for 35 and 40-hp. tractors and 6 and 8-cu. yd. scrapers for the 60 and 70-hp. machines. Scrapers are also being built up to 45-cu. yd. capacities. Those up to 12-cu. yd. capacity are mostly

Two-Wheel Scraper — Capacity 4 Cu. Yd., Unloading Position.

Crawler-Mounted Shovel—½ Cu. Yd.

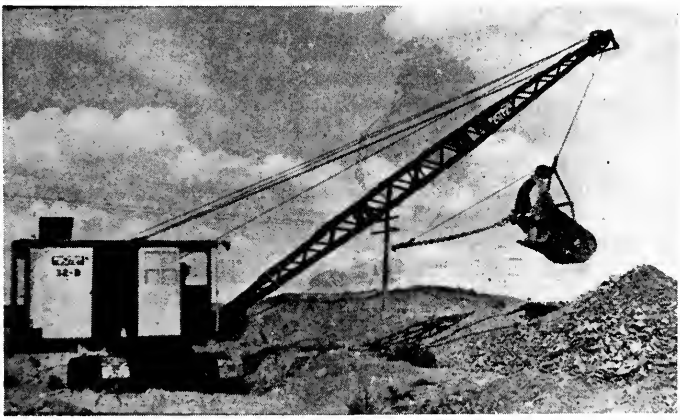
operated by hydraulic action and larger machines by cable. There are two kinds of wheel mountings: two-wheel and four-wheel. The two-wheel machine is more desirable for several reasons; it can be operated in restricted clearances, dumps from the rear, and since most railroads have small tractors, the smaller machines can be operated with the tractors they now have. The four-wheel scrapers are used mostly on large dirt moving jobs, and larger tractors are required in conjunction with their use. Due to their large size, the four-wheel machines cannot be operated where clearance is limited; they also must be dumped from the same end as loaded and the material cannot be dumped at one time, requiring several feet to get rid of the load. Therefore, four-wheel scrapers are recommended for large areas and the two-wheel machines for restricted space. It is expected that this type of machine will be more fully utilized in the near future.

Shovels

Crawler-mounted shovels hold an important place among off-track machines. Few of these machines, however, are purchased as straight shovels. Approximately half of the machines reported on are combination dragline-shovels. The shovel capacities of machines reported on vary from ⅜ to 2 cu. yd. Smaller machines up to ¾-cu. yd. capacity are more desirable for right-of-way work. The large shovels are generally used in gravel pits, or for securing riprap and emergency material. The use of the machines has also proved advantageous in track work on branch lines where traffic is light and side-hill work is involved, ditching on one side and building up shoulder on the other; and in filling bridges; with trucks making line changes; digging ditches; excavating for buildings; cleaning slides, etc.

Draglines

The dragline is one of the most important off-track ditchers due to the wide variety of work which it is capable of performing. These machines are used to advantage in bank widening, replacing shoulders, channel changing, channel cleaning, replacing eroded channel banks, surface ditching, ditching cuts, and loading gravel, cinders, sand, coal,



Crawler-Mounted Dragline—1¼-Cu. Yd. Bucket.

emergency material, etc. For use on the right-of-way where there are many obstructions, machines with buckets of not over ¾-cu. yd. capacity are most popular. Larger sizes, up to 1½-cu. yd. capacities, are used for heavier work. Some railroads are equipping these machines with clamshell buckets and magnets and using them in scrap yards, freight yards, and shops for handling heavy material.

Typical Applications

Some of the machines mentioned in this report are used in conjunction with each other. On one railroad, during a slack season, it was necessary to do 14 miles of ditching in double-track territory, most of which was side-hill work, with some work to be done in cuts. As there was very light traffic through this territory in the daytime, and no passenger trains, it was decided to tie up one track for ten hours and use a shovel and a dragline on the job. The shovel was used to cast the inside material over to the outside where the dragline was ditching, and then the dragline was used to dispose of the material. Where the dragline could not waste the material far enough, a bulldozer was used. The only machine fouling the track was the shovel. Therefore, a foreman and three laborers were stationed with the machines, two men flagging, and the others assisting the shovel over the track and keeping the track clear of rocks and other material that dropped from the shovel on the live track. These men were also used in securing lineups and assisted in clearing up at the finish of work and when starting out at the beginning of the day. This particular job was done at a great saving compared with what it would have cost had on-track ditchers been used.

Another railroad had a job of track shifting to perform, and it was decided to use a bulldozer on the job. The work was accomplished by the machine alone in one day, while ordinarily it would have cost 100 percent more to do the work by other available methods. This job involved leveling the fill on a dump and swinging the track over on the leveled-off portion. The saving effected through the use of the bulldozer on this job can readily be seen. The same railroad encountered a bridge removal job on a side track which was to be done under traffic, involving difficulties of falsework, dismantling, filling in, etc. A bulldozer was used to push the fill under the bridge high enough to permit blocking, the steel was cut apart and removed, and the fill was completed in 30 days less than the estimated time, at an appreciable saving.

Conclusion

The use of off-track grading equipment will expedite work, minimize traffic delays, perform work that it is impossible to do with on-track equipment, and effect gratifying returns on investment costs.

The report is presented as information and it is recommended that the subject be discontinued.

Report of Committee 22—Economics of Railway Labor

G. M. O'Rourke, *Chairman*,
Lem Adams
C. W. Baldridge
E. J. Bayer
F. J. Bishop
W. H. Brameld
E. J. Brown
H. G. Carter
H. A. Cassil
J. I. Catherman
A. B. Chaney
Armstrong Chinn
C. M. Chumley
W. E. Cornell
E. A. Craft
F. L. Guy
C. C. Haire
G. H. Harris
J. G. Hartley
W. E. Heimerdinger
W. H. Hillis
E. T. Howson
H. E. Kirby
T. Z. Krumm
D. A. Kuebler
G. M. Magee
J. B. Martin
J. S. McBride
E. H. McIlheran
L. L. Adams, *Vice-Chairman*,
J. M. Miller
F. R. Paisley
J. A. Parant
A. E. Perlman
W. G. Powrie
F. S. Schwinn
H. M. Stout
R. R. Strother
W. H. Vance
J. C. Wallace
Edward Wise, Jr.
W. H. Woodbury
C. R. Wright

Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

No report.

2. Analysis of operations of railways that have made marked progress in the reduction of labor required in maintenance of way work.

Progress report, embracing studies of the Central of Georgia Railway "back-to-back flat method" of track maintenance. Submitted as information .... page 214

3. The relative economy of combined vs. separate bridge and building gangs.

Final report—with recommendations for inclusion in the Manual .... page 217

4. Labor economies resulting from improvements in drainage practices.

Final report—submitted as information .... page 219

5. Review and revise factors previously established for equating track values for labor distribution.

No report.

6. Labor economies possible through the use of highway motor vehicles for maintenance forces.

No report.

7. Added labor economies resulting from use of off-track maintenance equipment.

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8. Labor economies resulting from periodic spot welding of rail ends as compared with less frequent out-of-face welding.

No report.

9. Labor economies to be derived from keeping vegetation out of ballast.

No report.

Special—Mechanization in Maintenance of Way Department—Testimony of Carriers Special Committee before the Railroad Carrier Industry Committee.

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The Committee on Economics of Railway Labor,
G. M. O'Rourke, *Chairman*.

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* Page number refers to page on which this report appeared in Bulletin 419—September–October, 1940, and to the page in which it will appear in the Monograph Section of the Proceedings for 1941.

Bulletin 421, December, 1940.

Report on Assignment 2

Analysis of Operations of Railways That Have Made Marked Progress in the Reduction of Labor Required in Maintenance of Way Work

H. A. Cassil (chairman, subcommittee), Lem Adams, E. J. Bayer, F. J. Bishop, E. J. Brown, H. G. Carter, C. C. Haire, W. E. Heimerdinger, E. T. Howson, H. E. Kirby, D. A. Kuebler, G. M. Magee, J. B. Martin, J. S. McBride, F. R. Paisley, J. A. Parant, F. S. Schwinn, W. H. Vance.

Certain changes in methods of track maintenance that were put into effect on the Central of Georgia Railway in 1932 have been followed by a marked reduction in the labor required. This subcommittee has, therefore, examined the methods now in effect on that road and submits its report on their nature, advantages and disadvantages, and their applicability to other railroads or portions of railroads.

In order to permit the members of the committee, and particularly members of the subcommittee, to observe conditions at first hand and talk with maintenance of way officers and employees, a meeting was held at Macon, Ga., on April 23, 1940, in connection with which a motor car inspection was made of the Central of Georgia tracks between Atlanta, Ga., and Macon and between Macon and Birmingham, Ala., a total distance of 388 miles.

The Central of Georgia forms a network which covers a large part of Georgia and Alabama, the principal freight traffic lines extending from Birmingham to Macon and thence easterly to Savannah, Ga., and northerly to Atlanta. Freight traffic density on these lines averages between 1,300,000 and 2,400,000 net tons per year. Lines with less traffic reach important terminals at Chattanooga, Tenn., Albany, Ga., and Augusta, while branches with still lighter traffic connect with other points. A considerable part of the passenger traffic between Florida and the middle north moves over its rails. The mileage of road maintained in 1939 was 1,861.

On practically the entire line, stable roadbed conditions exist and drainage is excellent. Standard widths of roadbed are 18 ft. for principal lines, 17 ft. for secondary lines and 16 ft. for branches. The ballast is Birmingham slag, with bank run gravel and cinders on the less important lines. Ties are creosoted pine except for some untreated cypress, and are all produced on line. Ties are bored, adzed and treated at the company's treating plant at Macon. Tie plates are extensively used. All new rail is 112 lb. and is now control-cooled and end hardened at the mill.

Prior to 1932, the practice on this road was to require each section gang to give one-fourth its track a full out-of-face lift each year, making necessary tie renewals and gaging, lining, etc. The remainder of each section received but little attention, except where conditions demanded immediate repairs. The track was patrolled daily.

The practice begun in 1932 and still in effect, sometimes known as the "flat work" system, contemplates a procedure in which the section gangs work over all tracks in an orderly sequence once every 12 to 18 months. Working back to back, that is, two gangs starting at the line between their sections and working away from each other, each gang begins early in the year and goes over its entire section, doing all of the following work where a raise on new ballast is not involved:

Replacing all ties that will not last another year
Squaring up and spacing crossties
Setting up and replacing missing rail anchors

Gaging, with replacement of corroded tie plates
Tapping down spikes and replacing bad spikes
Smoothing and cross-leveling out-of-face
Correcting irregularities in line
Tightening and replacing bolts and oiling joint bars

New ballast is applied in track surfaced out-of-face by extra gangs where new 112-lb. rail is laid, or where the ballast has so deteriorated that satisfactory results cannot be obtained by the "flat work" of the section gangs.

Section gangs consist of a foreman and four laborers. When business increased during 1937 the gangs were raised to six men per crew, commencing with April. If traffic again becomes as heavy the number of laborers will, very probably, be increased to six men. This minimum force is employed the year round and devotes ten months of each year to track repairs and two months to mowing and burning weeds and brush and cleaning ditches. Generally the work is started in January and completed on schedule unless too much emergency repair work interferes.

The full gang is employed five days per week. In addition, on Saturday the foreman and two men patrol the section, inspect switches and police the property. Daily track patrol is not required of the section foreman, except in the event of heavy rains or other unusual situations. Road supervisors cover their districts three or four times each week, including one trip on a locomotive, and direct section foremen when to discontinue the regular work temporarily to make needed repairs.

Comparison of Labor Employed in 1929 and 1939

	1929	*1939*	*Decrease*	*Percent Decrease*
Miles main line maintained	1,926	1,861	65	3
Average length of sections	7.82*	17.18*	9.36**	119**
Number of section foremen	246	108	138	56
Number of B&B foremen	23	15	8	35
Number of extra gang foremen	6	5	1	17
Number of section laborers	1,150	600	550	49
Number of extra gang laborers	126	100	26	21
Number of B&B laborers	94	76	18	19
Number of B&B carpenters	80	43	37	46

* Miles. ** Increase.

Five extra gangs are employed on the Central of Georgia, consisting of a foreman, an assistant foreman and 20 men. One gang is worked on the Savannah division and two each on the Macon and the Columbus divisions. They lay rail, augmented by section gangs; raise and surface track out-of-face and assist section gangs that fail to complete flat work repairs on their entire sections. They are, as a rule, assigned to primary main line territory of 710 miles.

In switching yards, "sweepers" are employed to keep the grounds clean, pick up scrap, oil switches, etc. These men work under the yard section foreman but do not work with the track gangs and are not included in the track labor allowances. Each has a wheelbarrow, a scoop and a heavy rattan push broom.

The section gangs of experienced trackmen, familiar with the system that has now been in effect since 1931, and relieved of daily track patrol, the policing of yard tracks and switching leads, and the general out-of-face work done by the 20-men extra gangs, produce thoroughly satisfactory results. The progress is greatly expedited by the fact that a uniform force is worked and that the working season extends throughout the year.

Monthly reports are made by foremen, supervisors and division engineers showing the miles completed for the current month and to date.

A comparison of the labor employed in 1929 and 1939 is shown in the table.

Computations based on returns to the Interstate Commerce Commission show a 51 percent decrease from 1929 to 1939 in man-hours of sectionmen time per equated track mile, although freight traffic density was only 22 percent less in 1939 than in 1929.

It is obvious that only a part of this reduction in labor can be ascribed to the change in method. A considerable part of it is due to the same causes which have resulted in reducing maintenance labor expense on most railroads; namely, curtailment or abandonment, because of reduced revenue, of work formerly considered necessary; and greater efficiency of labor. It is the experience of this road that the "flat work" method now followed is better adapted to its conditions than the "cycle" method formerly in vogue.

The method now used is not novel, but with some modifications, is in effect on a large share of the railroad mileage of this country, especially on tracks which carry medium and light traffic. The back-to-back feature is not essential, although widely used because it cuts in half the number of intervals of unworked track. The conditions which favor the use of this method are:

1. Medium to light traffic
2. Stable roadbed, with good drainage and few soft spots, slides, or other features that require frequent attention
3. Fairly uniform tie renewals
4. No daily patrol by section gangs

This method has some important advantages where conditions favor its use, chief among which are the following:

1. Less time lost in moving from place to place
2. Better control of labor output
3. More uniform tie conditions
4. Maintenance of more uniform track conditions
5. Permits closer check and comparison of work done on different sections, thus strengthening the competitive spirit

A disadvantage of this method, even where conditions favor its use, is that it does not permit tie renewals to be made early in the season and, in general, does not permit the doing of the more important things first. This objection has less weight where there is a long working season.

It is not adapted for a track where heavy traffic necessitates frequent light surfacing, where attention must frequently be given to chronic places of trouble, or where forces are so small that attention can only be given to bad conditions as they arise.

Conclusions

1. The "flat work" method employed in track maintenance on the Central of Georgia merits consideration on lines of medium to light traffic, with fairly uniform tie renewals and with a stable roadbed having few soft spots or other conditions requiring frequent and special attention.

2. On such lines it reduces the amount of time lost in moving forces from place to place, permits better control of the labor output, brings about the more uniform distribution of tie renewals, creates more uniform track conditions and permits comparisons to be made of the work done on different sections, thereby strengthening the competitive spirit among the forces.

3. This method is not adapted to tracks where heavy traffic necessitates frequent light surfacing, where frequent attention must be given to places of chronic and recurring trouble or where the forces are so small as to require their constant attention to one trouble spot after another.

Report on Assignment 3

The Relative Economy of Combined vs. Separate Bridge and Building Gangs

C. M. Chumley (chairman, subcommittee), W. H. Brameld, H. A. Cassil, J. I. Catherman, A. B. Chaney, Armstrong Chinn, W. E. Cornell, E. A. Craft, T. Z. Krumm, E. H. McIlheran, F. R. Paisley, A. E. Perlman, H. M. Stout, R. R. Strother, W. H. Vance, J. C. Wallace, C. R. Wright.

In making a study of this subject, the committee's interpretation is that "combined" gangs handle renewal and maintenance work on bridges and culverts (except steel bridges), buildings and miscellaneous structures (except those of considerable importance, probably of steel, brick or stone construction) over an assigned territory, or as directed; while "separate" gangs comprise bridge gangs, which handle only bridge and culvert work and other miscellaneous heavy work, as directed, carpenter gangs, which do only building and lighter miscellaneous work, and paint gangs, which do only painting, both bridge and building.

In the combined gangs, your committee excludes those which work on steel bridges for the reason that most roads prefer to handle this work with special or system gangs, provided with special tools and roadway machinery. For similar reasons, the more important building work is excluded or left optional, since it is felt that an ordinary gang will not be equipped to erect structures larger than the average station, office building, or shop building. However, the combined gang or the separate building gang, should be able to maintain such structures economically.

In order to determine the prevailing practice, a questionnaire was forwarded to 53 representative railroads throughout the United States and Canada, 38 of which replied, furnishing valuable information on the subject. These 38 roads have a combined mileage of approximately 232,202, with 3,303 miles of steel and masonry bridges, 1,500 miles of timber bridges, and with approximately 80 percent of the buildings and miscellaneous structures of wood. Twenty-seven of these roads, with 85 percent of the total mileage, 95 percent of the steel and masonry bridges, and 80 percent of the timber bridges, use combined gangs. Eleven roads, with 15 percent of the total mileage, 5 percent of the steel and masonry bridges, and 20 percent of the timber bridges, use separate gangs.

It was found that some of the roads, which use combined gangs as a general practice, have separate gangs for building work in their larger terminals. Other roads, which use combined gangs for bridge and building maintenance, use separate gangs for painting, while several roads, which use separate gangs for bridge and building maintenance, combine the painting with the building gangs.

Some of the economies claimed for the combined gangs are:

Reduction in number of foremen

Fewer outfit cars

Reduced investment in motor cars, tools and other roadway machinery

More economical distribution of available force, with much less loss of time in movement of gangs

Training bridge and building men in all phases of the work in that department, resulting in all employees being available and qualified to render efficient service on any assignment

Simplifies handling seniority problems, in that all bridge and building employees in the various classifications appear on one roster so that they can be assigned according to their seniority without regard to whether they are bridge carpenters, helpers, etc., or building carpenters, helpers, etc.

Affords more continuous employment, thereby developing more highly trained and efficient men

Shortens the designated maintenance district, permitting closer inspection of bridges and buildings, producing greater efficiency through better planning of work

Facilitates handling of materials and supplies

Condenses supervision

Some of the advantages or economies claimed for separate gangs are:

Opportunity for working fewer men in gangs assigned to building or other light work

Improvement in efficiency by being able to select foremen and men more highly trained in the separate classes of work, thereby increasing production and improving quality

The ability to use tools and roadway machinery more continuously, enables a road to effect the economies resulting from a larger investment in such tools and equipment

Much additional argument can be produced for both combined and separate gangs, but after considerable study and careful analysis of the subject, the committee arrives at the following conclusion, supported by appropriate definitions.

RELATIVE ECONOMY OF COMBINED AND SEPARATE GANGS

The relative economy of combined or separate gangs for bridge and building work depends upon the conditions prevailing on individual railroads and, in many cases, on grand divisions or districts of a single railroad. For railroads in general, with half or more of their bridges of timber construction and with a large proportion of their buildings of frame construction, combined gangs are preferable to separate gangs. See definitions for Gang—Combined, and Gang—Separate, in the Glossary.

Gang—Combined.—One handling renewal and maintenance work on bridges (other than those of steel) and culverts, buildings and miscellaneous structures (other than those of considerable importance and commonly of steel, brick or stone construction) over an assigned territory, or as directed.

—Separate.—One handling only bridge and culvert work and other miscellaneous heavy work as directed; or handling only building and lighter miscellaneous work; or handling only painting, both bridge and building, or either.

The committee recommends that the above conclusions be adopted and published in Chapter 22 of the Manual, following the matter on programming of bridge and building work, and that the definitions be adopted and published in the Glossary.

Report on Assignment 4

Labor Economies Resulting From Improvements in Drainage Practices

E. H. McIlheran (chairman, subcommittee), L. L. Adams, Lem Adams, C. W. Baldridge, F. J. Bishop, J. I. Catherman, A. B. Chaney, C. M. Chumley, W. E. Cornell, E. T. Howson, T. Z. Krumm, D. A. Kuebler, J. B. Martin, A. E. Perlman, F. S. Schwinn, R. R. Strother, W. H. Vance, W. H. Woodbury.

Your committee refers to pages 1–43 to 1–63, inclusive, of the Manual for general descriptions of and information about the various types of drainage, including intercepting ditches for cuts and fills, side ditches at the foot of slopes, tile pipe and perforated corrugated pipe for draining road beds, French or rock drains, and other special drainage practices and will not repeat these descriptions in this report.

Many reports have been made to the Association indicating the necessity for good roadway drainage and the benefits to be derived therefrom, some of which are found in the following volumes of the Proceedings: Vol. 40, p. 346; Vol. 39, pp. 320–562–565; Vol. 38, pp. 173–357; Vol. 37, p. 141; Vol. 36, p. 1092; Vol. 35, p. 348; Vol. 34, p. 132; Vol. 33, p. 304–330–377; and Vol. 32, p. 169. Vol. 31, p. 601, gives references to studies made in former years.

These reports indicate savings in labor for roadway maintenance and for track laying and surfacing, due to stabilization of the roadbed by improved drainage, as well as reductions in ballast requirements, in damage to rail and other track materials, and in damage to rolling stock and lading, and the elimination of train delays due to slow orders.

Your committee has attempted to determine the monetary saving in labor resulting from improvement in drainage practices, and mailed inquiries to 52 railroads, operating about 208,000 miles of road. We received replies from 30 railroads, operating 152,690 miles of road, but of these only 20 furnished any figures, although practically every officer replying stated that economies resulted from improvement in drainage. The replies received from railroads which furnished some figures are shown in the table.

Number of Railroads Reporting	Type of Installation	Feet of Track Drained	Cost of Installation	Annual Saving in Labor: Amount	Annual Saving in Labor: Percent of Cost	Date of Installation
	Sub-Surface Drainage					
11	Tile pipe in cuts ..	487,460	$553,114	$96,974	17.6	1912–1939
1	Tile pipe in fills ..	1,475	5,719	372	6.5	1929
8	Perforated metal pipe in cuts	18,618	45,584	9,019	20.0	1927–1939
14	Perforated metal pipe in fills	93,083	238,109	37,063	15.6	1928–1940
10	French or rock drains	155,480	225,031	38,771	17.2	1923–1939
	Surface Drainage					
5	Intercepting ditches	114,598	$ 53,696	$23,746	44.2	1890–1939
2	Grading the right of way	50,600	3,902	6,104	156.0	1937–1939

Tile Drains

An example of the economies secured from tile drain pipe is afforded by an installation in a cut on the main line of the St. Louis Southwestern Railway a short distance south of Pine Bluff, Ark., on what is known as Sorrells hill. At this location the track is on a one percent gradient for 1½ miles and is then practically level for a mile across four small ridges. There is one cut 3,500 ft. long half way up the one-percent grade, another cut 1,000 ft. long at the summit of the grade, and four cuts each 1,000 ft. long in the next mile. The distance from the beginning of the first soft spot to the end of the last one is 2.2 miles.

The material in these cuts is clay that has very little supporting quality when wet, and these cuts were saturated at all times. The track was ballasted with gravel, but it could not be held to line and surface, and although either section or extra gangs were employed on the track in these cuts practically every day, it was impossible to keep it in a condition that would preclude derailments.

In 1920, tile drains were installed in all six of these cuts, a total of 8,349 ft. of track being drained by installing 8-in. longitudinal drains on both sides of the track and 6-in. laterals at intervals of 16½ ft. along the track, one lateral draining into the longitudinal pipe on one side of the track and the next one into the pipe on the opposite side. The tile drains were installed according to the general instructions shown in Proceedings Vol. 22, page 719, Exhibit 1½, for the drainage of soft spots by tile on both sides of the track. The total cost of the installation was $15,162.17.

As soon as the tile was installed, water began flowing from the drains, the condition of the track improved, and within 12 months the roadbed became solid and all trouble from irregular surface and line from this section of road disappeared. Permanent slow orders of 10 or 15 miles per hour were removed and trains now operate at a speed of 60 miles per hour. The tile in the long cut on the one-percent grade and in three of the other cuts is still functioning, but in two of the cuts where the tiles were not laid on a steep grade some indication of heaving developed about three years ago and some poles were driven to correct the condition.

It is estimated there was a reduction of three track laborers, which at present rates of pay amounts to $2,620 per annum, in addition to the large savings due to increases in train speeds and reductions in damage to rolling stock and lading.

Perforated Corrugated Metal Pipe Drain in Fill

An example of the economies secured from the installation of perforated galvanized metal drain pipe is afforded in a fill on the Illinois Central Railroad on the north approach to the crossing of the Bayou De Chien drainage canal about 8 miles north of Fulton, Ky., on the Bluford district. This fill was constructed in 1925 with material secured from adjacent cuts, which, when excavated dry, seemed to be satisfactory for embankment construction, but which after being placed and becoming wet, had very little supporting power and began to slide. After the line was placed in operation, the slides were filled with earth and cinders, but a section about 1,000 ft. long with an average height of 50 ft. continued to cause trouble. Due to a slide in 1928, it was necessary to drive 219 ft. of open-deck trestle across this fill in order to maintain traffic. By 1934 this trestle had been extended to a total of 466 ft. because of additional slides. When it became necessary in 1939 to make heavy repairs to the portion of the trestle first constructed, an investigation was made to determine the exact condition of the fill and ascertain if it could be stabilized. This investigation, which consisted largely of test borings with a two-inch auger, revealed a large number of water pockets in the deposits of cinders and gravel which had been unloaded to restore the embankment.

This fill was drained with 8-in. perforated, corrugated, asphalt-coated iron pipe. Thirty-one laterals were placed at intervals of not to exceed 50 ft. and were from 58 ft. to 207 ft. long, extending into the fill from both sides to the bottom of the water pockets. From the end of each lateral pipe in the water pockets a perforated riser extended upward to the surface of the fill. In addition, four short laterals were placed where water pockets existed directly beneath the track. When some of the water pockets were tapped, as much as 100 gal. per min. flowed from the pipe for several days before the pockets were completely drained.

Altogether, 4,000 lin. ft. of pipe was installed in the fill, in the 31 main laterals and risers and 4 short laterals. Since the completion of the work, the fill has apparently stabilized. The total cost of this job was about $13,500, and the estimated annual saving is $2,250, consisting of $1,000 for labor patrolling track, $500 for work trains unloading material at slides, $500 for labor unloading material and surfacing, and $250 for maintenance of the trestle.

Conclusion

The study made by this subcommittee substantiates the conclusions reached by previous committees of this Association that (a) adequate drainage of the roadbed is essential to the economical maintenance of track, (b) that economies can be effected by the various methods reported on herewith, and (c) that the particular type of installation best adapted to any location varies with the local conditions existing at the specific point.

This report is submitted as information.

Report on Assignment 7

Added Labor Economies Resulting from Use of Off-Track Maintenance Equipment

Armstrong Chinn (chairman, subcommittee), L. L. Adams, Lem Adams, E. J. Bayer, W. H. Brameld, E. J. Brown, H. A. Cassil, F. L. Guy, W. H. Hillis, E. T. Howson, H. E. Kirby, T. Z. Krumm, G. M. Magee, J. S. McBride, J. M. Miller, A. E. Perlman, W. H. Woodbury.

The assignment, as stated, implies that labor economies result from the use of maintenance equipment, consequently, the purpose of this report is to point out the additional economies that may be expected when work is done with off-track equipment. When we try to determine the economies or savings that may be expected from the use of a certain type of equipment we must, of necessity, compare it with something else, such as another type of equipment, another method of doing the work or other conditions affecting labor or material before we can arrive at any sort of an answer. For instance, the labor cost of renewing ballast is reduced when the life of the ballast is extended by cleaning it, but as a rule the labor cost of cleaning it will be less with off-track equipment than with rail-bound equipment requiring expensive work train service. Also, recent interpretations of certain labor agreements have so increased the cost of operating some classes of rail-bound maintenance equipment as to make its use prohibitive. This is a trend that is being met, to some extent, by the development of off-track equipment.

Generally speaking, the development of off-track maintenance equipment has been brought about by the following factors:

(a) Today main line tracks must be kept clear for the fast and exacting schedules that are being run on most railroads in both passenger and freight service, and maintenance of way gangs are being forced to conduct their work in a way that will not interfere materially with the operation of trains.

(b) Working agreements with certain classes of employees make it desirable to keep work equipment off the rails.

(c) More hours of productive work can be secured from off-track equipment than rail-bound equipment as there is little or no time lost in clearing trains.

(d) The proximity of good highways to many railroads makes it easy and economical to move men, some classes of materials and certain types of off-track equipment quickly with trucks running on the highways instead of with motor cars running on the rails. This applies particularly to specialized gangs, such as in the water service department and to men, materials and equipment needed for emergency work.

(e) Off-track equipment has the ability to get to places and to do work that cannot be reached with rail-bound equipment.

A partial list of track maintenance equipment divided between rail-bound equipment, off-track equipment and equipment which is used on the rails but can be set off to clear traffic is shown in the table.

Where air compressors and electric generators are mentioned in the list, it is understood that the numerous small tools that can be operated by these power sources are included.

As will be noted from the list, a wide variety of off-track equipment is now available and it is expected that this list will grow as its advantages are recognized and additional equipment is developed for new uses.

With the exception of some recently developed earth-moving equipment, rail-bound equipment is, as a rule, heavier and has more power than off-track equipment, and as a result will do more work in a given period of time, but because of traffic interruptions, work train and flagging expenses, and the additional men in the operating crew required by recent interpretations of certain labor agreements, the unit costs are usually higher. As these extra costs are increased, additional incentive will be given for further development and use of off-track equipment. The costs of train slow-ups and delays caused by rail-bound equipment are seldom considered when figuring the unit costs of work done by it, but they are there and at times are considerable.

The development of the crawler tread has probably done more than any other one thing to release work equipment from the rails and now numerous types of earth-moving equipment, mounted on crawler treads, are replacing car-mounted shovels and car-top ditchers. The most popular of these is the combined crawler shovel and drag-line. Machines of this type have moved earth for bank widening at costs ranging from 6 to 12 cents per cubic yard, compared with 15 to 45 cents per cubic yard for car-top ditchers. Most of this saving is in the labor, as the off-track equipment can be operated with smaller crews and without the service of a work train and work train crew.

Labor costs have been reduced by crawler-mounted and portable air compressors and electric generators used for operating tamping tools as these power units can move along with the work without the labor cost and lost time inherent in moving long pipe and power lines.

The committee has been unable to find any railroads that have kept comparative cost data showing in dollars and cents the additional labor savings that will be realized

Classification of Maintenance Equipment

Rail-Bound Equipment	Off-Track Equipment	Equipment Used on the Rails But Which Can Be Set Off the Track
1. Power shovels	1. Crawler shovels	1. Power ballaster
2. Locomotive ditchers	2. Crawler draglines	2. Power cribber
3. Spreader ditchers	3. Crawler bulldozers	3. Ballast scarifier
4. Car-top ditchers	4. Crawler tractors with front end loaders	4. Power weed and ballast discers
5. Locomotive cranes	5. Crawler-pulled carry-all scrapers	5. Power jacks
6. Large ballast cleaners	6. Crawler cranes with pile driving leads	6. Power track shifters
7. Ballast scarifiers on AAR trucks	7. Crawler cranes	7. Power tie adzers
8. Ballast cars	8. Trucks	8. Power tie cutters
9. Dump cars	9. Truck-mounted crane	9. Power tie borers
10. Pile drivers	10. Truck-mounted air compressors	10. Tie pullers
11. Large rail and joint oilers	11. Truck-mounted generators	11. Power spike pullers
12. Roadbed oilers	12. Truck-mounted earth drill	12. Air compressors
13. Weed burners on AAR trucks	13. Portable air compressors	13. Electric generators
14. Chemical weed sprayers on AAR trucks	14. Portable generators	14. Power and hand rail layers
15. Detector cars	15. Portable wheel-mounted weed burners	15. Power cranes and rail layers
16. Snow plows	16. Portable chemical weed sprayers	16. Power rail saws
	17. Portable oil sprayers	17. Power and hand rail drills
	18. Power weed mowers	18. Power wrenches
	19. Power ballast cleaners	19. Rail expanders
	20. Self-contained gasoline ballast tampers	20. Rail grinders
	21. Oxy-acetylene welding and cutting equipment	21. Oxy-acetylene rail end hardening machine
	22. Rail switch and frog grinders	22. Rail and joint oilers
	23. Tie spacers	23. Weed mowers
	24. Track liners	24. Motor cars, push cars and trailers
		25. Auto railers
		26. Trackbarrows
		27. Monocars

from the use of off-track equipment, and is therefore unable to give any comparative figures; however, the committee finds that the use of off-track equipment, as compared with rail-bound equipment, should make possible labor economies as follows:

1. Greater production per man-hour, as little or no time will be lost clearing trains.

2. A substantial reduction in flagging expense, as very little, if any, will be required.

3. Elimination of work train crew expense.

4. Elimination of additional and unnecessary men required on rail-bound equipment by recent labor board decisions.

5. A reduction in the cost of doing work that could not be reached by rail-bound equipment and therefore had to be contracted or done by less efficient methods.

6. A marked saving in time, on certain classes of work, by moving men, materials and equipment in trucks on highways instead of by motor cars on the rails or, for longer distances, by train, with resulting lost and dead time on account of infrequent train service.

It is pointed out, however, that in considering the labor economies resulting from the use of off-track equipment one must not lose sight of the fact that rail-bound equipment has its place and is not likely to be displaced for certain work.

This report is submitted as information.

Report of Committee 6—Buildings

L. H. Laffoley, *Chairman,*
C. M. Angel
G. A. Belden
E. Christiansen
H. M. Church
H. G. Dalton
A. G. Dorland
W. T. Dorrance
Hugo Filippi
J. P. Gallagher
W. G. Harding
A. T. Hawk
E. G. Hewson
C. D. Horton
N. D. Howard
A. C. Irwin
F. R. Judd
L. P. Kimball
H. C. Lorenz
E. K. Mentzer
H. A. Pasman
A. C. Copland, *Vice-Chairman,*
G. A. Rodman
C. H. Sandberg
C. P. Schantz
E. W. Scripture, Jr.
L. W. Smith
A. L. Sparks
A. B. Stone
O. G. Wilbur

Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

No report.

2. Preparation of specifications for railway buildings.

No report.

3. Requirements and design of garage buildings for railway service.

Final report—submitted as information below.

4. Railroad warehouse requirements for handling quick frozen products.

No report.

5. Methods of determining the protective value of paints.

Final report—submitted as information .... page 227

6. Refrigerator equipment for cold storage houses and rooms, collaborating with Committee 1—Power Supply, Electrical Section, Engineering Division, AAR.

No report.

The Committee on Buildings,
L. H. Laffoley, *Chairman.*

Report on Assignment 3

Requirements and Design of Garage Buildings for Railway Service

J. P. Gallagher (chairman, subcommittee), W. G. Harding, N. D. Howard, A. C. Irwin, H. C. Lorenz, H. A. Pasman, G. A. Rodman, O. G. Wilbur.

General

Transportation of passengers over the highways in buses operated by railways, and the movement of express and freight by automobile equipment, have so expanded during recent years that it has become necessary to develop garages at terminals and large way station points, where buses, trucks and other equipment can not only be properly stored and handled, but running repairs, general overhauling and maintenance can be done under economical and modern methods. In the development of garages, facilities for the operating personnel and other employees should also be carefully studied and analyzed.

In planning these facilities consideration must be given to the location, design, construction and arrangement, consistent with the importance of the contemplated improvement, the size of the initial development, and probable future increase in various operations in the plant and the storage requirements.

Bulletin 421, December, 1940.

Location

Garages, whether small or large, should be isolated from other structures in order to reduce to a minimum the hazard of exposure from fire. The introduction of garage occupancies into portions of buildings used as storehouses or shops, or other railroad facilities, is not recommended. Large bus and truck garages should be located as near the passenger, freight or express facilities or terminal as possible, so as to reduce the expense of non-productive operation between the garage and the operating terminal.

Design

Garage facilities for the storage and maintenance of bus or trucking equipment, should be of simple but substantial design. The introduction of columns into the building should be reduced to a minimum, where possible, consistent with the type of structure selected. This is particularly recommended in the live and dead storage areas where the bus or trucking equipment is stored or handled.

In terminal units, the entire layout of offices, shops and storage area should be placed on one floor. The dead storage area should preferably be confined in the rear of the building, and should be of adequate size to meet the demands of the terminal, and be cut off from the remainder of the facilities by fire walls with openings large enough to handle the equipment. The live storage areas should be equipped with wash racks, and oiling and greasing pits or elevating racks near the entrance. Pits or elevating racks for inspection and repair, should be located at the rear, or where they will not interfere with the movement of vehicles, should the cars require layover for light or heavy repairs. Permanent lighting and outlets for portable head lights should be provided. Oil and grease traps should be installed in drainage lines where sinks, floor drains or other plumbing fixtures are used to dispose of oils, grease and volatile materials.

Rooms cut off by standard fire walls should be constructed around the live storage areas for auxiliary facilities such as welding, painting and spraying, motor repairs, battery repairs and charging, upholstering, vulcanizing, and for storerooms for materials and repair parts. These facilities should be placed with due regard for efficient and economical shop operation. Toilet, wash rooms and locker facilities should be provided for machinists and workmen. Storage space for grease, lubricating oils, waste and wiping rags, should be segregated from the general storage supplies.

Fuel storage facilities for bus and truck terminals and shops should embody the most modern and latest layout of tank and pump design, and should be installed in accordance with the latest rules and regulations of the National Board of Fire Underwriters and other authorities having jurisdiction. Facilities for lubrication and tire inflation should be provided.

Offices for the personnel, consisting of necessary private offices, conference rooms, general office, toilet facilities, and registry and call rooms, should be included in the facility, and so located as to be easily accessible from the street and the live storage and repair shop areas. These rooms may be connected by corridors, but should, as a group, be cut off from the shop areas by fire walls with standard protected openings. Where adequate ground space is not available, offices and facilities for personnel may be placed in a second story over the live storage areas. If space limitations demand, some of the shop facilities, such as the upholstering shop, may also be placed on the second floor, with elevator service between the floors to handle repair parts and materials.

At terminal points, and at way stations where crews change or lay over, toilet and locker rooms, and rest rooms, should be provided for chauffeurs. In connection with bus chauffeurs' requirements, tailoring and valet service is deemed essential and should be worked into the layout.

Construction

Garage buildings should preferably be of fire resistive construction. Slow burning or mill construction may be used with proper safeguards.

When garage occupancies are introduced into storehouse or shop buildings to take care of one or two passenger cars or trucks, the garage area should be cut off from the remainder of the building by fire wall construction without access of any kind through the wall from the garage space.

Large facilities should be heated by a plant preferably housed in a separate building, or may be provided within the structure if properly cut off from the rest of the facilities by fire walls. All lighting should be electric with wiring run in rigid metal conduit in accordance with the latest National Electrical Code, and lighting fixtures provided with vapor-proof lamps and guards as may be required by the occupancy or use of the separate rooms. Openings in fire walls between room areas, should be properly protected with self-closing or automatic fire doors of approved types to meet the specifications of the National Board of Fire Underwriters and local building and fire law requirements. Special consideration should be given to the mechanical ventilation of paint and spraying rooms. Disposal of gases to the outer air from these rooms should be arranged so that the exhaust will not become a nuisance.

Fire Protection

Large structures for bus and truck storage and maintenance, should have a standard fire standpipe system, and it is further recommended that an approved automatic sprinkler system be installed. An approved system of watchmen's tour service should be provided if the facility warrants such protection. Fire fighting apparatus and portable equipment should meet the requirements as established by the latest rules of the National Board of Fire Underwriters and local building and fire laws applying to such installations.

Conclusion

As a whole, each problem of large bus or truck garage design must be treated separately, so that all facilities will be in proper relation to each other and to the plant as a unit. In addition, the plan should be studied so that any final arrangement adopted may permit of proper expansion without materially affecting the elements of efficiency and economy embodied in the initial layout.

The report is presented as information.

Report on Assignment 5

Methods of Determining the Protective Value of Paints

C. M. Angel (chairman, subcommittee), H. M. Church, H. G. Dalton, A. G. Dorland, A. T. Hawk, C. D. Horton, A. C. Irwin, L. P. Kimball, G. A. Rodman, C. H. Sandberg, E. W. Scripture, Jr.

Introduction

Paint has become one of the most important materials used by railroads; its use results in great savings in maintenance and appearance. Therefore, railroads have become keenly interested in the durability of paints for the purposes used.

Today the railroads in many cases must rely on the paint manufacturer's prediction of the life of a paint. The producer bases his claim on extensive long-time atmospheric tests to determine to what extent breakdown of the material will occur. As the railroads have no way to check these claims, it is sometimes found that a so-called long-life paint fails early in service, in which case the railroad suffers a loss, as many gallons of the paint may have been applied when failure is discovered. This not only involves the cost of the material but also the cost of the labor.

In time, factors will be developed from the tests suggested herein whereby the durability of one paint can be readily compared with another. In other words, the paints must be studied from the angle of durability or resistance to breakdown.

To ascertain the manner in which paints are now being purchased by the railroads and the tests being made to check the life of paints used, a survey was made of the practices of 39 railroads. The facts disclosed by this investigation are summarized as follows:

	Number of Railroads
Using ready mixed paints	38
Mixing all paints used	1
Mixing part of paints used	1
Using trade name paints only	20
Using specification paints only	10
Using trade name and specification paints	9
Making weatherometer check tests and no chemical tests	3
Making chemical tests and no weatherometer tests	9
Making both weatherometer and chemical check tests	7
Making exposure panel tests	2
Making check tests before paint is purchased	2

All except two of the railroads surveyed purchase all their paints ready mixed, including paints purchased to specifications or trade name. One railroad mixes some of the paints it uses, namely, enamels, lacquer, building paints and shellacs; another mixes all paints used.

The railroads that buy paint on specifications do so for the purpose of insuring delivery of a product which has been found under certain conditions to give relatively good surface protection or decoration. The use of these specifications has been perpetuated regardless of their age, as the purchaser is fearful of substituting a manufacturer-recommended paint, as no means are available to the railroad to evaluate the claims in a short period of time.

Since research is constantly developing better paints, railroads committed to specification paints may lose the economies which result from paint improvement. They may also pay a higher price for a product complying with specification requirements which could be purchased on the paint manufacturer's recommendation at a lower cost. When a standardized method of testing paints has been adopted by the railroads, the trend will be somewhat away from the use of specification paints and toward the purchase of paints recommended by the paint manufacturer.

Tests conducted by the railroads should be as simple as possible. It should not be inferred that such tests are designed to determine the extreme life of the paints, as this would be duplicating work previously done by the manufacturers in evaluating the life of their products. The railroad test must be such as will make it possible to select from a group of paints recommended for certain work, one having the greatest economic value. To do this three methods may be considered: (1) Long-time exposure tests, (2) chemical analysis, and (3) laboratory accelerated weathering, in which the paint is subjected to moisture, light, heat and cold under definitely prescribed cycles, or other special tests.

The tests outlined by your committee in this report are offered as suggested means through which paints can be tested to ascertain their comparative qualities.

Paint Testing Procedure

In testing paints care must be exercised to conduct tests under conditions similar to those to which the paint will be subjected after application.

It will not suffice to test a paint only for light, heat, moisture and cold, when it is to be used on train sheds where the paint will be continually subjected to sulphur gases from locomotive smoke. An additional test is needed to ascertain the film breakdown under sulphur gas. If a paint were recommended for use where salt air is prevalent, then a test would be required to ascertain the film reaction to saline moisture. When protective paints are being considered for the coating of steel coal bins, they should be tested for resistance to abrasion and to the dilute sulphuric acid leachings which result from the sulphur in the coal combining with the moisture present. In a like manner, paints for use on hot surfaces should be tested under temperatures within the range of service conditions.

Therefore, in view of the large number of paints now on the market, it is impossible to set up a test procedure for each class and its use. If each group, however, is tested under the same set of predetermined conditions, factors will be developed whereby one paint can be compared with another and proper selection made from the group tested.

Paint Failures

Before taking up the actual test procedure of paints, it may be well to consider and define briefly the various paint failures:

Checking (Figures 1 and 15).—This defect takes the form of fine splits or ruptures in the paint which break the surface into innumerable small irregular areas, but which are in the top coats only and do not extend through to the surface underneath. Slight checking is not a serious defect because the durability and the protective value of the paint are not affected, nor does checking make repainting difficult. The usual cause of checking is the presence of too soft an undercoat, which can be avoided by allowing plenty of drying time between paint coats and by making sure that each undercoat is properly formulated to insure its being harder than the succeeding coat.

Alligatoring (Figures 2 and 14).—This defect is similar to checking in character although the ruptures in the paint film are much wider and the surface is broken into larger irregular areas. Like checking, it affects the top coats only and does not extend through to the surface underneath. Alligatoring, however, gives the surface an unsightly appearance. It seriously affects the durability of the paint and makes repainting difficult. The cause of alligatoring is always too soft an undercoat. This may be due to the use of too much oil, to insufficient drying time between coats or to the use of impure oil or other vehicles which dry to a soft film.

To avoid alligatoring, make sure that the undercoats have plenty of time in which to dry and that they are properly formulated to insure their being harder than the succeeding coats.

Cracking and Scaling (Figures 3, 13, 17 and 19).—These two defects are closely related, since scaling is a later stage of cracking. Cracking is a rupture of the paint film extending down to the surface to be protected. This allows moisture to enter behind the paint film, which loosens the paint and scaling results. This defect is caused by the use of a paint which becomes hard and brittle as it ages and can no longer follow the movement of the surface underneath.

If cracking and scaling have occurred over the entire surface it is usually advisable to remove all of the old paint by means of a torch and scraper before repainting. Otherwise, the old film will probably continue to scale, carrying the new paint with it.

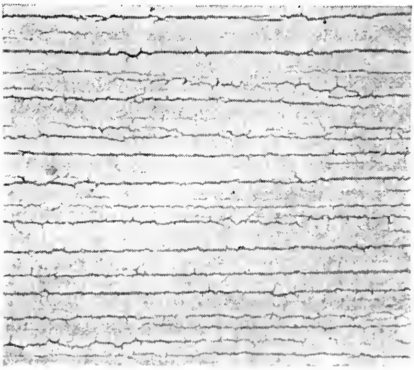

Fig. 1.—Cracking and Checking and Cracking.

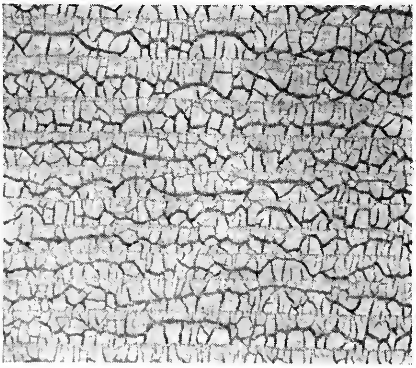

Fig. 2.—Alligatoring.

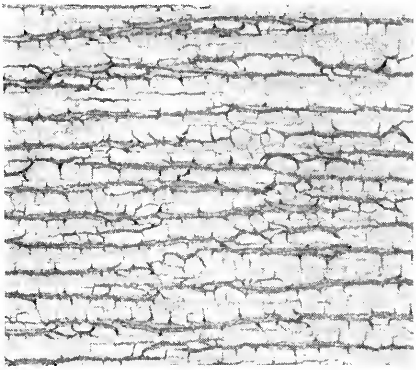

Fig. 3.—Cracking and Scaling.

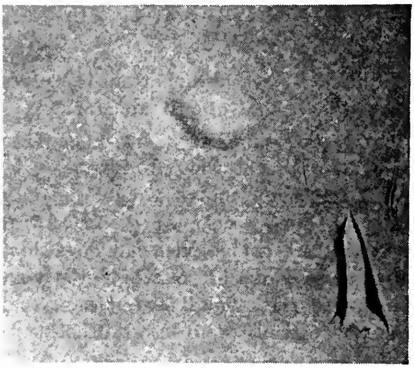

Fig. 4.—Blistering and Peeling.

Fig. 5.—Spotting.

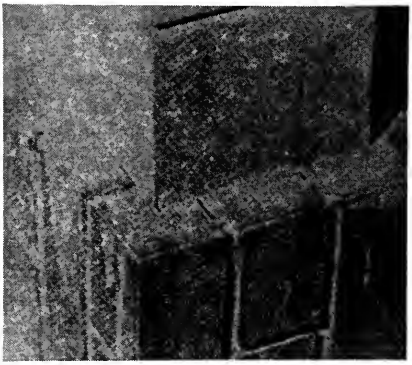

Fig. 6.—Washing.

Common Painting Defects

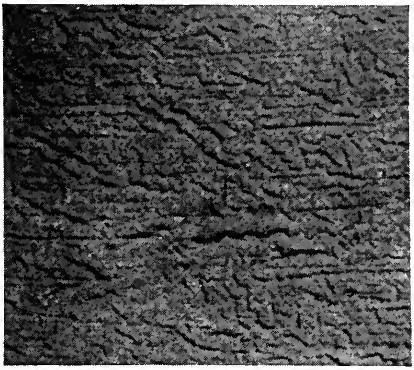

Fig. 7.—Wrinkling.

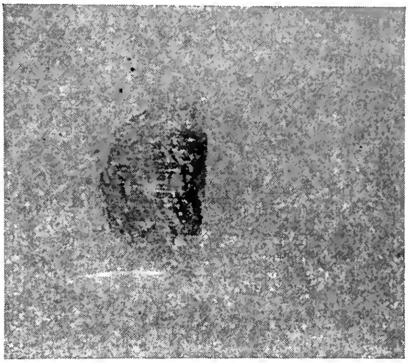

Fig. 8.—Bleeding Over Knot.

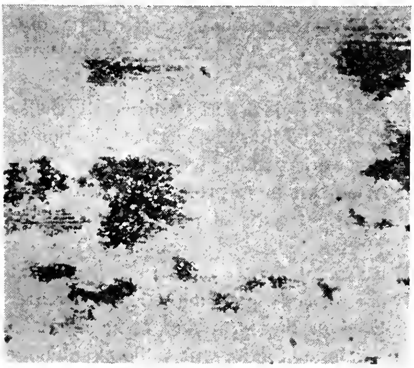

Fig. 9.—Discoloration Over Cedar or Red Wood.

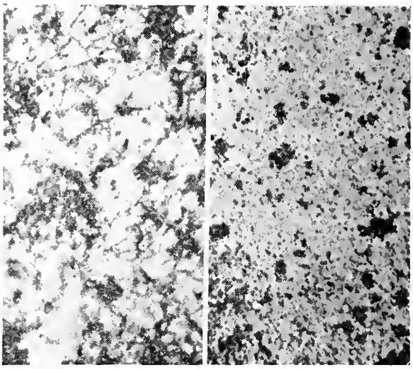

Fig. 10.—Dirt Discoloration (left) Mildew (right).

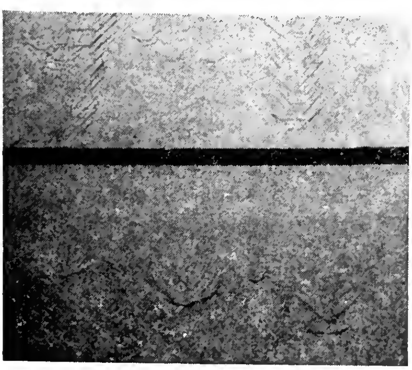

Fig. 11.—Sagging.

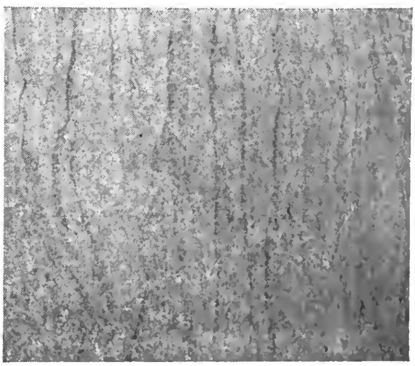

Fig. 12.—Running.

Common Painting Defects

Blistering and Peeling (Fig. 4).—The most common cause of blistering is the presence of moisture in the material behind the paint film. Peeling quite naturally follows blistering in most cases, since the paint which has blistered no longer grips the surface properly, and a comparatively small amount of pressure is sufficient to force it completely from the surface. In some cases, the heat of the sun is enough to increase the vapor pressure of the moisture in the material so that it will cause blistering. In interiors, it is usually the heat of a radiator or a riser which causes the trouble. The more moisture-tight a paint is, the more apt it is to blister. Therefore, a paint that permits some escape of the moisture behind it, and that grips the surface properly is less likely to develop this trouble.

The best way to avoid blistering is to make sure that the surface to be painted is thoroughly dry. In the case of porch columns which are painted on all sides, it is necessary to be particularly careful, because blistering is apt to occur if there is moisture in the column when it is painted.

On repainting a blistered surface, it is necessary to scrape off all the defective paint, allow the surface to dry thoroughly and repaint as on new work. The priming coat on such work, if properly designed and given adequate drying time, will permit the surface to dry more thoroughly, and yet tend to prevent the entrance of moisture from the outside. If leaks or faults in construction are responsible for the presence of moisture, these should, of course, be properly repaired before anything else is done.

Spotting (Fig. 5).—Spotting is characterized by loss of gloss, fading and early chalking in spots or small areas due to absorption of oil from the finishing coat by the porous surface underneath. It is very likely to occur on new work that is given only two coats, or old work painted with one coat. Spotting usually appears more prominently with dark tints and colors. This defect will not occur when sufficient coats of properly formulated paint are applied.

Washing (Fig. 6).—This condition occurs when a paint film contains ingredients that are soluble in water or when soluble compounds are formed by chemical reactions after the paint has been applied. Washing may be noticed in the form of streaks near the lower edge of clapboards and in accumulations on column footings or building foundations. The material that is dissolved out of the paint will collect in these places and when the water evaporates the streaks can be plainly seen.

Wrinkling (Fig. 7).—The principal cause of this defect is an excessively thick coat of paint, sometimes exaggerted by the excessive use of drier. When paint is applied in too thick a film, it is impossible for it to dry uniformly and after the surface skin has formed the later drying of the part underneath causes the surface to wrinkle. There are sometimes contributing factors, such as changes in temperature or excessive humidity during the drying period, but even under unfavorable drying conditions, wrinkling can be avoided if the coat is brushed out to a thin, even film. It is not customary to remove the old paint when wrinkling has occurred, although in some cases this is the easiest way of producing a first-class repaint job. If the wrinkling has occurred only over limited areas, the ridges can be rubbed down with a fairly coarse sandpaper before repainting.

Bleeding Over Knots (Fig. 8).—Bleeding of this type is caused by the oil in the paint dissolving substances in the knot, and can usually be prevented by coating knots with a thin resin-free shellac or other recommended materials after the priming coat has been applied. One-half of the knot shown in Fig. 8 has been so treated.

Discoloration Over Cedar or Redwood (Figures 9 and 16).—This appearance of dark spots through or on the paint film is caused by dark-colored water-soluble substances in the wood which are brought to the surface by moisture and deposited there. The paint

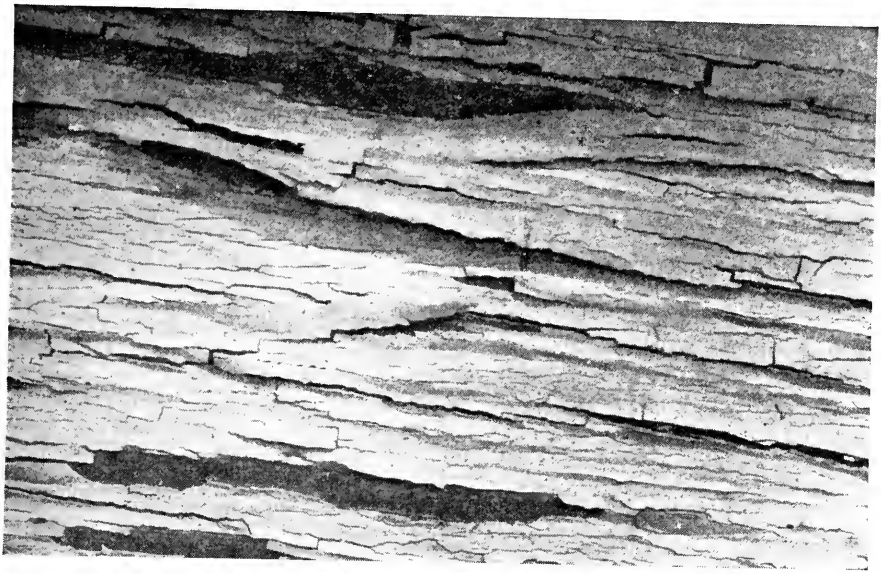

Fig. 13.—Flaking of Paint Over Summerwood of Ponderosa Pine.

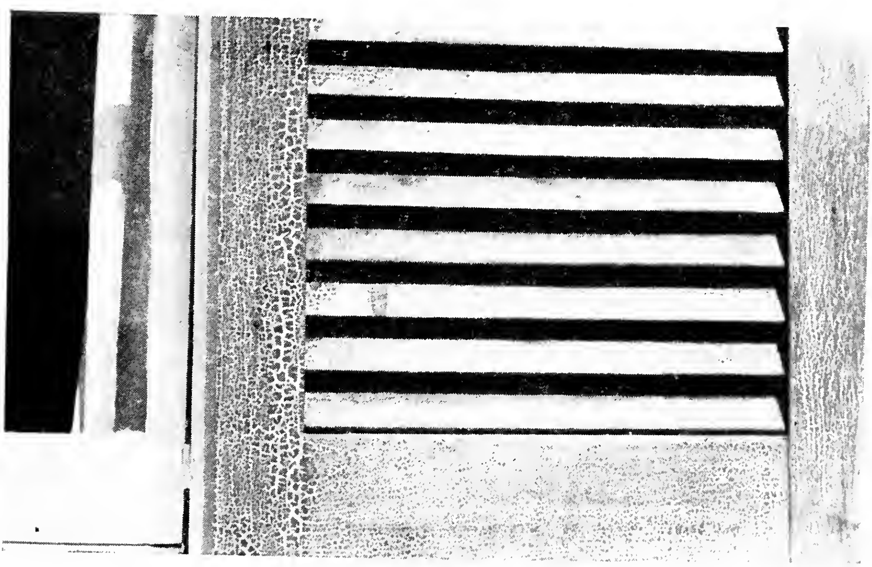

Fig. 14.—Alligatoring of a Mixture of White Paint and Dark Blue Enamel.

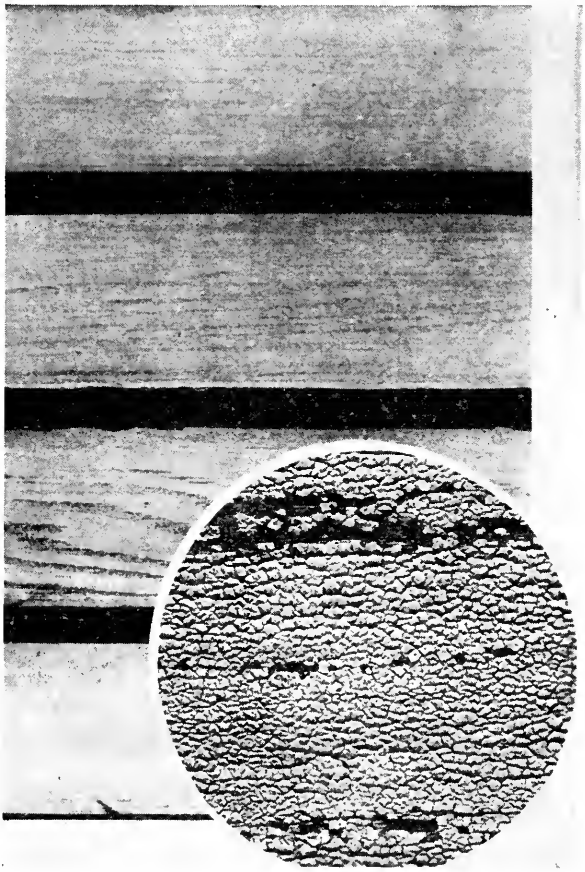

Fig. 15.—Checking and Crumbling of White Lead Paint
That Has Been Neglected.

is in no way responsible for this trouble, which may be avoided by allowing the wood to weather thoroughly before it is painted.

Dirt Discoloration and Mildew (Fig. 10).—These conditions are frequently confused with each other. The right half of the illustration shows a mildewed surface and left half dirt discoloration. Finishing coats that contain too much oil are likely to dry soft and tacky, forming the type of surface that catches and holds every particle of dust and dirt. On the other hand, a finishing coat made on the basis of a good formula will produce a glossy but sufficiently hard film to resist excessive dirt collection. Mildew is a dark-colored fungus growth which tends to form under the combined conditions of moisture, warmth and shade. It also develops more readily on soft paint films than on harder ones. Where mildew is encountered, as much of it as possible should be removed before repainting.

Early Loss of Gloss and Early Chalking (Fig. 18).—If pronounced sudden loss of gloss or chalking occurs shortly after painting, it is probably due to incorrect formulation of the paint or to the presence of moisture in some form (frost, fog, rain, etc.) during the drying of the paint. Soft undercoats which were not allowed sufficient time for drying may reduce the gloss of the finish coat.

Running and Sagging (Figures 11 and 12).—Running and sagging are associated defects. Both are nearly always due to the application of too much paint. If the paint is high in oil content, there is a tendency to apply it too freely, and consequently the paint will run or sag. A paint of correct formulation, brushed on a suitable surface in

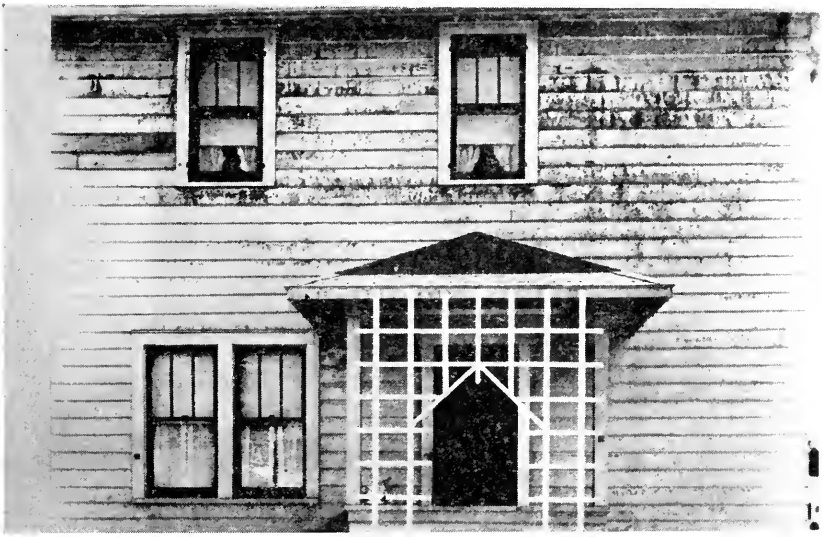

Fig. 16.—Bleeding of Redwood Extractives Through Paint, Because of Moisture in the Walls. Puddles of Water Were Formed in the Basement, Because Tree Roots Clogged the Sewer.

a workmanlike manner, never will show either of these defects. For repainting, the preparation of a surface with these defects is similar to the preparation of a surface that has shown wrinkling; that is, the rough portions of the surface are smoothed with sandpaper before the first repaint coat is applied.

Physical Characteristics—Test Procedure

In testing paints certain physical characteristics must be considered along with the life. These physical characteristics determine in the beginning whether it is even worth while to make extensive tests.

In addition to others, a test should be conducted on a fairly large area to ascertain the number of square feet the paint will cover. Further physical tests include determinations of the drying time, adhesiveness of the paint, gloss after application, and brittleness or elasticity. It should be ascertained whether the paint will sag in application and if it grips satisfactorily the material or priming coat to which it is to be applied.

One of the important characteristics of a paint film is its elasticity or, conversely, its tendency to turn brittle under service conditions. The elasticity can be tested in the laboratory by applying the paint on a thin metal panel and, after drying, by bending the panel around a one-inch mandrel, coated surface out. The comparative failures are evalu-

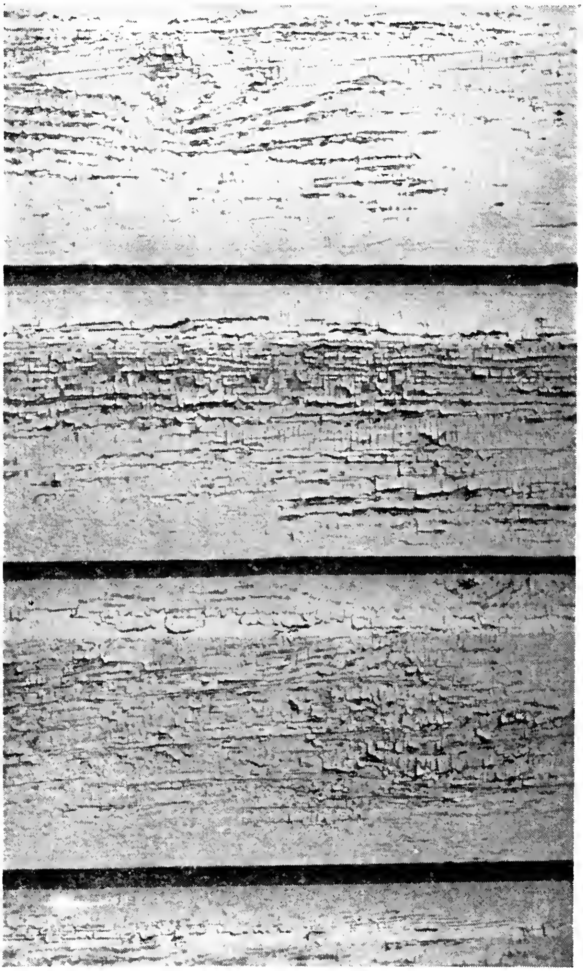

Fig. 17.—Scaling Due to Prolonged Neglect of Hard Type Paints.

ated by the number of degrees of bend the paint will stand before failure. The elasticity of a paint film can be tested after it has been in service by cutting the surface with a sharp knife. If the paint has become brittle it will crack; if it is still elastic only the sharp cut will be observed in the paint film.

The drying time can be ascertained by preparing a paint panel and observing the time required for it to dry sufficiently so it will be no longer tacky to the touch.

Adhesiveness can be tested after drying by observing the resistance offered to efforts to scrape the paint film from the test panel with a sharp edged instrument.

Gloss and sagging can be noted from visual observation.

Chemical Analysis

A chemical analysis should be made of each paint sample to be tested. This should show (1) the percentages by weight of the total solids and the total liquids and (2) the chemical composition of both the solids and the liquids expressed in percentages of their constituents.

Accelerated Weathering Tests

For some years accelerated weathering machines, called weatherometers, have been available for standard weathering tests of paints, and methods of procedure have been developed for their use. They consist of apparatus for exposing paint panels to refrigeration, wet and dry conditions, water spray and artificial sunlight under accurately

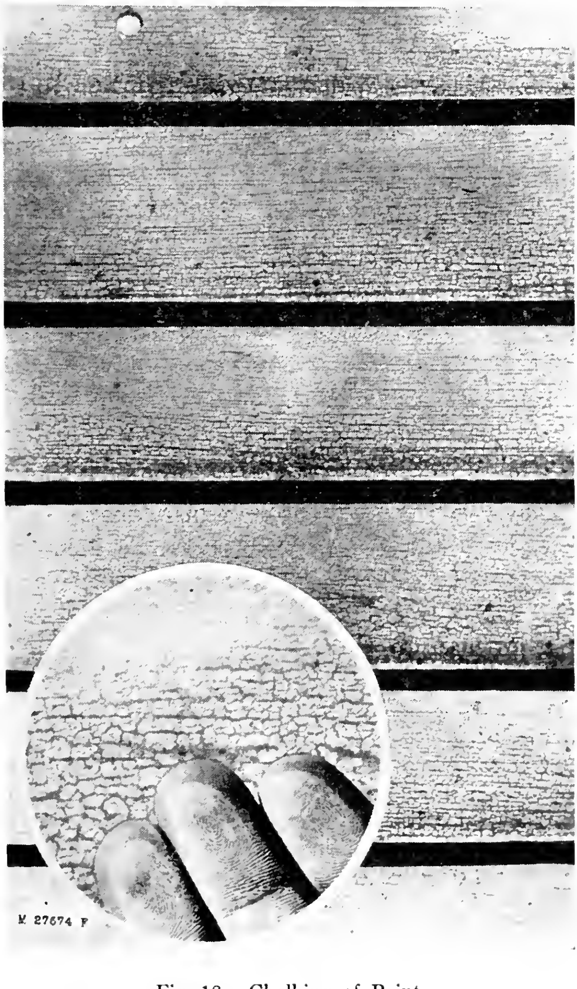

Fig. 18.—Chalking of Paint.

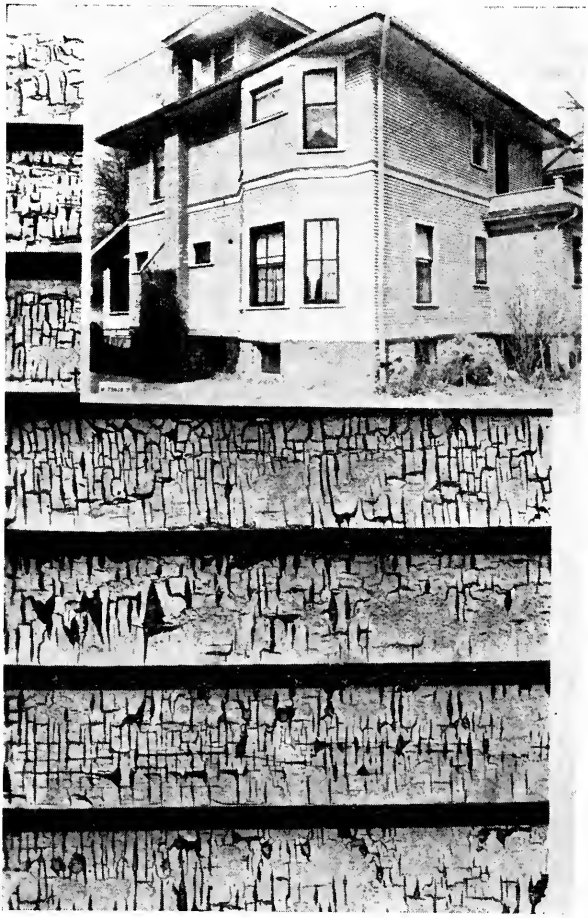

Fig. 19.—Cross-Grain Cracking, Caused by Incompatibility of Paints of Various Colors Over One Another.

controlled conditions. A typical accelerated weather testing machine is shown by Figures 20 and 21.

Samples to be tested are placed in a framework which rotates slowly within a tank. The size of the test samples used is dependent on the type and size of the testing machine. A water spray and light within the tank permit samples to be subjected to the combined effects of radiation and moisture during a portion of each revolution.

In the accelerated tests, a complete record must be maintained of all weatherometer tests, along with the chemical analysis of the paints tested. Also, each paint tested in the weatherometer should be subjected to an out-of-doors exposure panel test at three or more locations on the railroad. This arrangement of tests will give not only the film breakdown of the paint, both from the weatherometer and the outside exposure tests, but also a record of the chemical analysis of each paint tested.

When one or a group of paints is to be tested the panels are prepared on surfaces similar to that on which the paint is to be applied. If the paint is to be used on wood surfaces it is placed on a wood panel; if for use on metal surfaces it is placed on a steel panel. Paint panel specimens should be coated in a manner as nearly similar as possible to that which will be used for application of the paint in practice. For example, if two coats of paint were to be applied to a sand-blasted steel surface, then the panel should be prepared by first giving it a light sand blast and then applying two coats with a proper drying interval between the application of the coats.

The best method of coating panels, when ascertaining the physical characteristics of the paint, is to fasten them to the surface to be painted. The panels will then receive the paint in a manner similar to that employed in applying paint to the buildings or structures for which the paint is being considered. This eliminates any variable which might arise from the testing of laboratory prepared panels. After the test panels are prepared they are ready to be placed in the weatherometer. In this test the drum revolves

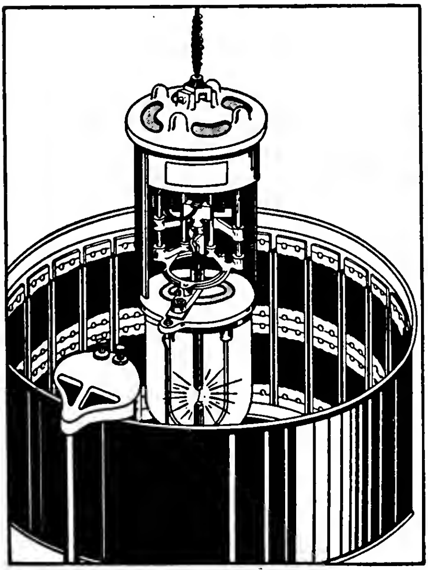

Fig. 20.—Apparatus for Accelerated Weathering Test.

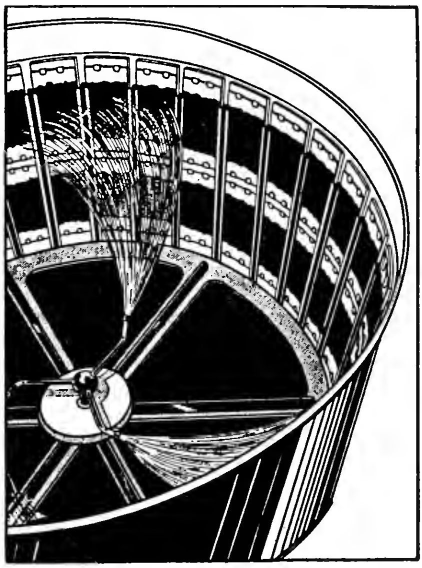

Fig. 21.—View of Apparatus Showing Rotary Sprinkler.

the specimens around the light and water spray at the rate of approximately 15 to 20 min. per revolution.

Many weathering cycles are employed, but the cycle recommended is refrigeration 1 hour, wet and dry 3½ hours (panel is sprayed on one side and dried by the light rays on the other as the drum is revolved); rain by water spray 3½ hours, and sun (artificial light) 16 hours. It must be clearly understood that the cycle recommended can be varied or adjusted to suit any personal ideas, but after a cycle has been adopted it should be maintained throughout all the tests conducted, so that a proper comparison can be made at all times with paint tested in the past.

The refrigeration test can be made in any refrigerator or cold box capable of maintaining a temperature of 10 deg. F., or lower, to suit desired conditions. The panels should be so placed in racks that the painted surface of all the samples will be exposed to the same temperature. This test can also be conducted by placing ice in the weatherometer.

For light, rain, and light-spray exposure periods the panels should be placed in the holders of the weatherometer cylinders. For the rain period the lamp should be raised above the cylinder and the latter covered, and the samples sprinkled vigorously with water by means of a rotary spray. During the light period the lamp should be operated with the revolving cylinder, and should shine on all the specimens continuously.

During the light and water spray period the light from the lamp should shine on the specimens continuously while the water is running constantly from a spray at a fixed point, thus wetting the specimens in the revolving cylinder once every 15 or 20 min. The position of the test specimens in the revolving cylinders should be changed for each repetition of any one of the cycles, especially with respect to their location in the upper or lower tiers of slots or hooks, in order to compensate for unavoidable differences in their relation to the light source.

The panels of the paint on test should be inspected after each cycle of weathering and a record made of any noticeable change in the paint film surface. If the paint film begins to check, alligator or crack, etc., a suitable record should be made of the number of accumulated accelerated hours to the time of failure.

The result of the accelerated weathering test should be determined by comparing specimens of the unweathered material with those that have been weathered. The durability of the material may be expressed as the number of cycles or hours of accelerated weathering that were required to bring about failure or definite changes in the materials tested.

Outside Exposure Tests

For each panel prepared for the weatherometer, three or more should be prepared in the same manner for outside exposure tests on the racks at three or more locations on the railroad. Each test panel should be provided with a waterproof hood to cover one-third to one-half of the painted surface. The purpose of the hood is to protect the covered portion from the sun and rain and other atmospheric conditions, so that when an inspection is made, the hood may be removed to afford a direct comparison of the paint film as applied and as weathered.

The outside exposure tests are slow and in some cases are continued for a long time. This is due to variations in light intensity, as the effect of sunlight is relatively low during a large portion of the daylight hours. Exposure racks placed in locations subject to marked climatic changes, will show wide variations in results.

Inspection of the outside exposure panels should be made at intervals of not less than three months nor more than six months, and the condition of the paint film surface compared with that of weatherometer panels of the same samples of paints.

Special Tests

In testing of paints many cases will arise where the accelerated weathering tests and the outside exposure tests will not give a comparative evaluation of the material. Such situations call for special tests and the construction of special apparatus. A few examples will give an idea of the manner in which special tests are arranged and conducted. However, in this type of testing it should be borne in mind that such tests should be practical and as nearly parallel as possible with the conditions to which the paint will be subjected in actual service. These examples are as follows:

Sulphur Gas Test

In some cases it is necessary to paint metal structures exposed to sulphur gas. The accelerated weathering test furnishes some information as to the lasting qualities of the paint, but the outside exposure test should be made in a location where sulphur gas contaminates the atmosphere, for example, in the top of a roundhouse. Metal panels, the number to depend on the number of inspections to be made, are coated all over, including the edges. They should be hung in close relation with each other in top of the roundhouse. A predetermined test schedule is arranged and at each test inspection a panel is removed and examined closely. It is then filed as information and not returned to its former location. When the last one has been removed, all of the panels can be laid down in a row and evaluated with respect to the period of time they were on test.

Cinder Cutting

Where cinder cutting must be considered, a test on top of a locomotive cab will disclose an interesting comparison. The paints to be tested are painted in squares on the top of the cab roof, which should be sand blasted before the application is made. During the test the paint squares are inspected and rated as to their condition. This type of test gives not only the effect of cinder cutting, but also an acid test because the steam moisture and sulphur gases combine to form dilute sulphuric acid.

Abrasive Tests

Protective paints are sometimes considered for use where abrasion is the most important factor. This statement refers to coal bins and other places where such materials are to be used.

A simple test for the abrasive qualities involves the use of a plate ⅛ in. thick and about 12-in. wide by 18-in. long, each end of which is tapered off at 30 deg. The surface to be coated for test should be sand blasted. Not more than three paints can be tested at a time on one plate. It is divided into six parts 4 in. wide and 9 in. long; the three sections at one end of the plate are coated with the three different paints; the three sections at the other end are painted with the same materials but their locations are reversed. The plate is then bolted in the chute of a coal dock where it will be subjected to the abrasive action of the moving coal. If possible to do so, it is advisable to log the tons of coal passing over the plate for comparison with other tests of this character.

A laboratory test can be made by placing small coated plates in a rotating device containing small lumps of coal. The machine is then slowly rotated until the coatings fail, in a manner similar to that occurring in the test above described. The number of hours to failure is recorded.

Acid Leaching Test

Protective paint coatings are sometimes used where acid leachings or dilute sulphuric acid are present. A test for exposure of this type can be conducted by means of a wooden box approximately six feet square and five feet deep. The bottom of the box is made of a heavy metal screen. About six inches of coal is placed on the screen and the coated test panels laid flat on this layer of coal. The panels are coated on both sides and the edges. Four feet of coal is placed on top of the coated plates. Then, each day a measured amount of water is sprayed on the coal, allowing this water to run through the coal down on the plate surface. The coal can be removed from time to time and the plates inspected and graded.

In a test of this type it is of value to analyze the coal for sulphur content, and also take samples of some of the leachings to ascertain the acid content. A laboratory test can be conducted to determine the effect of acid leachings on protective coatings by immersing small coated steel specimens in a one percent sulphuric acid solution.

Brine Drippings

The effect of salt must be considered where paint film coatings are subjected either to salt air or "salt fogs", or to direct brine drippings. The salt solutions are prepared so as to parallel as nearly as possible the conditions under which the paint is to be used. One cubic centimeter of the brine solution, of desired strength, is applied twice daily until the paint film fails. The panels are rated with respect to their resistance to the salt solution.

Paint Testing Equipment and Staff

The paint laboratory should be established at a location close to the paint supply storage, where samples of all paint are conveniently accessible. It should be equipped with paint spray apparatus and a hood ventilated with an exhaust fan. Approved fire extinguishing equipment is also important. Glassware test apparatus and a centrifuge for analysis of paints are required. A weatherometer for testing paint panels should be conveniently located adjacent to the paint room.

The capacity of the test racks for outside atmospheric exposure will depend upon the number of test panels to be tested. A typical yard exposure rack is shown in Fig. 22. The test panels may be of any convenient size. However, for railroad work a panel seven by twelve inches is satisfactory, as it can be conveniently filed for future reference after the tests are completed.

Exposure racks of lasting qualities can be constructed from angle irons welded together. They should be coated with a good protective paint. The racks should be so constructed as to expose the test paint panels at an angle of 45 deg. to the sun, with a southern exposure. These racks can be located in a field, but the most desirable location is on the roof of a one or two-story shop building.

At least three outside exposure paint test racks should be provided, one located close to the paint testing department and the others at various locations over the railroad where extreme atmospheric conditions may occur.

Special equipment will have to be constructed to meet the various problems entering into the paint testing work. No specific suggestions regarding the design of this equipment can be offered to supplement that given in each case, under the procedure for making special tests. It is necessary, in each case to reproduce as nearly as possible the conditions under which the paint materials are to be used.

The staff necessary to carry on the investigation will depend on the amount of paint tested. However, the minimum force should consist of a paint chemist to make chemical analyses of the paints and care for the weatherometer, and a paint inspector to examine outside exposure panels on the railroad and do routine paint testing work. If the paint testing work is of sufficient volume the services of a clerk will be required to assist the chemist and inspector with the records.

Correlation of Test Data

There has always been considerable discussion of the value of outside exposure tests and weatherometer tests of paints, particularly with respect to the correlation of the results obtained from both types of tests on the same sample of paint.

The accelerated weathering testing machine will not forecast the life of a paint in terms of accelerated hours converted into years of service, until the results are correlated with actual service of the paint. However, pending such correlation the weatherometer will give very useful indications and, used in conjunction with other tests, may serve as a

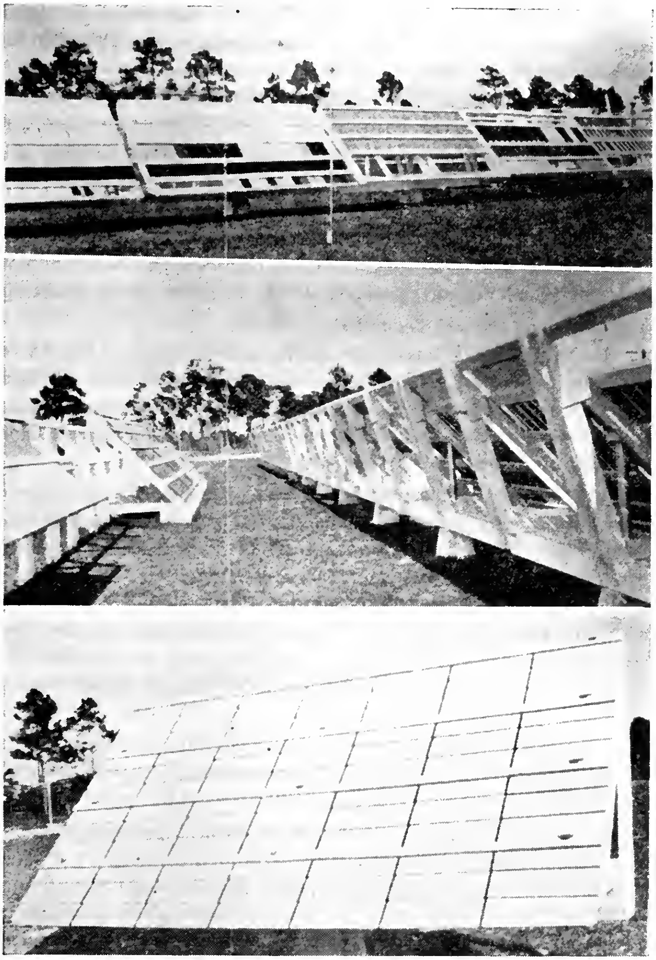

Fig. 22.—Test Rack for Outside Exposure of Paint Panels.

means of evaluating the probable life of paints. Under controlled conditions it should also permit the determination of the uniformity of successive paint deliveries.

No test can replace the test of a paint applied to a surface and weathered until failure. Outside exposure tests on panels at locations where the paint is to be applied would undoubtedly classify the paint, but such a test could not be completed until long after the selection of the paint must be made.

Comparative outside exposure tests afford the most ideal method of predicting the life of a paint at the locations where paint is to be used. Climatic conditions have a marked effect on the breakdown of a paint film, so the exposure tests should be conducted in each locality where the paint is to be used. On the majority of the railroads such tests would not be practical.

The accelerated weathering machine tests the paint samples under fixed conditions with a definitely prescribed cycle; therefore, tests made at any time can be compared with other samples tested in the past, if the same cycle and conditions are maintained. This type of test gives the comparative result in a very short time as compared with the outside exposure test.

As an illustration, a railroad desires to purchase 500 gal. of building paint and five manufacturers have submitted samples which they recommend on the basis of their own outside exposure tests. If panels are prepared in the same manner for each manufacturer's paint, and are placed in the weatherometer and tested under the same cycle of weathering, it is reasonable to assume that the paint on the panel accumulating the greatest number of hours without breaking down would be the most acceptable paint for purchase from among the samples tested.

Although the paint manufacturers lean to the outside exposure test on test farms at various locations over the country, the fact remains that one or more weatherometers are to be found in their paint laboratories. It is assumed that these weatherometers are used for the purpose of selecting those paints that have possibilities for outside exposure before being offered to the railroads.

From the tests outlined in the report four basic elements have been developed: The quick accelerated weathering test; the outside exposure test at three or more locations on the railroad, which takes into consideration the different climatic conditions which may be encountered; the chemical analysis of the material; and the physical characteristics of the paint being tested. The question then arises, will the field service test show any interesting agreement with the accelerated weathering tests, and what part does the chemical analysis play in classifying the paints? In other words, after all of the data have been developed, is it possible to correlate them to bring about a distinct classification of the paints?

The use of the same solids from similar raw materials and liquids, when mixed in the same proportions, and compounded in the same manner, should give the same relative life in the weatherometer and the outside service test under similar climatic conditions.

This correlation can be best illustrated by a typical problem. A paint sample is selected for test and its physical characteristics are found suitable for the type of material on which it is to be used. Weatherometer panels are prepared and tested to accelerated weathering, and failure is found to occur in 2,000 hours. The exposure panel at the north end of the line showed an identical failure in three years, the panel at the south end of the railroad failed in four years, and the panel centrally located failed at three years. The average life from the outside exposure test would be 3⅓ years over the entire railroad. Then, by dividing 2,000 by 3⅓ we find that 606 hours of accelerated weathering of the paint tested is equal to one year of average service on the railroad. Or, if desired, the hours of accelerated test equivalent to one year's service can be worked out for the territory represented by each field exposure test.

Suggested Method of Paint Purchases

Any railroad that initiates tests of the kind outlined in this report is confronted with the fact that the field exposure tests must be continued for three or four years before they would develop any information of practical value. This obstacle may be overcome by adopting for temporary use a ratio of 500 hours of accelerated weathering to one year of average service. Then, as groups of tests are conducted this ratio can be raised or lowered in accordance with the results shown by the exposure panels at the various locations over the railroad.

It is suggested, when paint is purchased, that the bidders furnish a one-gallon sample of the paint which they would supply if the contract were awarded them, and that an accelerated weathering test be conducted under the same cycle of weathering on all of the samples furnished by bidders, the sample resisting failure the longest being selected for purchase, with due consideration for its economy. An analysis should be made of the paints from the original samples furnished so that when the paint purchased has been received a check analysis can be made for comparison with the original sample.

This report has been presented by your committee primarily as a guide for those who use paints. By reason of the tremendous growth of the paint industries and of the research which they carry on, many new paint materials are being introduced from year to year. Therefore, the selection of paints from among the many varieties available will have to be based on correlated test data prepared as correctly as possible.

The report is presented as information.

Report of Committee 7—Wood Bridges and Trestles

H. M. Church, *Chairman,*	G. V. Guerin, Jr.	R. P. Hart, *Vice-Chairman,*
H. Austill	Hugh Everett, Jr.	J. A. Newlin
M. W. Beach	W. E. Hawley	W. H. O'Brien
S. Blumenthal	H. C. Heinlen	W. A. Oliver
H. F. Bober	C. J. Hogue	W. L. Peoples
G. M. Cornell	C. S. Johnson	G. W. Rear
F. H. Cramer	J. V. Johnston	Arthur Ridgway
G. S. Crites	W. D. Keeney	W. C. Schakel
D. H. Dowe	J. E. Myer	L. W. Smith
S. F. Grear	W. O. Nelson	William Walkden
		Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of the Manual.

Progress report including recommended revisions of the Manual necessary for compliance with revised American Lumber Standards .... page 248

2. Simplification of grading rules and classification of timber for railway uses, collaborating with other organizations interested.

Progress report—submitted as information .... page 273

3. Overhead wood or combination wood and metal highway bridges, collaborating with Committee 15—Iron and Steel Structures: Confer with proper committee of American Association of State Highway Officials.

No report.

4. Specifications for design of wood bridges and trestles.

Progress report—submitted as information .... page 273

5. Bearing power of wood piles, with recommendation as to methods of determination, collaborating with Committee 8—Masonry.

Report on this assignment presented under Subject 6.

6. Recommended relationships between the energy of hammer and the weight or mass of pile for proper pile driving, to include concrete piles, collaborating with Committee 8—Masonry.

Progress report—submitted as information .... page 282

7. Design of timber structures—

(a) To give longer life with lower cost of maintenance.

(b) For heavy loading.

No report.

8. Fireproofing wood bridges and trestles, including placing of fire stops.

Final report—with recommendations for inclusion in the Manual .... page 291

9. Specifications and design of fastenings for timber structures, including metal joint connectors.

No report.

10. Use of tar and asphalt compositions for wearing surfaces on wood floored highway bridges.

No report.

The Committee on Wood Bridges and Trestles,
H. M. Church, *Chairman.*

Bulletin 422, January, 1941.

Report on Assignment 1

Revision of Manual

R. P. Hart (chairman, subcommittee), G. V. Guerin, Jr., W. E. Hawley, J. V. Johnston, Arthur Ridgway, William Walkden.

The committee reviewed American Lumber Standards—Simplified Practice Recommendation R-16-39, which was approved by the National Bureau of Standards October 15, 1939, and in collaboration with the AREA representative on the Central Committee on Lumber Standards has approved the revisions, which are recommended for inclusion in the Manual together with changes as follows:

Withdraw the Specifications for Wood Shingles appearing on pages 7-11 to 7-15, inclusive.

Revise the Specifications for Structural Timbers as set forth in detail below:

Page 7-18, in the Foreword—

Delete Paragraph 7, reading as follows:

7. No piece of exceptionally light weight should be accepted for structural timber use.

Renumber Paragraphs 8, 9 and 10 as Paragraphs 7, 8 and 9.

Page 7-19, under I General Requirements—

Add the following to Paragraph 102. General Quality:

No pieces of exceptionally light weight shall be permitted in any structural grade.

Pitch pockets are not required to be limited in structural grades.

Revise Paragraph 104 to read as follows:

104. Wane

When wane is permitted, the bark shall be entirely removed. Wane is measured at the point of most wane on any face.

Renumber Paragraph 106. Heartwood, as Paragraph 105.

Delete Paragraph 105. Crossgrain, and substitute the following:

106. Slope of Grain

Slope of grain shall be measured over a distance sufficiently great to determine the general slope, disregarding short local deviations.

In joists and planks, beams and stringers, slope of grain is limited only within the middle half of the length of a piece.

In posts and timbers, slope of grain is limited in any part of a piece.

Pages 7-20 to 7-23, inclusive—

Withdraw Paragraphs 107 to 121, inclusive, and replace with the following new Paragraphs 107 to 150, inclusive:

Density

107. The following methods for determining density of Douglas fir and southern pine are for use with the grades where density is required.

108. Dense Douglas fir and southern pine shall average on either one end or the other not less than 6 annual rings per inch, and, in addition, one-third or more summerwood (the darker, harder portion of the annual ring) over a 3-inch portion of a radial line located as described below. The contrast in color between summerwood and springwood shall be distinct.

109. Pieces averaging less than 6 annual rings per inch shall be accepted as dense if averaging one-half or more summerwood.

110. In inspection for density, reasonable variation of opinion between inspectors must be recognized. In reinspection of a particular lot of lumber for density, for every three pieces accepted as having one-third or more summerwood, one of the remaining pieces shall be accepted if agreed upon as having between 30 and $33\frac{1}{3}$ percent summerwood.

Radial Line

111. The radial line shall be representative of the average growth on the cross section.

112. When the radial line specified is not representative, it shall be shifted sufficiently to present a fair average, but the distance from the pith to the beginning of the 3-inch portion of the line in boxed-pith pieces shall not be changed.

113. In case of disagreement, two radial lines shall be chosen, and the number of rings per inch and percentage of summerwood shall be the average of these lines.

Location of Radial Line in Douglas Fir and Redwood

114. In boxed-pith pieces the radial line shall run from the pith to the corner farthest from the pith. When the least dimension is 6 inches or less, the 3-inch portion of the line shall begin at a distance of 1 inch from the pith. When the least dimension is more than 6 inches, the 3-inch portion of the line shall begin at a distance from the pith equal to one-fourth the least dimension of the piece.

115. In pithless pieces the center of the 3-inch portion of the radial line shall be at the center of the end of the piece.

116. If a 3-inch portion of a radial line cannot be obtained, the measurement shall be made over as much of a 3-inch portion as is available.

Location of Radial Line in Southern Pine

117. In boxed-pith pieces the measurement shall be made over the third, fourth, and fifth inches from the pith along the radial line.

118. In pieces containing the pith, but not a 5-inch radial line, which are less than 2 by 8 inches in section or less than 8 inches in width, that do not show over 16 square inches on the cross section, the inspection shall apply to the second inch from the pith. In larger pieces that do not show a 5-inch radial line, the inspection shall apply to the 3 inches farthest from the pith.

119. In cases where pieces do not contain the pith and it is impossible to locate it with any degree of accuracy, the same inspection shall be made over 3 inches on an approximate radial line beginning at the edge nearest the pith in pieces over 3 inches in thickness, and on the second inch nearest the pith in pieces 3 inches or less in thickness.

Close Grain

120. The following methods for determining rate of growth of Douglas fir and redwood are for use with grades where close grain is required.

121. Close-grained Douglas fir shall average on either one end or the other not less than 6 nor more than 20 annual rings per inch, over a 3-inch portion of a radial line located as described below.

122. Pieces averaging 5 rings or more than 20 shall be accepted as equivalent of close grain if having one-third or more summerwood.

123. Close-grained redwood shall average on either one end or the other not less than 10 nor more than 35 annual rings per inch, over a 3-inch portion of a radial line located as described below.

Holes

124. Holes from knots and from causes other than knots are measured and limited as are knots.

Faces and Edges

125. The faces of a piece of lumber are the four longitudinal surfaces of the piece, sometimes further designated as "wide" faces or "narrow" faces.

126. The edges of a piece of lumber are understood to be the narrower faces, and the sides the wider faces. In describing the locations of knots and other grade limitations in structural lumber, however, the edges of a given face are understood to be the intersection of two adjacent faces, commonly called corners.

127. In a piece of lumber graded for use in bending, wide faces shall be taken as vertical faces, and narrow faces as horizontal faces, unless otherwise specified.

128. When the faces of structural lumber, 5 by 5 inches and larger, are of equal nominal width, grades for posts and timbers shall be used, unless otherwise specified. When such faces are of unequal nominal width, grades for beams and stringers shall be used, unless otherwise specified.

Knots

129. Knots crossing the corners of pithless pieces which do not extend beyond the area of permissible wane are not considered.

130. Cluster knots are not permitted in structural grades.

Knots in Joists and Planks

131. In joists and planks the only knots measured on narrow faces, except knots that cross the corners of pithless pieces, are those which do not show on wide faces, and their size is the distance between lines enclosing the knot and parallel to the edges of the piece.

132. On wide faces the size of knot is its average diameter, except that knots which cross the corners of pithless pieces and contain the intersections of adjacent faces shall be measured only on the end appearing on the face containing the shorter portion, and knots which extend entirely across a face shall be measured at both ends, both measurements between lines enclosing the knot and parallel to the edges of the piece.

133. The size of knots on narrow faces and at edges of wide faces may increase proportionately from the size permitted in the middle third of the length to twice that size at the ends of the piece.

134. The size of knots on wide faces may increase proportionately from the size permitted at the edge to the size permitted along the center line.

135. The sum of the sizes of all knots within the middle half of the length of any face, measured as specified by paragraphs 131 and 132 for the face under consideration, shall not exceed, in a piece 16 feet long, four and one-half times the size of the largest knot allowed on that face. In other lengths this sum shall not exceed the sum permitted in the 16-foot length multiplied by the fraction $(L + 16)/32$, where $L =$ length in feet. In pieces longer than 16 feet the sum of the sizes of the knots within any 8-foot portion of the middle half of the length shall not exceed four and one-half times the largest knot allowed on that face.

Knots in Beams and Stringers

136. In beams and stringers, the size of a knot on a narrow face is the distance between lines enclosing the knot and parallel to the edges of the piece, except that when the knot extends into the adjacent fourth of the wide face the smallest diameter is its

size. The size of a knot on the wide face is its smallest diameter, but at the edges the size is limited as on the narrow face.

137. Knots which cross the corners of pithless pieces and contain the intersections of adjacent faces shall be measured only at the end appearing on the face containing the shorter portion; knots which extend entirely across a face shall be measured at both ends, both measurements between lines enclosing the knot and parallel to the edges of the piece.

138. The size of knots on narrow faces and at edges of wide faces may increase proportionately from the size permitted in the middle third of the length to twice that size at the ends of the piece, except that the size of no knot shall exceed the size permitted along the center line of the wide face.

139. The size of knots on wide faces may increase proportionately from the size permitted at the edge to the size permitted along the center line.

140. The sum of the sizes of all knots within the middle half of the length of any face, measured as specified by paragraph 136, for the face under consideration, shall not exceed, in a piece, 16 feet long, four times the size of the largest knot allowed on that face. In other lengths this sum shall not exceed the sum permitted in the 16-foot length multiplied by the fraction $(L + 16)/32$, where $L =$ length in feet. In pieces longer than 16 feet the sum of the sizes of the knots within any 8-foot portion of the middle half of the length shall not exceed four times the largest knot allowed on that face.

Knots in Posts and Timbers

141. In posts and timbers, the size of a knot at any point on any face is its average diameter, except that knots which cross the corners of pithless pieces and contain the intersections of adjacent faces shall be measured only at the end appearing on the face containing the shorter portion, and knots which extend entirely across a face shall be measured at both ends, both measurements between lines enclosing the knot and parallel to the edges of the piece.

142. The sum of the sizes of all knots in any 6 inches of the length of a piece, measured as specified in paragraph 141, shall not exceed twice the maximum permissible size of knot. Two knots of maximum permissible size are not allowed in the same 6 inches of length on any face.

Shakes, Checks, and Splits

143. The sum of the sizes of shakes, checks, splits, or any combination thereof shall not exceed the permissible size of shake.

144. Checks extending entirely across the end within the middle half of the height shall not extend into the piece at the center of the width at the end a distance greater than the size of the allowable shake.

Shakes in Joists and Planks, Beams and Stringers

145. Shakes are measured at the ends of a piece. Only those within the middle half of the height of the piece are considered. (Height equals width of wide face.) The size of a shake is the distance between lines enclosing the shake and parallel to the wide faces of the piece. The permissible size is determined by the width of the narrow face of the piece.

Shakes in Posts and Timbers

146. The size of a shake is the greater dimension of a rectangle enclosing the shake and having its sides parallel to the faces of the piece.

Checks and Splits in Joists and Planks, Beams and Stringers

147. The limitations apply to both ends but only within the middle half of the height of a piece and within three times the height from the end. (Height equals width of wide face.) The size of checks within this portion of a piece shall be their estimated area, along the horizontal section showing maximum area, divided by three times the height of the piece. When checks on two parallel faces are opposite or approximately so, the sum of their sizes is taken.

Checks and Splits in Posts and Timbers

148. Size of checks shall be the sum of seven depth measurements, one on the end and three on each of two sides, divided by 3. Each measurement shall be the greatest depth of any check within the above-specified portion of the piece; the measurement on the end made at the middle of the width of the piece and the six measurements on the sides at 1, 2 and 3 times the height of the piece from the end in joist, plank, beams and stringers, and the width of the piece from the end in posts and timbers. Each depth measurement shall be determined by the penetration into the piece of a probe $\frac{1}{64}$ inch thick and ¼ inch wide.

Dimensions

149. The standard sizes of structural timbers are as shown in the following table:

	Joists and Planks	*Beams and Stringers*	*Posts and Timbers*
Nominal thickness	2″ to but not including 5″	5″ or more	5″ or more
Nominal width	4″ or more	8″ or more	5″ or more
Standard length	Multiples of 2′	Multiples of 2′	Multiples of 2′

Sizes in fractional inches or odd feet are special cutting.

Tolerances and Surfacing Allowances

150. The actual dimensions of structural timbers when green shall conform to the following tolerances and surfacing allowances.

	Nominal Thickness	*Minimum* Rough Thickness*	*Surfaced Thickness S1S or S2S*	*Nominal Width*	*Minimum* Rough Width*	*Surfaced Width S1E or S2E*
Joists, planks and other framing members with load applied to either wide face or narrow face.	2″	⅛″ off	⅜″ off	4″	$\frac{3}{16}$″ off	⅜″ off
	3″	$\frac{3}{16}$″ off	do	6″	do	do
	4″	do	do	8″ & wdr.	¼″ off	½″ off
Beams, stringers and other heavy members with load applied to narrow face.	5″, 6″	do	½″ off	8″ & wdr.	do	do
	8″ and thicker	¼″ off	do			
Posts, timbers and other members to carry longitudinal loads.	5″	$\frac{3}{16}$″ off	⅜″ off	5″	$\frac{3}{16}$″ off	⅜″ off
	6″	do	½″ off	6″	do	½″ off
	8″ and thicker	¼″ off	do	8″ & wdr.	¼″ off	do

* Permissible in not to exceed 20 percent of the pieces in any one shipment.

Pages 7–23 and 7–24

Renumber Paragraphs 122 to 128, inclusive, as Paragraphs 151 to 157, inclusive.

Page 7–69

Delete bold face heading:

GRADING RULES AND CLASSIFICATION OF TIMBER AND LUMBER FOR RAILWAY USES

and replace with the following:

NOMENCLATURE OF COMMERCIAL DOMESTIC SOFTWOODS AND HARDWOODS

1940

Revise Paragraph heading 101 reading—

101. Nomenclature of Commercial Domestic Softwoods
to read:

501. Softwoods

Page 7–71

Revise Paragraph 102 reading—

102. Nomenclature of Commercial Domestic Hardwoods
to read:

502. Hardwoods

Pages 7–73 to 7–80, inclusive

Withdraw the heading II CLASSIFICATIONS and all of the material following on pages 7–74 to 7–80 inclusive, and substitute the following matter:

DEFINITIONS OF TERMS USED IN DESCRIBING STANDARD GRADES FOR LUMBER

601. Definitions

The commonly recognized characteristics and conditions occurring in lumber are:

Bark pockets
Bird's-eye
Checks
Cross breaks
Cross grain
Decay
Gum spots and streaks, etc.
Holes
Knots
Mismanufacture
Pitch
Pitch pockets
Pitch seams
Pitch streaks
Pith
Pith flecks
Shake
Splits
Stain
Wane
Warp

advanced (or typical) decay. See DECAY.

air dried. Seasoned by exposure to the atmosphere, in the open or under cover, without artificial heat.

all-heart. Of heartwood throughout; that is, free of sapwood.

American standard lumber. See paragraph 830.
annual ring. Growth layer put on in a single growth year.
bark pocket. Patch of bark partially or wholly enclosed in the wood; classified as are pitch pockets.
bastard sawn. With annual rings which form angles of 30° to 60° with the surface of the piece.
beam. Lumber of rectanguler cross section, graded with respect to its strength in bending when loaded on the narrow face. Nominal thicknesses: 5 or more inches; Nominal widths: 8 or more inches. Standard sizes: S1S, S1E, S2S, or S4S, ½ inch off each way. Standard lengths: Multiples of 2 feet.
bird's-eye. Small central spot with the wood fibers arranged around it in the form of an ellipse, so as to give the appearance of an eye. Not objectionable, unless unsound or hollow.
blemish. Anything marring the appearance of lumber which is not classifiable as a DEFECT.
board. See paragraphs 802 and 848.
bow. See WARP.
boxed pith. When the pith is between the four faces on an end of a piece..
branch knot. See KNOT.
break. See CROSS BREAK.
bright (sapwood). Unstained.
broadleaved. See HARDWOOD.
burl. Distorted grain surrounding the piths of several buds which did not develop.
burn. See MACHINE BURN.
butted. Sawed square at the ends.
characteristics. Distinguishing features which by their extent and number determine the quality of a piece of lumber.
check (seasoning). Lengthwise separation of the wood, most of which occurs across the rings of annual growth.
surface check. Occurs on a surface of a piece.
small surface check. Perceptible opening not over 4 inches long.
medium surface check. Not over $\frac{1}{32}$ inch wide and over 4, but not over 10 inches long.
large surface check. Over $\frac{1}{32}$ inch wide and over 10 inches long.
end check. Occurs on an end of a piece.
through check (split). Extends from one surface through the piece to the opposite surface or to an adjoining surface.
heart check. See SHAKE.
chipped grain. Area where the surface is chipped or broken out in very short particles below the line of cut. Not classed as torn grain and, as usually found, is not considered unless in excess of 25 percent of the surface involved.
clear. Free of all blemishes, characteristics, or defects.
close grain. See paragraphs 120, 123.
closed pitch pocket. See PITCH POCKET.
coarse grain. Wide annual rings, or rings made conspicuous by considerable difference in proportions of springwood and summerwood.
common lumber. See paragraph 844.
conifer. See SOFTWOOD.
crook. See WARP.
cross break. Separation of the wood cells across the grain, such as may be due to tension resulting from unequal shrinkage or mechanical stress.

cross cutting. See CUTTING.

cross grain (slope of grain). Deviation of the fiber from a line parallel to the sides of the piece. Cross grain may be diagonal, spiral, or both.

slight cross grain. Slope of grain not over 1 inch in a length of 15 inches.

medium cross grain. Slope of grain over 1 inch in a length of 15 inches, but not over 1 inch in a length of 10 inches.

steep cross grain. Slope of grain over 1 inch in a length of 10 inches.

cross grain (shingles). Deviation of the fiber from the longitudinal axis of the shingle. See paragraph 868.

cup. See WARP.

cup shake. See SHAKE.

cutting. The portion of a board or plank obtained by sawing it crosswise or lengthwise, or both ways, which is then flat enough to be surfaced on both sides to standard thickness and which has straight edges.

decay. Disintegration of wood substance due to action of wood-destroying fungi. Also known as dote and rot.

advanced (or typical) decay. Older stage of decay in which disintegration is readily recognized because the wood has become punky, soft, and spongy, stringy, shaky, pitted, or crumbly. Decided discoloration or bleaching of the rotted wood is often apparent.

incipient decay. Early stage of decay in which disintegration has not proceeded far enough to soften or otherwise change the hardness of the wood perceptibly. Usually accompanied by a slight discoloration or bleaching of the wood.

pocket rot. Typical decay which appears in the form of a hole, pocket, or area of soft rot, usually surrounded by apparently sound wood.

water soak or stain. Water-soaked area in heartwood, usually interpreted as the incipient stage of certain wood rots.

defect. Any irregularity in or on wood that may lower its durability, strength, or utility value.

de-grades. Pieces which on reinspection prove of lower quality than the grade in which they were shipped.

density rules. See paragraphs 107, 110.

diagonal grain (lumber). See CROSS GRAIN.

diagonal grain (shingles). Deviation of the grain from a line parallel to the edges of the shingle. See paragraph 869.

dimension. See paragraphs 802 and 848.

discoloration. See STAIN.

dote. See DECAY.

double end trimmed. Sawed square at both ends.

dressed lumber. See paragraph 804, Surfaced.

dry. Not green. See AIR DRIED, KILN DRIED, MOISTURE CONTENT, SEASONING, and SMOKE DRIED.

edge. See paragraph 126.

edge grain (vertical grain). Annual rings (so-called grain) which form an angle of 45° or more with the surface of the piece. See also FLAT GRAIN.

encased knot. See KNOT.

end check. See CHECK.

face. See paragraphs 125, 128.

firm knot. See KNOT.

firm red heart. A stage of incipient decay characterized by a reddish color in the heartwood, which does not unfit the wood for the majority of yard purposes.

flat grain (slash grain). Annual rings (so-called grain) which form an angle of less than 45° with the surface of the piece. See also EDGE GRAIN.

fleck. See PITH FLECK.

gouge. See MACHINE GOUGE.

grain. See CHIPPED, COARSE, CROSS, DIAGONAL, EDGE, FLAT, LOOSENED, MIXED, RAISED, SPIRAL, STRAIGHT, and TORN GRAIN.

green. Unseasoned; not dry.

gum pocket. Well-defined opening between rings of annual growth which usually contains, or did contain, more or less gum; classified as are pitch pockets. Bark also may be in the pocket.

gum seam. Check or shake filled with gum.

gum spot. Accumulation of gumlike substance occurring as a small patch. May occur in conjunction with a bird-peck or other injury to the growing wood.

gum streak. Well-defined accumulation of gum in a more or less regular streak; classified as are pitch streaks.

hard rot. See INCIPIENT DECAY.

hardwood. One of the group of trees which have broad leaves. The term has no reference to the hardness of the wood.

heart check. See PITH SHAKE.

heart face. Face side free of sapwood.

heart, red. See FIRM RED HEART.

heart shake. See PITH SHAKE.

heartwood. Inner core of the tree trunk comprising the annual rings containing nonliving elements; usually darker in color than sapwood.

hit and miss. Series of surfaced areas with skips not over $\frac{1}{16}$ inch deep between them.

hit or miss. To skip or surface a piece for a part or the whole of its length, provided it is nowhere more than $\frac{1}{16}$ inch scant.

holes. Holes may extend partially or entirely through a piece and be from any cause. To determine the size of a hole, average the maximum and minimum diameters, unless otherwise specified.

pin hole. Not over $\frac{1}{16}$ inch in diameter.

medium hole. Over $\frac{1}{16}$ inch, but not over $\frac{1}{4}$ inch in diameter.

large hole. Over $\frac{1}{4}$ inch in diameter.

hollow knot. See KNOT.

incipient decay. See DECAY.

industrial lumber. See paragraphs 848, 850.

intergrown knot. See KNOT.

joists. Lumber of rectangular cross section, graded with respect to its strength in bending when loaded either on the narrow face as joist or on the wide face as plank. Nominal thicknesses: 2 inches to, but not including, 5 inches. Nominal widths: 4 or more inches. Standard thicknesses: S1S or S2S, $\frac{3}{8}$ inch off. Standard widths: 4 to 7 inches S1E or S2E, $\frac{3}{8}$ inch off; 8 or more inches wide S1E or S2E, $\frac{1}{2}$ inch off. Standard lengths: Multiples of 2 feet.

kiln dried. Seasoned in a chamber by means of artificial heat.

knot. Branch or limb, embedded in the tree and cut through in the process of lumber manufacture; classified according to size, quality, and occurrence. To determine the size of a knot, average the maximum length and maximum width, unless otherwise specified.

knot size:

pin knot. Not over ½ inch in diameter.

small knot. Over ½ inch, but not over ¾ inch in diameter.

medium knot. Over ¾ inch, but not over 1½ inches in diameter.

large knot. Over 1½ inches in diameter.

knot quality:

decayed knot. Softer than the surrounding wood, and containing advanced decay.

encased knot. Its rings of annual growth are not intergrown with those of the surrounding wood. The encasement may be partial or complete; of pitch or bark.

hollow knot. Apparently sound and having in it a hole over ¼ inch in diameter.

intergrown knot. Its rings of annual growth are completely intergrown with those of the surrounding wood.

loose knot. Not held tightly in place by growth or position, and cannot be relied upon to remain in place.

unstable knot. Will hold its place in a dry piece under ordinary conditions; can be moved under pressure, though not easily pushed out.

pith knot. Sound knot having pith hole not over ¼ inch in diameter.

sound knot. Solid across its face, as hard as the surrounding wood, and showing no indications of decay. May vary in color from red to black.

star-checked knot. Having radial checks.

tight knot. So fixed by growth or position as to retain its place.

firm knot. Solid across its face, but containing incipient decay.

water-tight knot. Its rings of annual growth are completely intergrown with those of the surrounding wood on one surface of the piece, and it is sound on that surface.

knot occurrence:

branch knots. Two or more divergent knots sawed lengthwise and tapering toward the pith at a common point.

corner knot (in structural lumber only). Contains the intersection of adjacent faces; measured only as provided in paragraphs 131, 132, 137, 141.

knot cluster. Two or more knots grouped together, the fibers of the wood being deflected around the entire unit. A group of single knots is not a knot cluster.

single knot. Occurs by itself, the fibers of the wood being deflected around it.

loose knot. See KNOT.

loosened grain. Small portion of the wood loosened but not displaced.

lumber. See GENERAL, under American Lumber Standards for Softwood Lumber.

machine burn. Darkening or charring due to overheating by machine knives.

machine gouge. Groove due to the machine cutting below the desired line of cut.

massed pitch. See PITCH.

matched lumber. See paragraph 804.

miscut lumber. That having a greater variation in thickness or width at different places on the piece than that specified for VARIATION IN SAWING.

mismanufacture. Includes all defects or blemishes produced in manufacturing. See CHIPPED GRAIN, HIT AND MISS, HIT OR MISS, LOOSENED GRAIN, MACHINE BURN, MACHINE GOUGE, MISCUT LUMBER, MISMATCHED LUMBER, RAISED GRAIN, SKIP, TORN GRAIN, and VARIATION IN SAWING.

mismatched lumber. Worked lumber that does not fit tightly at all points of contact between adjoining pieces, or in which the surfaces of adjoining pieces are not in the same plane.

slight mismatch. Surface variation not over $\frac{1}{64}$ inch.

medium mismatch. Surface variation over $\frac{1}{64}$, but not over $\frac{1}{32}$ inch.
heavy mismatch. Surface variation over $\frac{1}{32}$ inch.

mixed grain. Any combination of edge grain and flat grain.

moisture content. Weight of the water in wood expressed in percentage of the weight of oven-dry wood.

patterned lumber. See paragraph 804.

peck (found in cedar and cypress). Channeled or pitted areas or pockets of localized decay.

pecky. Characterized by PECK.

pin hole. See HOLE.

pin knot. See KNOT.

pitch. Accumulation of resin in the wood cells in a more or less irregular patch.
light pitch. Lightly evident presence of pitch.
medium pitch. Trace of pitch slightly more evident than light pitch.
heavy pitch. Very evident presence of pitch showing by its color and consistency.
massed pitch. Clearly defined accumulation of solid pitch in a body by itself.

pitch pocket. Well-defined opening between rings of annual growth, usually containing, or which has contained, more or less pitch, either solid or liquid. Bark also may be present in the pocket.
very small pitch pocket. Not over ⅛ inch in width and not over 2 inches in length.
small pitch pocket. Not over ⅛ inch in width and not over 4 inches in length; or not over ¼ inch in width and not over 2 inches in length.
medium pitch pocket. Not over ⅛ inch in width and not over 8 inches in length; or not over ⅜ inch in width and not over 4 inches in length.
large pitch pocket. Width or length exceeds the maximum permissible for a medium pitch pocket.
closed pitch pocket. Does not show an opening on both sides of the piece.
open (through) pitch pocket. Is cut across on both sides of the piece.

pitch seam. Shake or check filled with pitch.

pitch streak. Well-defined accumulation of pitch in a more or less regular streak.
small pitch streak. Not over one-twelfth the width by one-sixth the length of the surface on which it occurs.
medium pitch streak. Over one-twelfth, but not over one-sixth the width by over one-sixth but not over one-third the length of the surface on which it occurs.
large pitch streak. Over one-sixth the width by one-third the length of the surface on which it occurs.

pith. Small soft core in the structural center of a log.
boxed pith. When the pith is within the four faces on an end of a piece.

pith fleck. Narrow streak resembling pith on the surface of a piece, usually brownish, up to several inches in length, resulting from burrowing of larvae in the growing tissue of the tree.

pith knot. See KNOT.

pith shake. See SHAKE.

plain sawed. See FLAT GRAIN.

plank. See paragraph 803; also JOISTS.

pocket. See BARK, GUM, and PITCH POCKET.

pocket rot. See DECAY.

post. Lumber of square or approximately square cross section, graded primarily for use as posts or columns carrying longitudinal load, but adapted to miscellaneous uses in which strength in bending is not especially important. Nominal sizes: 5 by 5 inches and larger. Standard sizes: S1S, S1E, S2S, or S4S, in less than 6 by 6 inches, 3/8 inch off each way; 6 by 6 inches and larger, 1/2 inch off each way. Standard lengths: Multiples of 2 feet.

quarter sawed. See EDGE GRAIN.

radial. Coincident with a radius from the axis (pith) of the tree to the circumference.

raised grain. Roughened condition of the surface of dressed lumber in which the hard summerwood is raised above the softer springwood, but not torn loose from it.

red heart. See FIRM RED HEART.

rift grain. See EDGE GRAIN.

ring. See ANNUAL RING.

rot, hard. See INCIPIENT DECAY.

rot, soft. See ADVANCED DECAY.

rough edge. Piece which failed to surface on both edges because of scant sawing.

rough lumber. See paragraph 804.

rough spot. See SKIP.

round shake. See SHAKE.

sap. See SAPWOOD.

sapwood. Outer layers of growth in a tree, exclusive of bark, which contain living elements; usually lighter in color than heartwood.

bright sapwood. Unstained.

saw sized. Sized with fine saws for uses where exact dimensions but not dressed surfaces are necessary.

sawing. See VARIATION IN SAWING, MISCUT LUMBER, BASTARD SAWN, BUTTED, DOUBLE END TRIMMED, PLAIN SAWED (FLAT GRAIN), QUARTER SAWED (EDGE GRAIN), SAW SIZED.

seam. See GUM and PITCH SEAM.

seasoning. Evaporation or extraction of moisture from green or partially dried wood. See paragraph 811, also AIR DRIED, KILN DRIED, MOISTURE CONTENT, SMOKE DRIED.

select lumber. See paragraph 844.

Shake. Separation along the grain, most of which occurs between the rings of annual growth.

fine shake. A barely perceptible opening.

slight shake. More than a perceptible opening, but not over 1/32 inch wide.

medium shake. Over 1/32, but not over 1/8 inch wide.

open shake. Over 1/8-inch wide.

cup shake. Does not completely encircle the pith.

round shake. Completely encircles the pith.

shell shake. When both ends of a shake which has been cut across occur on the face or edge of a piece.

through shake. Extending from one surface through the piece to the opposite surface or to an adjoining surface.

pith shake, (heart check). Extends across the rings of annual growth in one or more directions from the pith toward, but not to the surface of a piece. Distinguished from season check by having its greatest width nearest the pith, whereas the greatest width of a season check is ordinarily at the surface of a piece, and when a piece has boxed pith the greatest width of a season check is farthest from the pith.

shiplapped lumber. See paragraph 804.

side cut. A pithless piece.

single knot. See KNOT.

skip. Area on a piece that failed to surface, classified as follows:

slight skip. Area not over six times the width of the piece that the planer knife failed to surface smoothly.

shallow (small) skip. Area not over six times the width of the piece that the planer knife failed to touch by not over $\frac{1}{32}$ inch.

deep (heavy) skip. Area not over twelve times the width of the piece that the planer knife failed to touch by not over $\frac{1}{16}$ inch.

slash grain. See FLAT GRAIN.

smoke dried. Seasoned in the open, exposed to the heat and smoke of a fire maintained beneath and within stacks of lumber.

soak. See WATER SOAK.

soft rot. See ADVANCED DECAY.

softwood. One of the group of trees which have needle-like or scale-like leaves. The term has no reference to the softness of the wood.

solid knot. See KNOT.

sound. Free of decay.

spiral grain. Fibers which extend spirally about, instead of vertically along, the bole of a tree.

split (through check). Lengthwise separation of the wood extending from one surface through the piece to the opposite surface or to an adjoining surface.

short split. Length does not exceed either the width of a piece or one-sixth its length.

medium split. Length exceeds the width of a piece, but does not exceed one-sixth its length.

long split. Length exceeds one-sixth the length of a piece.

spot. See GUM and ROUGH SPOT.

springwood. More or less open and porous tissue marking the inner part of each annual ring, formed early in the period of growth.

square edged. Free of wane.

square (of shingles). See paragraph 871.

stain. Discoloration, occurring on or in lumber, of any color other than the natural color of the piece on which it appears; classified as follows:

light stain. Slight difference in color which will not materially impair the appearance of the piece if given a natural finish.

medium stain. Pronounced difference in color which, although it does not obscure the grain of the wood, is customarily objectionable in a natural but not in a painted finish.

heavy stain. Difference in color so pronounced as practically to obscure the grain of the wood.

straight grain. Wood in which the fiber does not deviate from a line parallel to the sides of the piece sufficiently to constitute slight cross grain.

streak. See GUM and PITCH STREAK.

stringer. See BEAMS.

strip. See paragraph 802.

structural lumber. See BEAMS.

summerwood. Denser fibrous outer portion of each annual ring, usually without conspicuous pores, formed late in the growing period, not necessarily in summer.

surface check. See CHECK.

surfaced lumber. See paragraph 804.

through check. See CHECK.

through shake. See SHAKE.

tight knot. See KNOT.

timbers. See paragraphs 802, 803. See BEAMS and POSTS.

torn grain. Part of the wood torn out in dressing; classified as follows:

slight torn grain. Not over $\frac{1}{32}$ inch in depth.

medium torn grain. Over $\frac{1}{32}$, but not over $\frac{1}{16}$ inch deep.

heavy torn grain. Over $\frac{1}{16}$, but not over ⅛ inch deep.

deep torn grain. Over ⅛ inch deep.

typical decay. See DECAY.

uneven sawing. See VARIATION IN SAWING.

unsound. Decayed.

unstable knot. See KNOT.

variation in sawing. Deviation from the line of cut. Slight variation is not over $\frac{1}{16}$ inch in 1-inch lumber, ⅛ inch in 2-inch, $\frac{3}{16}$ inch in 3- to 7-inch, and ¼ inch in 8-inch and larger lumber.

vertical grain. See EDGE GRAIN.

wane. Bark, or the lack of wood from any cause, on the corner of a piece.

slight wane. Not over ¼ inch wide on the surface on which it appears, for one-sixth the length and one-fourth the thickness of the piece.

medium wane. Over ¼ inch, but not over ½ inch wide on the surface on which it appears, for one-sixth the length and one-fourth the thickness of the piece.

large wane. Over ½ inch wide on the surface on which it appears, or over one-sixth the length and one-fourth the thickness of the piece, or both.

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Delete the following items:

CB1S&E	Edge and center bead one side; i.e., surfaced one or two sides and with a longitudinal edge and center bead on a surfaced face.
CB2S&E	Edge and center bead two sides; i.e., all four sides surfaced and with a longitudinal edge and center bead on the two faces.
CV1S&E	Edge and center V one side; i.e., surfaced one or two sides and with a longitudinal edge and center V-shaped groove on a surfaced face.
CV2S&E	Edge and center V two sides; i.e., all four sides surfaced and with a longitudinal edge and center V-shaped groove on the two faces.

Insert following alphabetically:

E&CB1S	Edge and center bead one side; surfaced one or two sides and with a longitudinal edge and center bead on a surfaced face.
E&CB2S	Edge and center bead two sides; all four sides surfaced and with a longitudinal edge and center bead on the two faces.
E&CV1S	Edge and center V one side; surfaced one or two sides and with a longitudinal edge and center V-shaped groove on a surfaced face.
E&CV2S	Edge and center V two sides; all four sides surfaced and with a longitudinal edge and center V-shaped groove on each of the two faces.
M.G	Mixed grain..

Pages 7–85 to 7–99, inclusive—

Delete all of the matter now appearing under the heading:

AMERICAN LUMBER STANDARDS FOR SOFTWOOD LUMBER

and substitute the following:

GENERAL

[Lumber is the product of the saw and planing mill not further manufactured than by sawing, resawing, and passing lengthwise through a standard planing machine, cross-cutting to length and working. Lumber of thickness not in excess of one-quarter inch to be used for veneering is classified as veneer.]

Classifications

Use classification

801. For the purpose of simplification of sizes and grades and of equalizing, among species used for similar general purposes, the grades of a similar name, lumber shall be classified by principal use as shown below. Different grading rules may apply to each class.

Yard lumber.—Lumber of all sizes and patterns which is intended for general building purposes. The grading of yard lumber is based on the intended use of the particular grade and is applied to each piece with reference to its size and length when graded, without consideration to further manufacture.

Factory and shop lumber.—Lumber intended to be cut up for use in further manufacture. It is graded on the basis of the percentage of the area which will produce a limited number of cuttings of a specified, or of a given minimum, size and quality.

Structural lumber.—Lumber that is 2 or more inches thick and 4 or more inches wide, intended for use where working stresses are required. The grading of structural lumber is based on the strength of the piece and the use of the entire piece.

Size classification

802. Yard lumber is classified by size as shown below:

Strips.—Yard lumber less than 2 inches thick and less than 8 inches wide.

Boards.—Yard lumber less than 2 inches thick, 8 or more inches wide.

Dimension.—All yard lumber except boards, strips, and timbers; that is, yard lumber from 2 inches to but not including 5 inches thick, and of any width.

Timbers.—Lumber 5 or more inches in least dimension.

803. Structural lumber is classified by size as shown below:

Dimension (joists and planks).—Lumber from 2 inches to but not including 5 inches thick, and 4 or more inches wide.

Timbers.—Lumber 5 or more inches in least dimension.

Beams and stringers.—Pieces of rectangular cross section 5 or more inches thick, and 8 or more inches wide.

Posts and timbers.—Pieces of square or approximately square cross section 5 by 5 inches and larger.

Manufacturing Classification

804. Lumber is classified according to the extent to which it is manufactured as shown below:

Rough lumber.—Lumber undressed as it comes from the saw.

Surfaced lumber.—Lumber that is dressed by running it through a planer. It may be surfaced on one side (S1S), two sides (S2S), one edge (S1E), two edges (S2E), or on a combination of sides and edges: (S1S1E), (S2S1E), (S1S2E), or (S4S).

Worked lumber.—Lumber which has been run through a matching machine, sticker, or moulder. Worked lumber may be:

Matched lumber.—Lumber that is worked to provide a close tongue-and-groove joint at the edges or, in the case of end-matched lumber, at the ends also.

Shiplapped lumber.—Lumber that is worked to provide a close rabbetted or lapped joint at the edges.

Patterned lumber.—Worked lumber that is shaped to a patterned or moulded form.

General Grading Rule Provisions

Size and Grade

805. To the extent to which differences in the characteristics of species, in quality of logs, in conditions of manufacture, and in the uses to which the product is put, will, in practical application, permit, the basic provisions for the grading of lumber shall be uniform.

806. Lumber not conforming to standard sizes or grades and that intended for special uses shall be covered by special contract and inspection.

807. The characteristics and limitations in any grade or species vary as the area of the piece to be graded increases or diminishes with respect to the basic size or area specified, but their size shall not exceed that permitted in the respective grading rules.

808. Whenever any characteristics other than those defined in regional association grading rules are encountered, they shall be regarded as equivalent (equal) to permitted characteristics or prescribed limitations in proportion to their effect on the strength, appearance, or other utility value of the piece in the grade under consideration.

809. Characteristics permitted and limitations prescribed in rough lumber shall be the same as those applying to dressed lumber of like kind and grade, and, in addition, such others as will disappear in dressing such lumber to standard sizes shall be allowed.

810. Mixed grades, other than the two highest recognized grades for each species, not specifying the proportion of each grade, are not American standard grades.

811. Specifications dealing with lumber seasoning and moisture content shall be developed by each regional manufacturers' association in accordance with its own conditions and the requirements of the users of its products. Such specifications adopted from time to time by any regional association shall be filed with the Central Committee on Lumber Standards for approval. Each association publishing grading rules shall include definitions of any terms used therein to describe condition of seasoning, such as air dry, kiln dry, shipping dry.

812. In addition to meeting its grade specifications, lumber shipped shall conform to such grain, heartwood, sapwood, moisture content, or other specifications as may have been agreed to in the contract of purchase and sale.

Description, Measurement, and Tally

813. To be *standard,* lumber shall be described by the thicknesses and widths specified in paragraph 852, and see also definitions of BEAMS, JOISTS and POSTS. Lumber of other sizes shall be considered *special.*

814. The dressed dimensions specified in paragraph 852 shall apply to lumber in the condition of seasoning as sold and shipped.

815. Board measure is the term used to indicate that a board foot is the unit of measurement of lumber. A board foot is the quantity of lumber contained in, or derived from, by drying, planing, or working, or by any combination of these means, a piece of rough green lumber 1 inch thick, 12 inches wide, and 1 foot long, or its equivalent in thicker, wider, narrower, or longer lumber.

816. Except moulding, which shall be tallied in linear feet, lumber shall be tallied *board measure.* The measurement of rough dry or dressed lumber shall be based on the corresponding nominal dimensions of rough green lumber. The measurement of lumber of thickness less than 1 inch shall be based on the surface dimensions; i.e., width and length.

817. To determine the board-foot contents of lumber thicker than 1 inch, the surface measure shall be multiplied by the nominal thickness in inches and fractions of an inch.

818. Lumber finished to special size shall be tallied as of the standard rough size necessarily used in its manufacture.

819. Lumber of stock sizes shall be tallied by the number of pieces of each size and length in the shipment.

820. Lumber shipped on the basis of board measure shall be tallied by the number of pieces and of board feet in each piece.

821. In shipments of lumber measured with a board rule on actual widths, pieces measuring to the even half foot shall be alternately counted as of the next higher and lower foot count; fractions below the half foot shall be dropped, and fractions above the half foot shall be counted as of the next higher foot.

Shipping Provisions

822. When lumber *not of standard size* is shipped, its actual thickness and width shall be shown on the invoice.

823. In shipments of rough finish and boards, pieces one-half inch or more above the count thickness, such as may be produced by uneven sawing, may, at the option of the buyer, be rejected, or accepted as of the next lower grade.

824. The average length of a shipment of lumber shall be computed by dividing the total length in feet by the total number of pieces in a shipment.

825. The average width of a shipment of lumber 1 inch or less in thickness shall be computed by dividing the total board feet by the total length in feet and multiplying the result by 12. The total board-foot tally of lumber thicker than 1 inch shall be divided first by the thickness as expressed in inches and fractions of an inch.

826. Each length of bundled lumber except end-matched lumber and bevel siding shall be bundled separately.

Tally Cards

827. Cards should be placed in cars of lumber at mill of origin, showing piece tally by grades and sizes: *Provided,* That a wholesale dealer or other buyer or shipper may,

by arrangement with mill of origin, provide for the use, for this purpose, of a wholesaler's or buyer's or shipper's car card: *Provided,* That in such case said wholesaler, buyer, or shipper whose name appears on card is financially responsible for the correctness of the tally as shown on such car card; *And provided,* That this shall not be construed as relieving the manufacturer from his responsibility, if any, to such wholesaler, buyer, or shipper.

828. The grades thus required to be entered on tally card shall be the official association grades as defined in published grading rules: *Provided,* That this requirement is not construed as prohibiting the entry on tally cards of special grades, but that such entry is not recognized under *American Lumber Standards.*

829. The *American Lumber Standards* shall not apply to "special" grades (that is, grades not recognized in published grading rules) whether entered on tally cards or not.

Inspection and Service

830. Lumber manufactured, graded, measured, and described, as herein provided, is American standard lumber. The purchase, sale, or shipment of lumber as American standard is construed as involving agreement to submit to official association inspection any complaint involving either standard sizes or standard grades.

831. Lumber must be accepted on grade in the form in which it is shipped. Any subsequent change by manufacture, millwork, or dry kilning will prohibit an inspection for the adjustment of claims, except with the consent of all parties interested.

832. Official association inspection service for the inspecting of lumber sold as of standard size and standard grade shall be available to nonmembers of associations upon request and at a reasonable charge.

833. In case of complaint on account of the grade or tally of any shipment of standard size or standard grade, official association reinspection shall be available.

834. Official inspection service is required to be available for the inspection of grades not described in association rules (see par. 806) only when written, detailed specifications accompany the request for such inspection; and for the inspection of standard grades in nonstandard sizes only on the basis of paragraph 807, unless otherwise prescribed in the contract of purchase and sale.

835. When buyers demand, and will pay the cost thereof, a certificate made by a certified association inspector shall be furnished with each shipment so arranged for.

836. Upon receipt of complaint from the purchaser the seller shall immediately request the association under whose rules shipment has been made to provide official reinspection or retally, as the case may be, according to its inspection rules in effect at the time of execution of contract, and the purchaser shall lend all reasonable assistance to facilitate the reinspection or retally.

837. The expense of such reinspection or retally may be divided between the buyer and seller, or may be borne by either, according to agreement between them, but the person calling for the reinspection shall be responsible to the association for the costs thereof.

838. In case of complaint involving tally, the entire item shall be held intact for retally.

839. In case of complaint regarding grade or size but not involving tally, the buyer is required to accept that portion of a shipment of lumber of standard grade or standard size which is up to grade or of standard size, as the case may be, holding intact that portion thereof the grade or size of which is in dispute for official association inspection,

but the action on the part of the buyer in accepting and using such portion of the shipment shall not be construed as his acceptance of the entire shipment. Further, the buyer shall pay in accordance with the terms of sale for that portion which he accepts, but acceptance by the buyer of a part of a shipment does not prejudice his just claims on account of any unused lumber that is alleged by him to be below standard grade or not of standard size. The complainant buyer shall hold disputed material intact, properly protected, for not exceeding 30 days after date of the request for official inspection or reinspection, and shall file complaint with seller within 10 days from receipt of shipment.

840. Each item in a carload or cargo shall be considered as of the grade invoiced, if, upon official association reinspection under the grading and inspection rules under which the lumber has been graded and sold, 95 percent thereof or more is found to be of said grade, the lumber below said grade to be accepted by the buyer as of its actual grade. Where the de-grades are in excess of 5 percent of such item, or where the de-grades are found upon official reinspection to be more than one grade lower than the grade invoiced, the de-grades shall be the property of the seller. These provisions shall not apply in the case of specially worked lumber.

841. Each association shall undertake to reinspect lumber for its members, and for nonmembers upon request.

842. All grading shall be done by properly supervised and qualified graders or inspectors.

843. Sales contracts should incorporate in substance the following clause: Shipment under this contract shall be in accordance with the *American Lumber Standards*. In the case of shipments made or received under such contracts, exemption from any provision of the *American Lumber Standards* shall be by special agreement and the burden of proof thereof shall be upon the person claiming exemption.

YARD LUMBER

[Lumber manufactured and classified into those sizes, shapes, and qualities required for ordinary construction and general-purpose uses]

Grade Standards

Basic Classification

844. On the basis of quality, yard lumber is classified as follows: (a) Select lumber, and (b) common lumber. These are again divided into two classes: Select lumber, into (1) that suitable for natural finishes, and (2) that suitable for paint finishes; common lumber, into (1) that which can be used without waste, and (2) that which permits some waste. Each of these four classes is further divided into quality classes or grades. The grade names of select lumber are A, B, C, and D, and of common lumber, No. 1, No. 2, No. 3, No. 4, and No. 5. These divisions, classes, and grades are differentiated as follows:

Total products of a typical log arranged in series according to quality as determined by appearance and use.	SELECT Lumber of good appearance and finishing qualities.	Suitable for natural finishes.	Grade A.—Practically clear. Grade B.—Of high quality—generally clear.
		Suitable for paint finishes.	Grade C.—Adapted to high-quality paint finishes. Grade D. — Intermediate between higher finishing grades and common grades, and partaking somewhat of the nature of both.
	COMMON Lumber not of finishing quality, but which is suitable for general utility and construction purposes.	Suitable for use without waste.	No. 1—Sound and tight knotted. May be considered watertight. No. 2—Less restricted in quality than No. 1, but of the same general character.
		Permitting some waste.	No. 3—Prevailing grade characteristics larger than in No. 2. No. 4.—Low quality. No. 5.—Lowest recognized grade but must be usable.

General Provisions

845. The rules for yard lumber shall prescribe the number, extent, and limitations of the characteristics permitted in the poorest pieces admissible in each grade. A grade shall be representative, however, and shall not comprise only low-line pieces.

846. Except in dimension and timbers, the grade of yard lumber, rough or surfaced two sides, shall be determined from the better or face side of the piece, and lumber which is surfaced one side only shall be graded from the surfaced side.

847. The grading of lumber cannot be considered an exact science, because it is based on a visual inspection of each piece and on the judgment of the grader. Grading rules, however, shall be sufficiently explicit to establish 5 percent below grade as a reasonable variation between graders.

Size Standards

Dressed Sizes

848. The terms "standard yard board" and "standard industrial board", and "standard yard dimension" and "standard industrial dimension" shall be the designations for 1-inch boards and 2-inch dimension, respectively.

849. $\frac{25}{32}$ inch, S1S or S2S, shall be the minimum thickness for the standard yard board; $\frac{26}{32}$ inch, S1S or S2S, for the standard industrial board.

850. 1⅝ inches, S1S or S2S, shall be the minimum thickness for standard yard dimension not more than 12 inches wide; 1¾ inches, S1S or S2S, for standard industrial dimension.

851. The minimum finished widths of finish S1E or S2E shall be ⅜ inch off on lumber of standard width of 3 inches; the finished widths of finish S1E or S2E shall be ½ inch off on lumber of standard widths of 4 to 7 inches, inclusive, and ¾ inch off on lumber of standard widths of 8 to 12 inches, inclusive; and the finished widths of strips, boards and dimension S1E or S2E shall be ⅜ inch off on lumber of standard widths less than 8 inches, and ½ inch off on lumber of standard widths of 8 to 12 inches.

852. The minimum thicknesses and widths of finished lumber, S1S, S2S, S1E, S2E, or any combination thereof, shall be as follows:

Strips, Boards, and Dimension

[The thicknesses apply to all widths and the widths to all thicknesses]

Product	Thickness			Width	
	Board measure	Minimum dressed dimensions		Board measure	Minimum dressed dimensions—standard
		Yard standard	Industrial standard		
	Inches	Inches	Inches	Inches	Inches
Finish		5/16		3	2 5/8
		7/16		4	3 1/2
		9/16		5	4 1/2
		11/16		6	5 1/2
	1	25/32	26/32	7	6 1/2
	1 1/4	1 1/16		8	7 1/4
	1 1/2	1 5/16		9	8 1/4
	1 3/4	1 7/16		10	9 1/4
	2	1 5/8	1 6/8	11	10 1/4
	2 1/2	2 1/8		12	11 1/4
	3	2 5/8			
Common: Strips and boards	1	25/32	26/32	3	2 5/8
	1 1/4	1 1/16		4	3 5/8
	1 1/2	1 5/16		5	4 5/8
				6	5 5/8
				7	6 5/8
				8	7 1/2
				9	8 1/2
				10	9 1/2
				11	10 1/2
				12	11 1/2
Dimension	2	1 5/8	1 6/8	2	1 5/8
	2 1/2	2 1/8		4	3 5/8
	3	2 5/8		6	5 5/8
	4	3 5/8		8	7 1/2
				10	9 1/2
				12	11 1/2

Factory Flooring, Heavy Roofing, Decking, and Sheet Piling

[The thicknesses apply to all widths and the widths to all thicknesses]

Thickness		Width			
Board measure	Minimum dressed dimen-sions—standard	Board measure	Minimum dressed dimensions, standard face width		
			D&M	Ship-lapped	Grooved for splines
Inches	Inches	Inches	Inches	Inches	Inches
2	1 5/8	4	3 1/8	3	3 1/2
2 1/2	2 1/8	6	5 1/8	5	5 1/2
3	2 5/8	8	7 1/8	7	7 1/2
4	3 5/8	10	9 1/8	9	9 1/2
		12	11 1/8	11	11 1/2

Note.—In patterned lumber 2 or more inches thick, board measure, the tongue shall be 3/8 inch wide in tongue-and-groove lumber and the lap 1/2 inch wide in shiplapped lumber, with the over-all widths 3/8 inch and 1/2 inch wider, respectively, than the face widths shown above.

SIDING, FLOORING, CEILING, PARTITION, SHIPLAP, AND DRESSED AND MATCHED

[The thicknesses apply to all widths and the widths to all thicknesses except as modified][1]

Product	Thickness		Width	
	Board measure	Minimum dressed dimensions—standard	Board measure	Minimum dressed dimensions—standard face width
	Inches	Inches	Inches	Inches
Bevel siding		7/16 by 3/16	4	3 1/2
		10/16 by 3/16	5	4 1/2
			6	5 1/2
Wide bevel siding		7/16 by 3/16	8	7 1/4
		9/16 by 3/16	10	9 1/4
		11/16 by 3/16	12	11 1/4
Rustic and drop siding (shiplapped)		9/16	4	3 1/8
		3/4	5	4 1/8
			6	5 1/16
			8	6 7/8
Rustic and drop siding (dressed and matched)		9/16	4	3 1/4
		3/4	5	4 1/4
			6	5 3/16
			8	7
Flooring		5/16	2	1 1/2
		7/16	3	2 3/8
		9/16	4	3 1/4
	1	25/32	5	4 1/4
	1 1/4	1 1/16	6	5 3/16
	1/2	1 5/16		
Ceiling		5/16	3	2 3/8
		7/16	4	3 1/4
		9/16	5	4 1/4
		11/16	6	5 3/16
Partition		3/4	3	2 3/8
			4	3 1/4
			5	4 1/4
			6	5 3/16
Shiplap	1	25/32	4	3 1/8
			6	5 1/8
			8	7 1/8
			10	9 1/8
			12	11 1/8
Dressed and matched	1	25/32	4	3 1/4
	1 1/4	1 1/16	6	5 1/4
	1 1/2	5/16	8	7 1/4
			10	9 1/4
			12	11 1/4

[1] In tongue-and-groove flooring and in tongue-and-groove and shiplapped ceiling 5/16, 7/16, and 9/16 inch thick, board measure, the tongue or lap shall be 3/16 inch wide, with the over-all widths 3/16 inch wider than the face widths shown above. In all other patterned lumber, 11/16, 3/4, 1, 1 1/4, and 1 1/2 inches thick, board measure, the tongue shall be 1/4 inch wide in tongue-and-groove lumber, and the lap 3/8 inch wide in shiplapped lumber, with the over-all widths 1/4 inch and 3/8 inch wider, respectively, than the face widths shown above.

Rough Dry Sizes

853. The standard rough dry thickness of the standard yard board shall be not less than 29/32 inch, allowing that 20 percent of a shipment may be not less than 28/32 inch; and the standard rough dry thickness of the standard industrial board shall be not less than 30/32 inch, allowing that 10 percent of a shipment may be not less than 29/32 inch.

854. The standard rough dry thickness of finish, common boards, and dimension of standard sizes 1¼ or more inches thick, board measure, shall be not less than ⅛ inch thicker than the corresponding standard finished dry thickness, allowing that 20 percent of the shipment may be not less than 3/32 inch thicker than the corresponding standard finished dry thickness.

855. The standard rough width of finish of 3-inch width, board measure, shall be not more than ¼ inch less than the nominal width; the standard rough-dry widths of finish, of widths 4 to 7 inches, inclusive, board measure, shall be not more than ⅜ inch less than the nominal widths, and widths 8 to 12 inches, inclusive, board measure, shall be not more than ⅝ inch less than the nominal widths; and the standard rough-dry widths of common strips, boards, and dimension, 7 inches and narrower, board measure, shall be not more than ¼ inch less than the nominal widths, and the widths 8 to 12 inches, board measure, shall be not more than ⅜ inch less than the nominal widths.

Description

856. The description of the dimensions of lumber shall be as follows:

Thickness of lumber described as—	Minimum thickness, S1S or S2S
	Inches
1 inch, board measure, to be not less than	25/32
1¼ inches, board measure, to be not less than	1 1/32
1½ inches, board measure, to be not less than	1 9/32
1¾ inches, board measure, to be not less than	1 7/16
2 inches, board measure, to be not less than	1⅝
2½ inches, board measure, to be not less than	2⅛
3 inches, board measure, to be not less than	2⅝
3½ inches, board measure, to be not less than	3⅛
4 inches, board measure, to be not less than	3⅝

NOTE.—Widths of finish, described as 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 inches, board measure, to be, respectively, not less than 2⅝, S1E or S2E, in the condition of seasoning as sold and shipped, and 3½, 4½, 5½, 6½, 7¼, 8¼, 9¼, 10¼, and 11¼ inches, S1E or S2E; widths of strips, boards, and dimension, described as 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 inches, board measure, to be, respectively, not less than 1⅝, 2⅝, 3⅝, 4⅝, 5⅝, 6⅝, 7½, 8½, 9½, 10½, and 11½ inches, S1E or S2E, in the condition of seasoning as sold and shipped.

The description of thickness of dressed stock less than 1 inch thick, board measure, S1S or S2S, to be its actual thickness in the condition of seasoning as sold and shipped.

It is to be understood that the standard dimensions of rough lumber are in excess of the dimensions of finished lumber of the corresponding size, board measure, by the amount necessary to permit of surfacing either 1 or 2 sides, 1 or 2 edges, or any combination of sides and edges.

Lengths

857. The marketing practice covering lengths of yard lumber shall permit the buyer to obtain specified lengths, specified assortments of lengths, or both.

858. Standard lengths of yard lumber shall be in multiples of 1 or 2 feet as specified in the manufacturers' association grading rules.

859. Unless otherwise stated in the contract of purchase, yard lumber shall be double end-trimmed within a tolerance not exceeding 3 inches in excess of the nominal length.

FACTORY AND SHOP LUMBER

[Lumber graded with reference to its use for doors and sash, or on the basis of characteristics affecting its use for general cut-up purposes, or on the basis of size of cuttings]

(Standards for Factory and Shop lumber are not included because of their limited application to railroad uses.)

STRUCTURAL LUMBER

[Basic provisions for selection and inspection where working stresses are required]

(Standards for Structural Lumber are included in "Specifications for Structural Timbers"—pages 7–17 to 7–35.)

SHINGLES[1]

[Thin lumber tapered lengthwise, used overlapped on roofs and side walls with a definite portion of the length exposed to the weather]

Grade Standard

Basic Classification

860. The basic classification for shingles is:

Random-width shingles	No. 1.—Edge grained, clear throughout, all heartwood, thickness uniform, butts and one face smooth. No. 2.[2] No. 3.[2]
Dimension shingles; i. e., of specified width.	No. 1.—Edge grained, clear throughout, all heartwood, thickness uniform, butts and one face smooth. No. 2.[2]

Size Standards

861. The standard sizes of shingles are 16 inches long by 5/2 thick, 18 inches long by 5/2¼ thick, and 24 inches long by 4/2 thick. (Shingles are measured at the butt ends, and their thickness designated as the number required to constitute a specified unit. Hence 5/2, 5/2¼, and 4/2 mean, respectively, 5 shingles to 2 inches, 5 shingles to 2¼ inches, and 4 shingles to 2 inches.) Standard widths for dimension shingles 16 and 18 inches long are 5 and 6 inches, and for 24-inch shingles, 6 inches.

862. Lengths may vary not more than 1 inch over or under in not to exceed 10 percent of any shipment, but shingles cut from equalized blocks or rebutted stock may be ¼ inch short.

863. The maximum width of shingles is 14 inches. The minimum width is 4 inches for 24-inch shingles. For 16- and 18-inch shingles, the minimum width is 3 inches, but shingles less than 4 inches wide shall not exceed 10 percent of the running inches in any shipment.

864. The width of shingles shall be uniform; that is, their sides shall not be out of parallel more than ¼ inch.

865. The width of dimension shingles when dry may be not more than ¼ inch scant.

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[1] This section covers No. 1 grade shingles of the following species: Western red cedar *(Thuja plicata)*, red cypress *(Taxodium distichum)*, and redwood *(Sequoia sempervirens)*.

[2] Basic descriptions for these grades are not included, because the various shingle-producing groups have not adopted a uniform classification extending beyond No. 1 grade.

866. Bundles of shingles may measure across the butts when dry 3 percent less than the calculated thickness based on size of shingle and number of courses in the bundle. Example: 14 courses of 4/2 shingles equals 7 inches across the butts.

General Provisions

867. The detailed rules for grading shingles shall prescribe the number, extent, and limitations of the characteristics permitted in the poorest piece admissible in each grade. A grade shall be representative, however, and shall not comprise only low-line pieces.

868. Cross grain which slopes from one face to the other within a longitudinal distance of 4 inches in any portion less than 12 inches from the butt is not permitted.

869. Diagonal grain which diverges from a line parallel to the edges of a shingle by 2 inches or more in 12 inches of length measured from the butt is not permitted.

870. Holes and knots which are not round shall be measured by the shortest dimension.

Packing and Shipping Provisions

871. When shingles are packed by the square, which is the quantity required to cover 100 square feet at the prescribed exposure to the weather, they shall be packed flat in straight courses in regulation frames 20 inches wide with band sticks at least 19½ inches long, and in random-width shingles there shall be an average of not less than 18½ running inches of shingles per bundle course.

872. Dimension shingles not packed by the square may be designated by the number of pieces per bundle.

873. When shingles are packed by the square, courses per bundle and bundles per square shall be as follows:

Shingle size (inches)	Number of courses per bundle [a]	Roof square		Side-wall square		Pieces per bundle
		Number of bundle	Exposure to weather	Number of bundles	Exposure to weather	
Random-width:			Inches		Inches	
24	13/14	4	7½	3	10	----------
18	18/18	4	5½	3	7½	----------
16	20/20	4	5	3	6¾	----------
Dimension:						
24 by 6	14/14	4	7½	3	10	84
18 by 5	16/16	4	5½	3	7½	[b]136
18 by 6	17/18	4	5½	3	7½	[b]113
16 by 5	18/18	4	5	3	6¾	[b]152
16 by 6	19/20	4	5	3	6¾	[b]125

[a] 13/14 means 13 courses on one end, 14 courses on the other, a total of 27.
[b] Including 8 cross shingles.

874. The class and grade shall be shown indelibly on each bundle of shingles.

875. A shipment is off grade when more than 4 percent of its total running inches consist of defective shingles.

Report on Assignment 2

Simplification of Grading Rules and Classification of Timber for Railway Uses

Collaborating with Other Organizations Interested

H. Austill (chairman, subcommittee), M. W. Beach, S. Blumenthal, D. H. Dowe, W. E. Hawley, C. J. Hogue, W. O. Nelson, J. A. Newlin, W. H. O'Brien, L. W. Smith.

Under this assignment your committee has participated actively in the revision of the National Lumber Standards, having reviewed and commented on the revisions, and maintained close contact with Mr. John Foley, AREA representative (and chairman) of the Central Committee on Lumber Standards.

The revised standards have been issued as Simplified Practice Recommendations R-16-39, approved by the National Bureau of Standards.

To effect the desired conformity with the revised American Lumber Standards, your committee in collaboration with Mr. Foley has prepared the revisions of the Manual presented for adoption in the report on Assignment 1—Revision of the Manual.

Report on Assignment 4

Specifications for Design of Wood Bridges and Trestles

R. P. Hart (chairman, subcommittee), S. Blumenthal, F. H. Cramer, S. F. Grear, G. V. Guerin, Jr., W. O. Nelson, W. A. Oliver, L. W. Smith, W. C. Schakel.

Your committee submits the following specification for consideration and constructive criticism at this time. After further study and suitable revision during the current year, it is expected the specification will be presented in 1942 for adoption as Manual material.

SPECIFICATIONS FOR DESIGN OF WOOD BRIDGES AND TRESTLES FOR RAILWAY LOADING

FOREWORD

The following specifications contemplate the use of sound wood piles and stress grades of structural timbers conforming to AREA specifications. The principles of design are based upon and conform with tests made at the U. S. Forest Products Laboratory. Unit working stresses adopted by the Engineer for the design of any structure should therefore conform with the stress grades of timbers to be used in the structure, making due allowance for "Continuously Wet" or "Occasionally Wet but Quickly Dried" conditions, as recommended in the Foreword to Specifications for Structural Timbers.

It should be kept in mind that wood piles and timbers have natural characteristics not common to other structural materials. Securing timbers to meet design requirements is not a matter of bringing together several natural materials according to a formula, but one of selecting pieces of suitable strength from nature's supply, all according to grading rules now well established and generally accepted. The outstanding characteristic of these wood materials is their ability to absorb shock resulting from sudden application of loads.

Working values for stress grades of structural timbers may be used without allowance for impact up to impact of 100 percent of loads figured. The ability of timbers to support loads is very dependent upon the duration of the stress. Tests have demonstrated that the load required to break timbers in several years is about $\frac{9}{16}$ of that required to break them as in ordinary laboratory tests. When the time is shortened still further, as in impact loading, the load required to break a timber is correspondingly increased. Approximately, this increase is 10 percent when the time is reduced 1/10 of the previous time. Working stresses for 5-minute loading may be increased 50 percent over those for longtime loading.

Working values for horizontal shear are maximum values. The maximum unit horizontal shear at any point in the length of a beam is usually calculated as being 3/2 of the average vertical shearing stress at that point. This assumption gives a very simple formula and though it is greatly in error with checked beams loaded near the supports, its continued use is recommended with certain assumptions as to the placement of live loads and the neglecting of certain loads near the supports for the purpose of correcting the most outstanding errors in the formula without complicating the caluculations. However, there is given a formula for use in conjunction with the ordinary shear formula whenever the simple assumptions as to loads and their placement are not sufficiently accurate.

GENERAL FEATURES OF DESIGN

1001. All members shall be so framed, anchored, tied and braced together as to develop the strength and rigidity necessary for the purposes for which they are used.

1002. Piles shall be driven to the required bearing capacity in accordance with AREA specifications for driving wood piles. Posts shall be provided with adequate foundation to support the loads superimposed upon them.

1003. Bents shall consist of a sufficient number of piles or posts, correctly spaced, so that no member in any bent will be overstressed under any condition of loading. For the purpose of computing stresses in the bents their spacing shall be considered as the distance center to center of caps thereon.

1004. Stringers shall be selected to provide:

(a) Depth, preferably, not less than $\frac{1}{12}$ of distance center to center of supports.
(b) Width, not less than ⅓ of the depth.
(c) Maximum deflection under design live load, 1/400 of the span.

For the purpose of computing stresses in stringers the span length shall be assumed as the clear distance face to face of bearings, plus 6 inches. Stringers in a group shall be placed to effect, as nearly as practicable, equal distribution of superimposed loads.

1005. Cross ties shall be of adequate size to distribute the track load equally to all stress-carrying stringers. Each tie shall be designed to carry not less than ⅓ of the maximum axle load. They shall be secured against bunching and the maximum space between them, on open deck bridges, shall be 6 inches.

DESIGN LOADS

1006. The following loads shall be considered:

(a) Dead load
(b) Live load
(c) Centrifugal force
(d) Lateral force due to wind load and nosing of locomotives
(e) Longitudinal force

1007. The dead load shall consist of the estimated weight of the structural member, plus that of the track, ballast and other portions of the structure supported thereby. The weight of unit quantities of materials shall be assumed to be as follows:

Track rails, inside guard rails, and fastenings	200 pounds per linear foot of track
Ballast, including track ties	120 pounds per cubic foot
Timber	5 pounds per foot board measure
Protective coverings	Actual weight

1008. The live load per track shall consist of that Cooper's loading which will produce a loading effect equivalent to the maximum engine or train load expected to be moved over the completed structure.

On bridges with ballasted deck the live load shall be assumed as distributed laterally over a width equal to the length of track ties, plus twice the depth of ballast below the base of tie, unless deck planks are designed to effect greater distribution of the load.

For members receiving load from more than one track all tracks contributing load shall be assumed fully loaded.

1009. The centrifugal force considered in the design of bridges supporting curved track shall be a percentage of the specified live load, assumed to act 6 feet above the top of traffic rails. The percentage used may be taken as $0.00117S^2 D$, where S is the speed in miles per hour and D is the degree of curve, or it may be taken from the following suggested table:

Degree of Curve	*Speed in M.P.H.*	*Percentage*
0°–20′	80	2.5
20′–40′	80	5
40′– 1°	80	7.5
Over 1°	65, and less	10

The effect of centrifugal force may be neglected in the design of stringers where the track is superelevated to compensate for maximum speed of moving load or where stringers in ballasted deck bridges are placed symmetrically about the intersection of resultant load at the plane of top of stringers.

1010. The lateral force due to wind shall be assumed as 30 pounds per square foot of vertical projection of structure, plus 300 pounds per linear foot of train, applied 8 feet above top of traffic rails. The wind force shall be assumed to act horizontally, perpendicular to the center line of track.

1011. The lateral force due to the nosing of locomotives shall be considered as a single moving force of 20,000 pounds applied at the top of the rail, in either lateral direction, at any point of the span. The resulting vertical forces shall be disregarded.

1012. For stresses produced by wind or other lateral forces, or by a combination of these forces with dead and live loads, the allowable working stresses other than modulus of elasticity may be increased 50 percent, provided the resulting sections are not less than those required for dead and live loads alone.

1013. The longitudinal force resulting from the starting and stopping of trains shall be considered as:

(a) For open deck bridges, the larger of

(1) Force due to braking, equal to 15 percent of the live load.

(2) Force due to traction, equal to 25 percent of the weight on driving wheels of engine.

(b) For ballasted deck bridges, 10 percent of the live load on the loaded portion of structure.

In any case the longitudinal force shall be assumed as acting 6 feet above the top of traffic rails.

COMPUTATION OF STRESSES

1014. Except as modified herein, or at the Engineer's discretion, all stress computations shall be based upon the actual size of timbers. Where members are dapped or otherwise framed in a manner such as to materially reduce the effective size the minimum cross section of the piece shall be considered.

1015. The following procedure shall be used for calculating the horizontal shear on the neutral plane in checked beams:

(a) Except as otherwise provided herein, use the following shear formula:

$$s = \frac{3R}{2bh}$$

in which s = maximum unit shear per square inch
R = Reaction in pounds
b = Breadth of beam in inches
h = Height of beam in inches

(b) Results obtained must not exceed the allowable unit shear stress.
(c) In calculating the reaction for use in the formula:
  (1) Take into account any relief to the beam under consideration resulting from loading being distributed to adjacent parallel beams by flooring or other members of the construction.
  (2) Neglect all loads within the height of the beam from both supports.
  (3) If there are any moving loads, place the largest one at 3 times the height of the beam from the support.
  (4) Treat all other loads in the usual manner
(d) If a timber does not qualify under the above recommendations, which under certain conditions may be over-conservative, the reactions for the concentrated loads should be determined by the following equation:

$$r = \frac{10P(L-a)\left(\frac{a}{h}\right)^2}{\left[2+\left(\frac{a}{h}\right)^2\right]}$$

in which r = Reaction to be used as due to a Load P
L = Span in inches
a = Distance in inches from reaction to Load P
h = Height of beam in inches

(e) Allowable shear stresses for joint details shall be taken as 50 percent greater than the values for horizontal shear given in the tables of working stresses.

1016. Timber acquires a permanent set under long continued loading. This set with a fully loaded beam is about equal to the deflection, using the modulus of elasticity as given in the tables. In calculating ultimate deflection under long-continued loading, this factor should be recognized.

1017. The working stresses for compression perpendicular to grain apply to bearings 6 inches or more in length located anywhere in the length of a timber and to bearings of any length at the ends of beams or other members. For bearings shorter than 6 inches located 3 inches or more from the end of a timber the stresses may be increased in accordance with the following factors:

Length of bearing (inches)	½	1	1½	2	3	4	6 or more
Factor	1.85	1.60	1.45	1.30	1.15	1.10	1.00

For stress under a washer the same factor may be taken as for a bearing whose length equals the diameter of the washer.

1018. The working stresses for compression parallel to grain are for use on posts, struts, etc., with an unsupported length not greater than 10 times their least dimension. They are also for use in end bearing on compression members, as a short column or strut is more likely to fail at the end than at any other point in its length, and the variations in moisture content are greater at that point.

For columns of intermediate length, the Forest Products Laboratory finds that a fourth-power parabola, tangent to the Euler curve, is a conservative representation of the law controlling the strength. That is, from the short block to the long column in which the strength is dependent on stiffness, there is a falling off in ultimate strength which follows a smooth curve, very flat at first but curving sharply to become tangent to the Euler curve at ⅔ of the ultimate crushing strength.

For columns from

$$\frac{P}{A} = C \text{ into } \frac{P}{A} = \frac{2}{3} C;$$

$$\frac{P}{A} = C\left[1 - \frac{1}{3}\left(\frac{L}{Kd}\right)^4\right]$$

Where P = Total load in pounds
A = Area in square inches
P/A = Unit compressive stress
C = Safe stress in compression parallel to grain for short columns
L = Unsupported length in inches
d = Least dimension in inches
E = Modulus of elasticity
K = The L/d at the point of tangency of the parabolic and Euler curves

at which $\frac{P}{A} = \frac{2}{3} C$

The value of K for any species and grade is $\frac{\pi}{2}\sqrt{\frac{E}{6C}}$

For allowable unit stress L/d, 10 to K, see Table A.

The influence of defects on the compressive strength of columns of constant cross section decreases as the length increases. When L/d equals the value of K for the species and grade, the strength-reducing factors allowable in the grade have little influence on the strength as a column. Beyond this length the investigation of the strength of columns by the laboratory indicated that the Euler formula is quite accurate for long wood columns with pin-end connections and that the maximum load is dependent upon stiffness. In such columns, a factor of safety of 3 should be applied to values of the modulus of elasticity in order to obtain safe loading.

The laboratory does not, with the present data and under ordinary conditions, find justification for increasing the stresses on square-end columns over those for carefully centered pin-end columns. Tests to determine the influence of end conditions are still being made and it is probable that under special conditions higher stresses can be used.

For long columns, including a factor of safety of 3:

$$\frac{P}{A} = \frac{\pi^2}{36} \frac{E}{\left(\frac{L}{d}\right)^2} = \frac{0.274E}{\left(\frac{L}{d}\right)^2}$$

For unit stress $\frac{L}{d}$ K to 50, see Table A.

Table A—Unit Compression Stresses For Standard Stress-Grades

Short Column Stress	*Modulus of Elasticity*	*K*	*Stress at Ratio of Length to Least Dimension (L/d)* 10	12	14	16	18	20	25	30	35	40	45	50
1300	1,300,000	20.3	1300	1247	1203	1132	1032	892	570	396	291	223	176	142
	1,600,000	22.5	1300	1265	1235	1190	1123	1030	701	487	358	274	216	175
1200	1,200,000	20.3	1200	1151	1110	1045	953	823	526	365	268	206	162	132
	1,300,000	21.1	1200	1158	1122	1068	989	827	570	396	291	223	176	142
	1,500,000	22.7	1200	1169	1142	1102	1042	959	658	457	336	257	203	164
	1,600,000	23.4	1200	1172	1148	1112	1060	986	701	487	358	274	216	175
1100	1,200,000	21.2	1100	1063	1031	981	910	810	526	365	268	206	162	132
	1,300,000	22.1	1100	1068	1041	999	938	854	570	396	291	223	176	142
	1,500,000	23.7	1100	1076	1055	1024	978	914	658	457	336	257	203	164
	1,600,000	24.4	1100	1078	1060	1032	991	935	701	487	358	274	216	175
1000	1,200,000	22.2	1000	972	947	910	856	780	526	365	268	206	162	132
	1,300,000	23.1	1000	976	955	923	877	813	570	396	291	223	176	142
	1,500,000	24.8	1000	982	966	942	908	859	658	457	336	257	203	164
	1,600,000	25.6	1000	984	970	948	918	876	697	487	358	274	216	175
900	1,000,000	21.4	900	870	845	806	750	674	438	304	224	171	135	110
	1,200,000	23.4	900	879	861	834	795	740	526	365	268	206	162	132
	1,600,000	27.0	900	888	878	863	841	810	680	487	358	274	216	175
800	1,000,000	22.7	800	779	762	734	694	639	438	304	224	171	135	110

Columns should be limited in slenderness to $L/d = 50$.

1019. For bearing stresses on surfaces at an angle to the direction of the grain, the following (Hankinson) formula has been found to be the best for general use in timber framing:

$$N = \frac{PQ}{P\, sin^2\Theta + Q\, cos^2\Theta}$$

Note: See chart "B" on next page for graphical solution.

Where N = Unit compressive stress in a direction at inclination with the direction of the grain.

P = Unit stress in compression parallel to the grain.

Q = Unit stress in compression perpendicular to the grain.

When the stress acts parallel to the grain, Θ is zero.
When the stress acts perpendicular to the grain, Θ is 90 degrees.
For $sin^2\Theta$ and $cos^2\Theta$, use the following table:

$Sin^2\Theta$	Θ	$Cos^2\Theta$	$Sin^2\Theta$	Θ	$Cos^2\Theta$
0.00000	0	1.00000			
0.00760	5	0.99240	0.58682	50	0.41318
0.03015	10	0.96985	0.67101	55	0.32899
0.06698	15	0.93302	0.75000	60	0.25000
0.11698	20	0.88302	0.82140	65	0.17860
0.17860	25	0.82140	0.88302	70	0.11698
0.25000	30	0.75000	0.93302	75	0.06698
0.32899	35	0.67101	0.96985	80	0.03015
0.41318	40	0.58682	0.99240	85	0.00760
0.50000	45	0.50000	1.00000	90	0.00000

DETAILS OF DESIGN AND APPLICATION OF GRADES

1020. Post and timber grades may be applied to material smaller than sizes tabulated in grading rules by limiting the size of knots to the proportion of width of face permitted on sizes given.

1021. For direct tension use the same unit stresses as for extreme fiber stress in bending. Straight grained wood has greater resistance to tension than to any other kind of stress. It has been difficult to design joints that will develop the full tensile strength, but the availability of mechanical or ring-connectors now largely eliminates this difficulty.

1022. Grades of joists or beams may be used for members in longitudinal tension, such as bottom chords or tension members of trusses, but grade limitations which apply to the center portions of joists and beams should be applied throughout the entire length of pieces subjected to longitudinal tension.

1023. The provisions of the joist and plank grades are such that material graded on them may be used on edge, as joists or rafters, or flat, as scaffold plank or factory flooring, and working stresses for these grades may be applied to such material used with wide faces either vertical or horizontal. Joist and plank grades apply to material not thicker than 4 inches. Material thicker than 4 inches, for use in bending, should be graded on beam and stringer grades. In such material, with loads applied to the wide face, the knot limitations for this face are those for the narrow face as given in the rules.

1024. Material to be used for such purposes as caps, bridge ties, etc., where strength in bending is a factor, should be specified in beam and stringer grades, although they are of a shape more commonly considered as of post and timber grades, as the method of measuring knots in post and timber grades makes it impracticable to assign bending stresses to them. Caps and bridge ties are often square or have horizontal faces wider

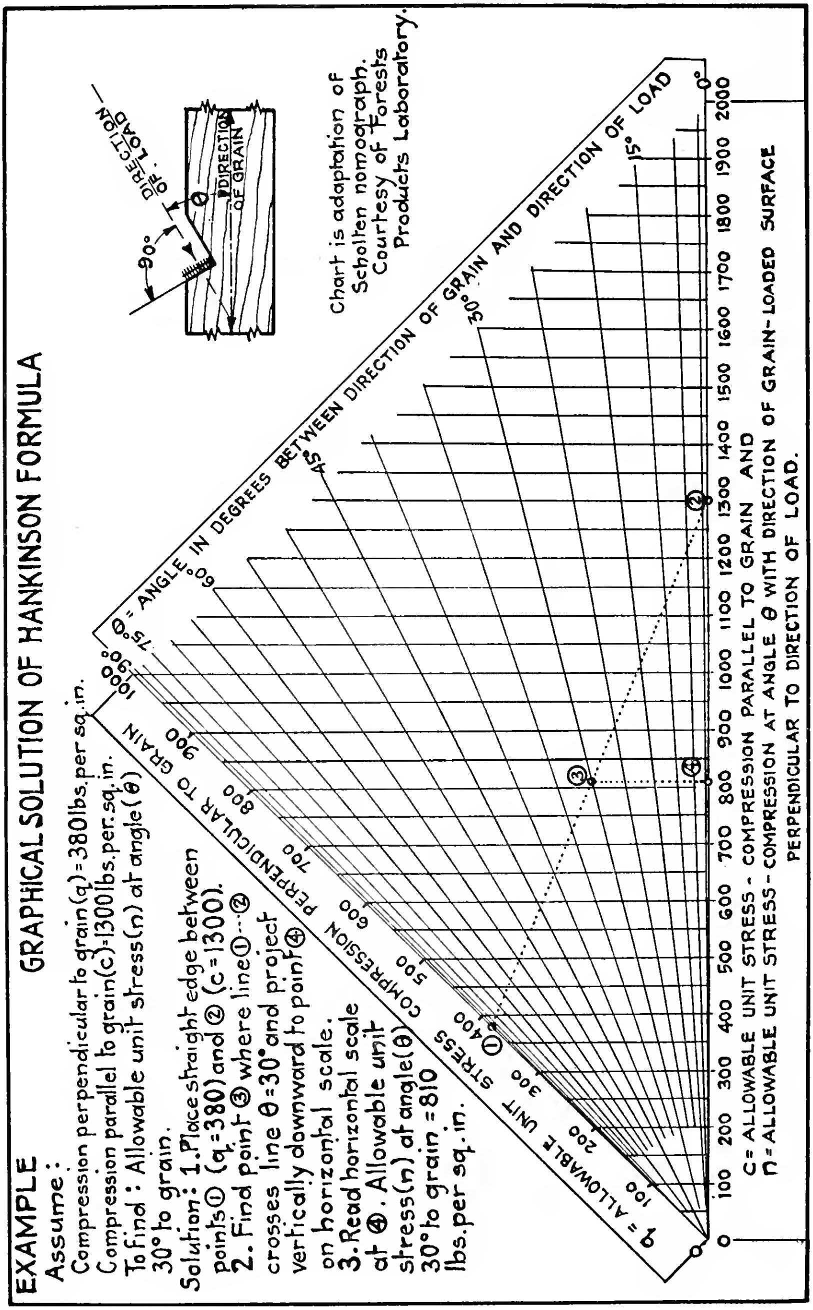

GRAPHICAL SOLUTION OF HANKINSON FORMULA
EXAMPLE
Assume:
Compression perpendicular to grain (q) = 380 lbs. per sq. in.
Compression parallel to grain (c) = 1300 lbs. per sq. in.
To find: Allowable unit stress (n) at angle (θ) 30° to grain.
Solution: 1. Place straight edge between points ① (q = 380) and ② (c = 1300).
2. Find point ③ where line ①--② crosses line θ = 30° and project vertically downward to point ④ on horizontal scale.
3. Read horizontal scale at ④. Allowable unit stress (n) at angle (θ) 30° to grain = 810 lbs. per sq. in.
DIRECTION OF LOAD
90°
θ
DIRECTION OF GRAIN
Chart is adaptation of Scholten nomograph. Courtesy of Forests Products Laboratory.
θ = ANGLE IN DEGREES BETWEEN DIRECTION OF GRAIN AND DIRECTION OF LOAD
90° 75° 60° 45° 30° 15° 0°
q = ALLOWABLE UNIT STRESS COMPRESSION PERPENDICULAR TO GRAIN
100 200 300 400 500 600 700 800 900 1000
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
C = ALLOWABLE UNIT STRESS - COMPRESSION PARALLEL TO GRAIN AND
n = ALLOWABLE UNIT STRESS - COMPRESSION AT ANGLE θ WITH DIRECTION OF GRAIN-LOADED SURFACE PERPENDICULAR TO DIRECTION OF LOAD.

Chart B.

than the vertical faces, in contrast to beams and stringers, in which the narrow faces are horizontal faces and the wide faces are vertical, and care should be exercised that knot limitations are applied to the proper faces.

1025. In railway stringers of two-span lengths, it should be specified that grade factors throughout the center two-thirds be limited as in the middle third or middle half of a single span stringer, for the maximum moment will be over the center support, and although the full positive moment will not be developed in either span as long as there is resistance to negative moment over the center support, there may be circumstances in which full positive moment of resistance at the centers of the two spans will be desirable.

1026. In material used over three or more spans, or subject to varying bending moments, grade limitations should be applied throughout the entire length as in the middle third or middle half of joist and plank and beams and stringers.

1027. The strength of timbers and posts in round form is greater than would be expected from the ordinary engineering formulas. The strength, stiffness, and horizontal shearing value in bending of round timbers of any species may be assumed to be identical with that of square timbers of the same grade and cross sectional area. Tapered timbers should be assumed as of uniform diameter, the point of measurement being 1/3 the span from the small end, but the diameter should not be assumed to be more than 1½ times the small end diameter.

1028. The strength of round columns may be considered the same as that of square columns of the same cross-sectional area. In long tapered columns the strength may be assumed as identical with that of a square column of the same length, and of cross-sectional area equal to that of the round timber measured at a point one-third its length from the small end. The stress at the small end must not exceed the allowable stress for short columns.

1029. In determining working stresses, the Forest Products Laboratory has considered both elastic limit and breaking strength. Elastic limit, however, is more variable and less definite than ultimate strength, and the latter is taken as the more dependable basis for the determination of safe working stresses.

1030. The factor of safety at a given working stress varies materially with the duration of the stress. At the recommended working stresses, the average timber in buildings has a factor of safety of 6* in impact loading, 4 under five minute loads and 2¼ under long-time loading, with a minimum factor of safety of 2 on 75 percent of the pieces under long-time loading, while about one piece in 100, of very light weight and with maximum defects for the grade, would be expected to break at 1½ times the recommended stress under loading of approximately ten years' duration. The factor of safety on new timbers in bridge work is about $\frac{1}{7}$ greater than the above values.

* If impact stresses are neglected when these amount to less than 100 percent of the live load producing them, the factor of safety, including such loads, will be reduced from 6 to a minimum of 3.

General Note: Detailed studies on the strength of timbers in round form are available in Reports 180 and 181 of the National Advisory Committee for Aeronautics on "The Influence of the Form of a Wooden Beam on Its Stiffness and Strength."

Report on Assignment 6

Recommended Relationships Between the Energy of Hammer and the Weight or Mass of Pile for Proper Pile Driving

To Include Concrete Piles, Collaborating with Committee 8—Masonry

H. C. Heinlen (chairman, subcommittee), G. S. Crites, C. S. Johnson, W. D. Keeney, J. E. Myer, W. A. Oliver, W. L. Peoples.

Your committee offers as information the following redraft of the conclusions presented in its report for 1940. The revision applies to that portion of the report under the heading of "Steam Hammers", where some limitations are recommended to serve as a guide in the selection of pile driving equipment.

General

In determining the weight or size and capacity of the hammer to be used for any service, due consideration must be given to the weight and spacing of the piles, the character and condition of the soil to be penetrated, conditions of driving, and previous experience at the site or under similar conditions. The blow should be struck by a ram having sufficient energy to overcome the inertia of the pile and the frictional and elastic resistance encountered, and having sufficient weight to reduce to a minimum the portion of this energy which is unavoidably dissipated in destructive work during impact. As a general rule, piles should be driven with the heaviest hammer that, in the judgment of the Engineer, can be used to secure maximum penetration without appreciable damage to the pile.

Steam Hammers

For driving concrete piles, of sizes up to 5 cubic yards in volume, the hammer shall have sufficient weight and power to develop an energy per blow, at each full stroke of the piston, of not less than 3,500 foot-pounds per cubic yard of concrete contained in the pile.

The weight of the ram should be not less than one fourth the weight of the pile to be driven.

The total energy developed by the hammer should be not less than 12,000 foot-pounds per blow.

The energy should be developed at the normal rate of speed of the hammer and the velocity shall not be increased beyond the equivalent of a five-foot free fall.

For concrete piles having a volume of more than 5 cubic yards, or where unusual conditions indicate that equipment of greater capacity may be required, the choice of equipment should be governed by previous experience at the site or under similar conditions elsewhere.

For driving wood piles, the weight of the striking part of the hammer should be not less than the weight of the pile to be driven.

For driving either concrete or wood piles, the minimum weight of the entire hammer, the weight of the striking part, and the length of stroke should, where practicable, be specified for each project.

Where hard driving is encountered, it may be necessary to reduce the length of stroke to avoid injury to the pile.

Gravity Hammers

For driving either concrete or wood piles, the weight of the striking ram shall be not less than 3,000 pounds and the drop shall be so regulated as to obtain the desired penetration without appreciable injury to the pile.

Weights of Hammers To Be Used

In 1936 the committee canvassed a number of agencies actively engaged in driving piles to ascertain their methods of determining proper weights of hammer to be used in actual pile driving practice. A summary of the replies received and a comparison of the more common pile bearing formulas with the results of available load tests were included in the report for that year.

Your committee has tabulated the supporting capacity of piles of different weights driven by various steam hammers in common use. The tables are based on the Engineering News or Wellington formula modified to take into account the efficiency of a hammer blow for different weights of piles. The efficiency factor is determined by the formula

TIMBER PILES - WEIGHT PER LIN. FOOT

Pine					
Average Dia.	Wt. Untreated	Wt. Treated	Average Dia.	Wt. Untreated	Wt. Treated
10"	26#	33#	13½"	48#	60#
10½"	29	36	14"	51	64
11"	32	40	14½"	55	69
11½"	35	43	15"	59	74
12"	38	47	15½"	63	79
12½"	41	51	16"	67	84
13"	44	55	16½"	71	89

CONCRETE PILES - WEIGHT PER LIN. FOOT

16" Octagonal		24" Octagonal	
Length - Ft.	Weight	Length - Ft.	Weight
20 - 25	218#	20	427#
26 - 30	220	25	444
31 - 35	223	30	452
36 - 40	228	-35	459
41 - 50	233	40	464
51 - 55	244	45	468
		50	470
		55	474
		60	475

of A. Hilley, as given in the report of this committee for 1936, and depends upon the ratio of the weight of the pile to that of the driving ram.

FORMULAS

(Engineering News)

$$L = \frac{2E}{S + 0.1} \text{ or } S = \frac{2E}{L} - 0.1$$

L = Pile capacity in pounds
E = Kinetic energy of blow in ft. lb.
S = Penetration in inches under one blow
Above formula provides safety factor of 6, and assumes 100 percent efficiency.

(A. Hilley)

$$e = \frac{1}{1 + \frac{p}{w}} + \frac{c^2}{1 + \frac{w}{p}}$$

e = Efficiency of blow
c = Coefficient of restitution = 0.25
p = Weight of pile and anvil
w = Weight of ram.

Tabulated blows per foot required $= 12 \div (S \times e)$

McKIERNAN-TERRY #11-B-3 DOUBLE-ACTING PILE HAMMER

Rated energy = 19150'# at 95 blows per minute

Weight of ram = 5000#

Weight of anvil = 820#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	e
Weight of Pile	Required Blows per Foot						
800#	12	18	23	29	35	41	.770
1000	13	19	24	30	36	42	.749
2000	14	21	27	34	41	48	.662
3000	16	24	30	38	45	53	.594
4000	18	26	33	42	50	58	.540
5000	19	28	36	45	54	64	.495
6000	21	31	39	49	59	69	.459
7000	22	33	42	52	63	74	.428
8000	24	35	45	56	67	79	.401
9000	25	37	48	59	71	84	.379
10000	26	39	50	62	74	88	.359
11000	28	41	53	66	76	93	.340
12000	29	43	55	69	80	97	.326
13000	30	45	58	72	83	101	.311
14000	32	47	60	75	87	106	.299
15000	34	49	63	78	93	110	.288

McKIERNAN-TERRY #10-B-3 DOUBLE-ACTING PILE HAMMER

Rated energy = 13100'# at 105 blows per minute

Weight of ram = 3000#

Weight of anvil = 625#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	e
Weight of Pile	Required Blows per Foot						
800#	23	31	41	51	63	76	.699
1000	24	32	42	53	65	79	.671
2000	29	38	50	63	78	94	.563
3000	34	44	58	73	90	108	.487
4000	38	50	66	83	102	122	.431
5000	42	56	73	92	113	136	.389
6000	46	61	80	100	123	148	.356
7000	50	66	86	108	134	161	.327
8000	54	71	93	116	144	173	.305
9000	57	76	99	124	153	184	.287
10000	61	81	105	132	163	197	.268
11000	64	85	111	139	172	207	.255
12000	67	89	116	145	180	217	.243

McKIERNAN-TERRY #9-B-3 DOUBLE-ACTING PILE HAMMER

Rated energy = 8750'# at 145 blows per minute

Weight of ram = 1600#

Weight of anvil = 400#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	e
Weight of Pile	Required Blows per Foot						
800#	41	60	80	104	134	168	.599
1000	44	64	85	111	142	179	.562
2000	57	82	110	143	183	230	.437
3000	68	98	132	172	220	277	.363
4000	79	114	153	199	256		.313
5000	90	128	173	226	289		.277
6000	99	142	192	250			.250
7000	108	156	210	273			.229
8000	117	168	226	295			.212
9000	125	179	241				.199
10000	133	190	256				.187

McKIERNAN-TERRY #9-B-3 DOUBLE-ACTING PILE HAMMER

Rated energy = 8100'# at 140 blows per minute

Weight of ram = 1600#

Weight of anvil = 400#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	e
Weight of Pile	Required Blows per Foot						
800#	46	66	89	118	153	196	.599
1000	49	70	95	126	163	209	.562
2000	63	90	123	161	210	268	.437
3000	75	108	147	194	252		.363
4000	87	126	171	225	292		.313
5000	99	142	193	254			.277
6000	109	157	214	282			.250
7000	119	172	234				.229
8000	129	186	252				.212
9000	137	197	268				.199
10000	146	210	286				.187

McKIERNAN-TERRY #9-B-3 DOUBLE-ACTING PILE HAMMER

Rated energy = 7500'# at 135 blows per minute

Weight of ram = 1600#

Weight of anvil = 400#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	e
Weight of Pile	Required Blows per Foot						
800#	50	73	100	134	176	230	.599
1000	53	78	107	143	187	244	.562
2000	69	100	137	183	241		.437
3000	83	120	165	220	290		.363
4000	96	140	192	256			.313
5000	108	158	216	288			.277
6000	120	175	240				.250
7000	131	191	262				.229
8000	142	206	283				.212
9000	150	219	300				.199
10000	161	234					.187

McKIERNAN-TERRY #9-B-3 DOUBLE-ACTING PILE HAMMER

Rated energy = 6800'# at 130 blows per minute

Weight of ram = 1600#

Weight of anvil = 400#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	e
Weight of Pile	Required Blows per Foot						
800#	57	84	116	158	213	287	.599
1000	60	89	124	168	227		.562
2000	78	115	160	216	292		.437
3000	93	138	192	260			.363
4000	108	160	223	300			.313
5000	123	180	252				.277
6000	136	200	279				.250
7000	148	218					.229
8000	160	236					.212
9000	170	251					.199
10000	181	268					.187

VULCAN #OR SINGLE-ACTING PILE HAMMER

Rated energy = 30225'# at 50 blows per minute

Weight of ram = 9300#

Weight of anvil = 2075# (solid base)

Pile Capacity	20-T.	25-T.	30-T.	35-T.	40-T.	45-T.	50-T.	55-T.	60-T.	e
Weight of Pile	Required Blows per Foot									
8000#	17	21	26	31	36	41	46	52	58	.514
9000	17	22	27	32	37	43	48	54	60	.494
10000	18	23	28	33	39	45	51	57	63	.471
11000	19	24	30	35	40	46	53	59	65	.453
12000	20	25	31	36	42	48	55	61	68	.436
13000	20	26	32	37	43	50	57	63	71	.421
14000	21	27	33	39	45	52	59	65	73	.407
15000	22	28	34	40	47	54	61	68	76	.393
16000	22	29	35	41	48	55	63	70	79	.380
17000	23	30	36	43	50	57	64	72	81	.370
18000	24	31	37	44	51	58	66	74	83	.359
19000	24	31	38	45	52	60	68	76	85	.350
20000	25	32	40	46	54	62	70	79	88	.340
22000	26	34	41	49	56	65	74	83	92	.324
24000	28	36	43	51	59	68	78	87	97	.308
26000	29	37	45	53	62	71	81	90	100	.296
28000	30	38	47	55	64	74	83	93	104	.285

VULCAN #0 SINGLE-ACTING PILE HAMMER

Rated energy = 24375'# at 50 blows per minute

Weight of ram = 7500#

Weight of anvil = 2075#

Pile Capacity	20-T.	25-T.	30-T.	35-T.	40-T.	45-T.	50-T.	55-T.	60-T.	
Weight of Pile	Required Blows per Foot									
5000#	20	25	31	37	43	49	56	64	71	.547
6000	21	27	33	39	46	53	60	68	76	.514
7000	22	28	35	41	48	55	63	72	80	.487
8000	23	29	37	43	51	58	67	75	84	.464
9000	24	31	38	45	53	61	70	79	88	.442
10000	25	32	40	47	56	64	73	83	92	.422
11000	26	34	42	50	58	67	76	86	96	.405
12000	28	35	44	52	61	70	80	90	100	.387
13000	29	37	45	54	63	73	83	94	104	.373
14000	30	38	47	55	65	75	85	97	108	.362
15000	31	39	49	58	68	78	89	100	112	.349
16000	32	40	50	60	70	81	92	104	116	.337
17000	33	42	52	62	72	83	95	107	119	.327
18000	34	43	53	64	74	86	98	110	123	.317
19000	35	45	55	65	77	88	100	113	126	.308
20000	36	46	56	67	79	91	103	116	130	.300
22000	38	48	59	70	82	95	108	122	136	.286
24000	40	50	62	74	87	100	113	128	143	.272
26000	41	53	65	77	91	104	118	134	149	.261
28000	43	55	68	80	95	108	123	140	156	.250

VULCAN #1 SINGLE-ACTING PILE HAMMER

Rated energy = 15000'# at 60 blows per minute

Weight of ram = 5000#

Weight of anvil = 360#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	45-T.	50-T.	e
Weight of Pile	Required Blows per Foot								
5000#	26	36	47	58	71	85	100	117	.514
6000	28	39	51	63	77	92	109	126	.475
7000	30	42	54	68	82	99	117	136	.442
8000	32	45	58	73	88	106	125	145	.414
9000	34	48	62	77	93	112	132	154	.390
10000	36	50	66	82	99	119	141	164	.368
11000	38	53	69	86	104	125	147	172	.350
12000	40	56	72	90	110	131	155	180	.333
13000	42	58	75	94	114	137	162	188	.319
14000	44	61	79	98	119	143	169	197	.305
15000	46	63	82	103	124	149	176	205	.293

VULCAN #2 SINGLE-ACTING PILE HAMMER

Rated energy = 7260'# at 70 blows per minute

Weight of ram = 3000#

Weight of anvil = 360#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	40-T.	e
Weight of Pile	Required Blows per Foot						
800#	42	62	85	114	152	198	.739
1000	44	65	89	120	159	206	.704
2000	53	78	106	143	191	249	.589
3000	62	91	124	167	222	290	.505
4000	70	102	140	190	252		.445
5000	78	115	157	213	283		.398
6000	86	126	172	233			.363
7000	93	137	187	253			.334
8000	100	148	202	272			.310
9000	107	158	216	291			.290
10000	115	168	230				.272

VULCAN #1800 DIFFERENTIAL-ACTING PILE HAMMER

Rated energy = 3600'# at 150 blows per minute

Weight of ram = 1800#

Weight of anvil = 135#

Pile Capacity	15-T.	20-T.	25-T.	e
Weight of Pile	Required Blows per Foot			
800#	126	221		.678
1000	135	235		.637
2000	174			.492
3000	211			.405
4000	246			.348
5000	280			.306
6000				.275
7000				.251
8000				.232
9000				.217
10000				.204

BROWNHOIST SHORT STROKE DOUBLE-ACTING PILE HAMMER

Rated energy = 6000'# at 150 blows per minute

Weight of ram = 1600#

Weight of anvil = 150#

Pile Capacity	15-T.	20-T.	25-T.	30-T.	35-T.	e
Weight of Pile	Required Blows per Foot					
800#	62	93	132	185	258	.648
1000	66	99	141	198	276	.607
2000	87	130	185	260		.463
3000	106	159	227			.378
4000	124	186	266			.323
5000	140	211				.285
6000	156	235				.256
7000	170	255				.235
8000	185	278				.216
9000	198	297				.202
10000	210					.190

Report on Assignment 8

Fireproofing Wood Bridges and Trestles Including the Placing of Fire Stops

J. V. Johnston (chairman, subcommittee), M. W. Beach, H. F. Bober, C. J. Hogue, J. E. Myer.

Your committee has given this important subject further consideration. It is certain that so long as timber, treated or untreated, is used in the construction of these structures, there will be hazard of fire, and adequate protective measures must be taken to prevent fires, keep them from spreading and limit the area that can be damaged.

Whether or not fireproofing pays, might be an open question. The expense incurred in replacing a burned trestle, which caused delays in train operation, and which might have been the cause of a disastrous wreck, can be easily determined; but it cannot definitely be said that a fireproofed bridge has actually prevented such an occurrence and saved a certain amount of expense.

There are numerous ways of decreasing the fire hazard at trestles. The more common methods in the order of efficiency, are as follows:

(a) Ballasted deck on trestle
(b) Metal covering over deck
(c) Bituminous mastic covering over deck with sand or limestone chips
(d) Metal covering over stringers and caps
(e) Fire retardant salts or resisting paint

The cost of these methods varies directly with the efficiency.

Your committee recommends that Paragraphs 2, 5 and 6, under the heading "Best Method of Fireproofing Wood Bridges and Trestles" appearing on page 7–66 of the Manual, be revised as presented below, and that Figures 1, 2, 3 and 4 be approved for publication as a part thereof.

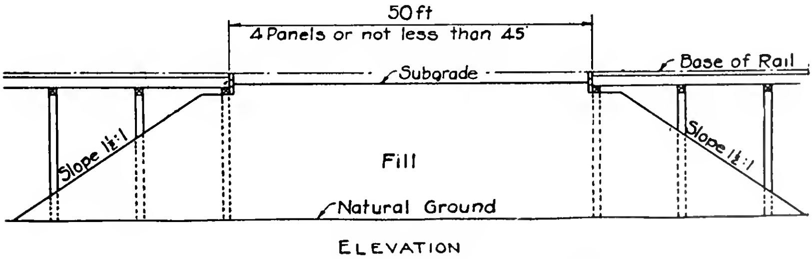


Fig. 1.—Earth Fill Break in a Long Trestle.

2. The decks of wood bridges should be protected from fires starting from hot coals dropped from locomotives, preferably by adopting ballasted deck trestles; or by covering the deck or the stringers and caps with rust resisting sheet metal. Bituminous mastic with sand or limestone chips may be used similarly to deflect any heated particles falling on the surfaces of the deck. The application of fire retardant salts or resisting paint to untreated timber in open deck trestles may also be employed.

5. Water barrels with buckets should be maintained on all timber bridges, one barrel each for structures up to 50 feet long and one additional barrel for each addi-

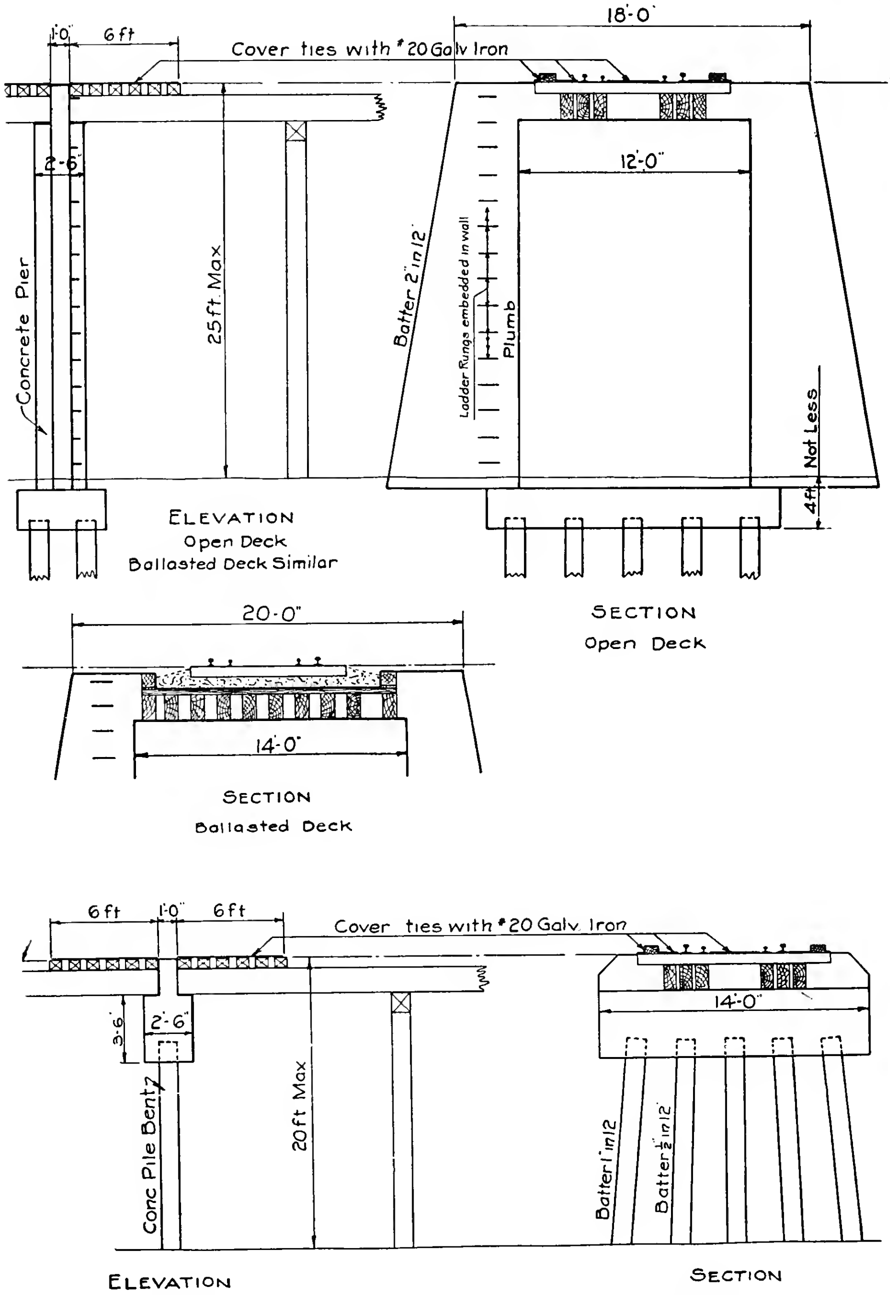


Fig. 2.—Reinforced Concrete Piers and Bents as Fire Stops.

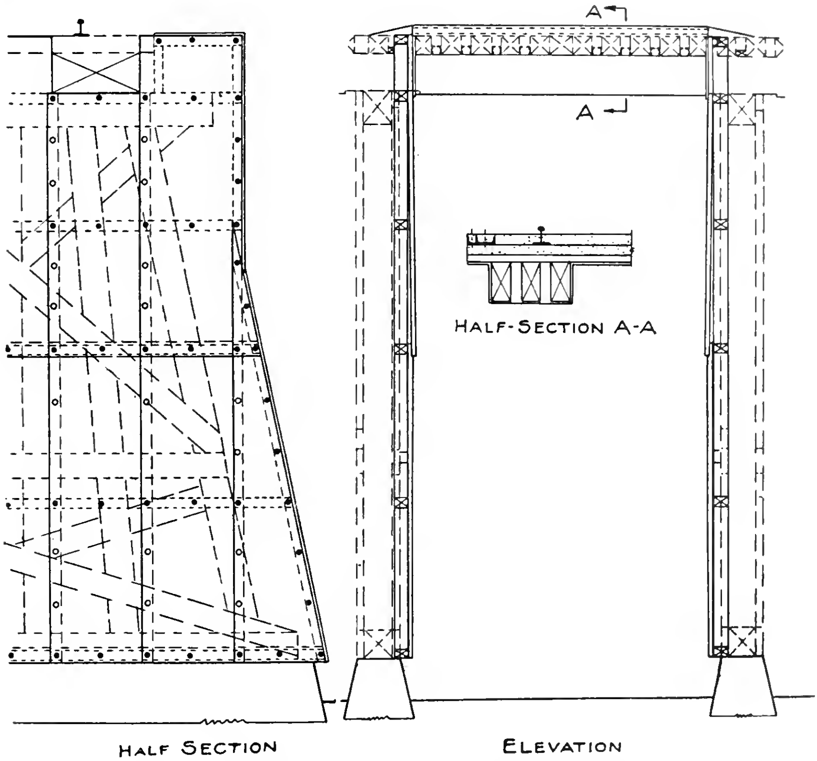


Fig. 3.—Wood Bents Faced with Fire Resisting Material.

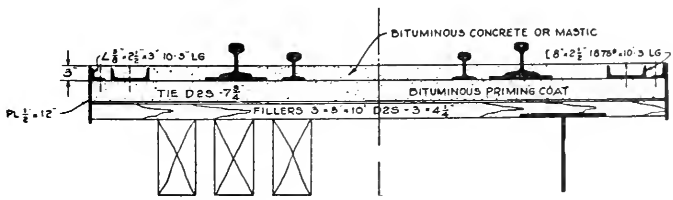


Fig. 4.—Application of Mastic Material to Open Deck Structures.

tional 150 feet. For creosoted structures, sand boxes with water tight covers for keeping the sand dry are recommended, dry sand being more effective than water in extinguishing small fires on creosoted structures.

6. On long bridges it is advisable to protect the bridge by introducing fire barriers at intervals of about 400 feet. This will reduce the hazard by preventing loss of the entire structure in case of fire. Such barriers for open deck and ballasted deck wood trestles may be grouped by types of construction, as follows:

1. Earth fill within long trestles
2. Reinforced concrete piers or concrete pile bents
3. Facing bents with fire resisting materials
4. Application of mastic materials to open deck structures

Report of Committee 8—Masonry

J. F. Leonard, *Chairman,*	M. L. Johnson	A. N. Laird, *Vice-Chairman,*
F. E. Bates	J. E. Kalinka	C. P. Schantz
G. E. Boyd	W. A. Kingman	G. E. Shaw
F. W. Capp	J. A. Lahmer	G. R. Smiley
Maurice Coburn	C. P. Marsh	A. W. Smith
T. L. Condron	R. L. Mays	C. H. Splitstone
Hardy Cross	L. M. Morris	E. O. Sweetser
G. H. Dayett	Roscoe Owen	J. H. Titus
Theodore Doll	O. V. Parsons	Jamison Vawter
G. F. Eberly	I. L. Pyle	L. W. Walter
W. K. Hatt	W. M. Ray	C. A. Whipple
Reuben Hayes	J. L. Rippey	W. R. Wilson
Meyer Hirschthal	F. B. Robins	J. J. Yates
L. H. Hornsby	G. E. Robinson	*Committee*

To the American Railway Engineering Association:

Your committee presents reports on the following subjects:

1. Revision of Manual.

Progress report, embracing minor revisions in the Specifications for Portland Cement Concrete and the Specifications for Shotcrete .... page 296

Other revisions of the Manual are presented in the reports on Assignments 2, 6 and 14.

2. Specifications and principles of design of plain and reinforced concrete for use in railway bridges, buildings and culverts, collaborating with Committees 1—Roadway and Ballast, 5—Track, 6—Buildings, 7—Wood Bridges and Trestles, 13—Water Service, Fire Protection and Sanitation, and 15—Iron and Steel Structures.

(a) Composite columns and pipe columns.

Progress report, embracing recommended revisions of the Manual .... page 298

(b) Reinforced concrete box culverts.

No report.

(c) Concrete bridge deck slabs of the non-ballast type, collaborating with Committee 5—Track.

No report.

3. Progress in the science and art of concrete manufacture.

Needed adjustments in field practice to use present-day cements to best advantage.

Progress report, presented as information .... page 305

4. Maintain contact with Joint Committee on Concrete and Reinforced Concrete.

The report of the Joint Committee was published as information in Bulletin 419, Part I, for September–October, 1940, and will appear on page 27 in the Monograph Section of the Proceedings for 1941.

5. Specifications for foundations, including excavation, cofferdam, piling, etc., collaborating with Committee 1—Roadway and Ballast on soil mechanics, and with Committee 7—Wood Bridges and Trestles on bearing power of wood piles and pile driving.

No report.

6. Methods and practices of lining and relining tunnels, collaborating with Committee 1—Roadway and Ballast.

Bulletin 422, January, 1941.

Two reports are presented; one for lining tunnels with liner plates and shotcrete, and the other for an alternate floor of the non-ballast type .... page 307

7. Review specifications for overhead highway bridges of the American Association of State Highway Officials, insofar as they relate to masonry, conferring with that association, and Committee 15—Iron and Steel Structures.

No report.

8. Progress in cement manufacture and testing.

A factual report is presented as information, describing the five types of Portland cement recently adopted by the ASTM as tentative .... page 310

9. Specifications for culvert pipe.

The specifications for placing which were submitted last year as information are now proposed for inclusion in the Manual .... page 315

10. Bibliography and review of current engineering literature pertaining to railroad masonry work.

No report.

11. Pressure grouting.

Specifications for Solidification of Masonry Structures by Pressure Grouting are submitted as information .... page 319

12. Specifications for concrete and reinforced concrete railroad bridges and other structures.

Brief progress report, submitted as information .... page 321

13. Specifications for test borings, collaborating with Committee 1—Roadway and Ballast.

Progress report, submitted as information .... page 321

14. Specifications for concrete placed under water.

Specifications are submitted for adoption to replace matter now in the Manual .... page 332

15. Durability of concrete.

Progress report, submitted as information .... page 335

THE COMMITTEE ON MASONRY,
J. F. LEONARD, *Chairman.*

Report on Assignment 1

Revision of Manual

G. E. Boyd (chairman, subcommittee), T. L. Condron, Meyer Hirschthal, L. H. Hornsby, J. A. Lahmer, F. B. Robins, C. P. Schantz, G. E. Shaw, C. A. Whipple, J. J. Yates.

The committee recommends the following revisions to Article 102.1 appearing on pages 8–3 and 8–4 of the Manual:

Section 1, change the ASTM designation from *D75–22* to D75–39T.

Section 2, Paragraph (a), change ASTM designation from *C87–36* to C87–39.

Section 2, Paragraph (d), change the ASTM designation from *C123–36T* to C123–39.

Section 2, Paragraph (e), change the ASTM designation from *C117–35T* to C117–37.

Section 2, Paragraph (h), the heading of this paragraph should be in italics to conform to the style followed in the remaining paragraphs of this section. Also change the ASTM designation from *C87–36* to C87–39.

Section 2, Paragraph (i), Subdivisions (1) and (2), change the ASTM designation from *C88–35T* and *C89–35T* to C88–39T.

Section 2, Paragraph (j), Subdivision (2), change the ASTM designation from *D289–28T* to D289–37T.

Section 2, Paragraph (k), change the ASTM designation from *C29–27* to C29–39.

The committee recommends changes in the ASTM designations in Article 104, Section 1 on page 8–4 as follows:

For Billet Steel Concrete Reinforcement Bars, from *A15–35* to A15–39.

For Axle Steel Concrete Reinforcement Bars, from *A160–36* to A160–39.

For Cast Iron Pipe and Special Castings, from *A44–04* to A44–39T.

The committee also recommends the deletion of the separate references to steel for bridges and buildings in this section and the substitution of a new reference.

Present Form

Steel for Bridges *A7–36*
Steel for Buildings *A9–36*

Proposed Form

Steel for Bridges and Buildings A7–39

The committee recommends that the ASTM designation for High Early Strength Portland Cement on page 8–5 of the Manual be changed from *C74–38* to C74–39.

The committee also recommends the following revisions in this specification:

Change the tolerance for loss of ignition in the table in Section 1, from *0.25* to 0.20 and change *sulfuric anhydride* to sulfur trioxide.

Delete the last sentence in Section 3, reading *Final set shall be attained within 10 hours.*

In the paragraph on Compressive Strength, Section 9, change the ASTM designation from *C109–34T* to C109–37T and delete the reference.

Delete the footnote on page 8–7.

The committee recommends that Section 5 of the Specification for Shotcrete, which appears on page 8–96 of the Manual, be deleted and that a new section be substituted as follows:

Present Form

5. Shotcrete shall consist of a mixture of Portland cement and sand, the fineness modulus of which shall be between 2.25 and 2.75, in the proportion of 1 bag of cement to 3 cubic feet of sand (dry loose measurement, due allowance being made for bulking), placed by pneumatic pressure through a Shotcrete machine, with proper amount of water for hydration applied in the mixing nozzle. The cement and sand shall be premixed dry in a batch mixer and screened through a ¼ inch screen before being placed in the hopper of the Shotcrete machine. The sand as used shall have only the normal water content, that is, from 3 percent to 8 percent of moisture.

Proposed Form

5. (a) Shotcrete shall consist of a mixture of Portland cement and sand, in the proportion of 1 bag of cement to 3 cubic feet of sand (dry loose measurement, due allowance being made for bulking), placed by pneumatic pressure through a Shotcrete machine, with the proper amount of water for hydration applied in the mixing nozzle.

The cement and sand shall be pre-mixed dry in a batch mixer and screened through a ¼ inch screen before being placed in the hopper of the Shotcrete machine. The sand as used shall have only the normal water content, that is, from 3 percent to 8 percent of moisture.

5. (b) Sand shall be well graded. The particles shall range in size within the limits below, percentage by weight:

Sieve Size	*Percent Retained*
No. 4	0
No. 8	5–30
No. 16	15–40
No. 30	35–55
No. 50	65–85
No. 100	92–98

The fineness modulus shall be between 2.25 and 2.75.

Report on Assignment 2 (a)

Composite Columns and Pipe Columns

A. N. Laird (chairman, subcommittee), Hardy Cross, G. H. Dayett, Theodore Doll, Meyer Hirschthal, J. E. Kalinka, J. L. Rippey, C. P. Schantz, A. W. Smith, E. O. Sweetser, Jamison Vawter, W. R. Wilson.

The committee recommends that subject matter of Section 307, Design of Columns, of the Specifications for Portland Cement Concrete, Plain and Reinforced, be withdrawn and that it be replaced by new Section 307, Design of Columns.

Present Form

Reference is made to present Section 307 on pages 8–49, 50 and 51 of the Manual.

Proposed Form

307—DESIGN OF COLUMNS*

1. General

(a) The following recommendations are based largely on the results of the extensive American Concrete Institute Column Investigation. Recognizing the presence of undesirable column shortening due to creep and shrinkage when small percentages of vertical steel are used, the minimum value is set at 1 percent; furthermore, a varying factor of safety is used, ranging, for axially loaded spiral columns, from about 3.6 for $p = 0.01$, to 2.75 for $p = 0.08$. A similar variation from about 4.5 for $p = 0.01$, to 4.0 for $p = 0.04$ is used with tied columns.

(b) The formula for spiral columns is based upon recognition of the fact that the strength produced by spirals is accompanied by spalling of the column shell and excessive column shortening, hence the spiral is utilized only as a toughening element or an insurance against a sudden and complete collapse of the column. With spiral reinforcement

* Section 307 conforms substantially to Sections 851–862 inclusive, of the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete as submitted to the constituent organizations, June 1940 (AREA Proceedings for 1941, Vol. 42, p. 27 of the Monograph Section.)

provided, which is somewhat stronger than the protective shell, these two elements of strength (which cannot act simultaneously) become interchangeable, and justify the formula which uses the gross area of column and omits any reference to the spiral. The formulas for tied and spiral columns are thus made identical, except that the latter is allowed 25 percent greater load-carrying capacity because of the presence of adequate spiral reinforcement to carry part of the load if the outer shell should spall.

(c) The design of long columns, both tied and spirally reinforced, is covered by a single equation based on the height-diameter ratio. With the test data available, no increase in accuracy would be attained by basing the slenderness ratio on the radius of gyration.

(d) The treatment of bending in columns is intended to correlate with the methods for continuous beams and frames. Recent studies of creep indicate that the current analyses of combined bending and direct stress are not accurate, and that for cases in which the compressive stress governs the design, the theory of the uncracked concrete section applies without serious error. The permissible combined stresses in Articles 307 (10) and (11) are based on test data; they embody the fact that permissible bending stresses may be greater than axial stresses, and they are based on the conventional value of n, which produces the most severe of the probable conditions that the concrete may meet under sustained loading.

2. Limiting Dimensions

The following articles on reinforced concrete and composite columns (except Article 307 (8)) apply to a short column, for which the unsupported length is not greater than 10 times the least lateral dimension. When the unsupported length exceeds this value the design should be modified as shown in Article 307 (8). Principal columns in buildings should have a minimum diameter or thickness of 10 inches. Posts, bearing walls, piers, or mullions, that are not continuous from story to story should have a minimum diameter or thickness of 6 inches.

3. Unsupported Length of Columns

(a) For purposes of determining the limiting dimensions of columns, the unsupported length of reinforced concrete columns should be taken as the clear distance between floor slabs with the following exceptions:

1. In flat slab construction, it should be the clear distance between the floor and the lower extremity of the capital.

2. In beam and slab construction, it should be the clear distance between the floor and the underside of the deepest beam framing into the column in each direction at the next higher floor level.

3. In columns restrained laterally by struts, it should be the clear distance between consecutive struts in each vertical plane; provided that to be an adequate support, two such struts should meet the column at approximately the same level and the angle between vertical planes through the struts should not vary more than 30 degrees from a right angle. Such struts should be of adequate dimensions and anchorage to restrain the column against lateral deflection.

4. In columns restrained laterally by struts or beams, with brackets used at the junction, it should be the clear distance between the floor and the lower edge of the bracket, provided that the bracket width equals that of the beam or strut and is at least half that of the column, and provided further that the face of the bracket makes an angle with the face of the column of at least 45 degrees.

(b) For all columns, that length should be considered which produces the greatest ratio of length to depth of section.

4. Spirally Reinforced Columns

(a) *Allowable Load.*—The maximum allowable axial load, P, on columns reinforced with longitudinal bars and closely spaced spirals enclosing a circular core is given by formula (36).**

$$P = 0.225 f'_c A_g + A_s f_s \qquad (36)$$

Wherein A_g = the overall or gross area of the column.

f'_c = compressive strength of the concrete, as found by tests of standard 6 by 12-inch control cylinders.

f_s = nominal working stress in vertical column reinforcement, to be taken at 40 percent of the minimum specification value of the yield point; viz., 16,000 pounds per square inch for intermediate grade steel and 20,000 pounds per square inch for hard grade steel.

$A_s = p_g A_g$.

p_g = ratio of the effective cross-sectional area of vertical reinforcement to the gross area, A_g.

(b) *Longitudinal Reinforcement—Amount and Spacing.*—The ratio p_g should not be less than 0.01 nor more than 0.08. The minimum number of bars should be six, and the minimum diameter of bar should be ⅝ inch. The center-to-center spacing of bars within the periphery of the column core should not be less than 2½ times the diameter for round bars or 3 times the side dimension for square bars. The clear spacing between individual bars or between pairs of bars at lapped splices should not be less than 1½ inch or 1½ times the maximum size of the coarse aggregate used.

(c) *Splices in Longitudinal Reinforcement.*—Where lapped splices in the column verticals are used, the minimum amount of lap should be as follows:

1. For deformed bars—with concrete having a strength of 3,000 pounds per square inch or above, 24 diameters of bar of intermediate grade steel and 30 diameters of bar of hard grade steel. For bars of higher yield point, the amount of lap should be increased in proportion to the nominal working stress. When the concrete strengths are less than 3,000 pounds per square inch the amount of lap should be one-third greater than the values just given.

2. For plain bars—the minimum amount of lap should be 25 percent greater than that specified for deformed bars.

Where changes in the cross-section of a column occur, the longitudinal bars should be sloped for the full length of the column, or offset in a region where lateral support is afforded by concrete capital, floor slab, metal ties, or reinforcing spirals. Where bars are offset, the slope of the inclined portion from the axis of the column should not exceed 1 in 6, and the bars on each side of the offset should be parallel to the axis of the column.

Welded splices or other positive connections may be used instead of lapped splices. Welded splices should preferably be used in cases where the bar diameter exceeds 1¼ inch. An approved welded splice should be defined as one in which the bars are butted and welded and that will develop in tension at least the yield point stress of the reinforcing steel used.

** To be logical the area of the steel should be subtracted from A_g in the formula. However, the effect of the small area of concrete displaced by the reinforcement has been taken into consideration in arriving at the coefficient 0.225 applied to f'_c.

(d) *Spiral Reinforcement.*—The ratio of spiral reinforcement, p', should not be less than the value given by Formula (37).

$$p' = 0.45\left[\frac{A_g}{A_c} - 1\right]\frac{f'_c}{f'_s} \qquad (37)$$

Wherein p' = ratio of volume of spiral reinforcement to the volume of the concrete core (out to out of spirals).

A_g/A_c = ratio of gross area to core area of column.

f'_s = useful limit stress of spiral reinforcement to be taken as 40,000 pounds per square inch for hot rolled rod of intermediate grade, 50,000 pounds per square inch for hard grade and 60,000 pounds per square inch for cold drawn wire.

Spiral reinforcement should consist of evenly spaced continuous spirals held firmly in place and true to line by at least three vertical spacer bars. For columns up to 18-inch core diameter, the minimum diameter of spiral bars should be ¼ inch. For columns larger than 18-inch core diameter, the minimum diameter of spiral bars should be ⅜ inch. Anchorage of spiral reinforcement should be provided by 1½ extra turns of spiral rod or wire at each end of the spiral unit. Splices, where necessary, should be made in spiral rod or wire by welding or by a lap of 1½ turns. The center to center spacing of the spirals should not exceed one-sixth of the core diameter. The clear spacing between spirals should not exceed 3 inches nor be less than 1⅜ inches or 1½ times the maximum size of coarse aggregate used. The column reinforcement should be protected everywhere by a covering of concrete cast monolithically with the core, for which the thickness should not be less than 1½ inches nor less than 1½ times the maximum size of the coarse aggregate, nor should it be less than required for fire protection and weathering. The reinforcing spiral should extend from the floor level in any story to the level of the lowest horizontal reinforcement in the slab, drop panel, or beam above. In a column with a capital, it should extend to the plane at which the sectional area of the capital is twice that of the column.

(e) *Limits of Column Section.*—For columns built monolithically with concrete walls or piers, the outer boundaries of the column section should be taken as a circle 1½ inches outside the column spiral or as a square the sides of which are 1½ inches outside the spiral. In case two or more spirals are used in such a column the outer boundary should be taken as a rectangle the sides of which are at any point at least 1½ inches outside of the spirals. For these types of spirally reinforced columns the value of A_g thus defined should be used in both Formulas (36) and (37).

(f) *Equivalent Circular Columns.*—As an exception to the general procedure of utilizing the full gross area of the column section, it should be permissible to design a circular column and to build it with a square, octagonal, or other shaped section of the same least lateral dimension. In such case, the allowable load, the gross area considered, and the required percentages of reinforcement should be taken as those of the circular column.

5. Tied Columns

(a) *Allowable Load.*—The maximum allowable axial load on columns reinforced with longitudinal bars and separate lateral ties should be 80 percent of that given by Formula (36). The ratio, p_g, to be considered in tied columns should not be less than 0.01 nor more than 0.04. The longitudinal reinforcement should consist of at least four bars, of minimum diameter of ⅝ inch placed with a clear distance from the column face of not less than 1½ inches plus the thickness of the tie, provided that when nearer a corner than 4 inches this covering shall be increased to 2 inches. Splices in reinforcing bars shall be made as described in Article 307 (4c).

(b) *Lateral Ties.*—Lateral ties should be at least ¼ inch in diameter and should be spaced apart not over 16 bar diameters, 48 tie diameters, or the least dimension of the column. When there are more than four vertical bars, additional ties should be provided so that every longitudinal bar is held firmly in its designed position.

(c) *Limits of Column Section.*—In a tied column which for architectural reasons has a larger cross section than required by considerations of loading, a reduced effective area A_g not less than one-half of the total area may be used in applying the provisions of Article 307 (5a), but the longitudinal reinforcement should be distributed over the full column section.

6. Composite Columns

(a) *Allowable Load.*—The allowable load on a composite column consisting of a structural steel or cast iron column thoroughly encased in concrete reinforced with both longitudinal and spiral reinforcement, should not exceed that given by Formula (38).

$$P = 0.225A_c f'_c + f_s A_s + f_r A_r \quad \text{(38)}$$

Wherein A_c = net area of concrete section $A_g - A_s - A_r$.
A_s = cross-sectional area of longitudinal bar reinforcement.
A_r = cross-sectional area of the steel or cast iron core.
f_r = allowable unit stress in metal core, not to exceed 16,000 pounds per square inch for a steel core; or 10,000 pounds per square inch for a cast iron core.

The remaining notation is that of Article 307 (4).

(b) *Details of Metal Core and Reinforcement.*—The cross-sectional area of the metal core should not exceed 20 percent of the gross area of the column. If a hollow metal core is used it should be filled with concrete. The amounts of longitudinal and spiral reinforcement and the requirements as to spacing of bars, details of splices, and thickness of protective shell outside the spiral should conform to the limiting values specified in Article 307 (4b, c and d). A clearance of at least 3 inches should be maintained between the spiral and the metal core at all points except that when the core consists of a structural steel H-column, the minimum clearance may be reduced to 2 inches.

(c) *Splices and Connections.*—Metal cores in composite columns shall be accurately milled at splices and positive provision shall be made for the alinement of one core above another. Transfer of loads to the metal core should be provided for by use of bearing members such as billets, brackets, or other positive connections; these should be provided at the top of the metal core and at intermediate floor levels where required. Ample section of concrete and continuity of reinforcement should be provided at the junction with beams and girders. The column as a whole should satisfy the requirements of Formula (38) at every section; in addition to this, the reinforced concrete portion should be designed to carry, in accordance with Formula (36), all floor loads brought onto the column at levels between the metal brackets or connections. In applying Formula (36) to a hollow core filled with concrete, the area of the concrete within the core should not be included in the area defined as A_g. At the column base, provision should be made to transfer the load to the footing at safe unit stresses in accordance with Article 308 (8). The base of the metal core should be designed to transfer the load from the entire composite column to the footing, or it may be designed to transfer the load from the metal section only, provided it is so placed in the pier or pedestal as to leave ample section of concrete above the base for the transfer of load from the reinforced concrete section of the column by means of bond on the vertical reinforcement and by direct compression on the concrete.

(d) *Allowable Load on Bare Metal Core.*—The metal cores of composite columns should be designed to carry safely any construction or other loads to be placed upon them prior to their encasement in concrete.

7. Combination and Pipe Columns

(a) *Combination Columns; Steel Columns Encased in Concrete.*—The allowable load on a structural steel column which is encased in concrete at least 2½ inches thick over all metal (except rivet heads) reinforced as hereinafter required, should be computed by Formula (39a).

$$P = A_r f'_r \left[1 + \frac{A_c}{100 A_r} \right] \qquad (39a)$$

Wherein A_r = cross-sectional area of steel column.
f'_r = allowable stress for unencased steel column.
A_c = total area of concrete section, $= A_g - A_r$.

The concrete used should develop a compressive strength, f'_c, of at least 2,500 pounds per square inch when tested according to the provisions of Article 202 (7). The concrete should be reinforced by welded wire mesh having wire not smaller than No. 10 gage, spaced in vertical direction not more than 4 inches, and in the horizontal direction not more than 8 inches. This mesh should extend entirely around the column at a distance of 1 inch inside the outer concrete surface and should be lap-spliced at least 40 wire diameters and wired at the splice.

Special brackets should be used to receive the entire floor load at each floor level. The steel column should be designed to carry safely any construction or other loads to be placed upon it prior to its encasement in concrete.

(b) *Pipe Columns.*—The allowable load on columns consisting of steel pipe filled with concrete should not exceed that given by Formula (39b).

$$P = 0.225 f'_c A_r + f'_r A_c \qquad (39b)$$

The value of f'_r should be that given by Formula (39c)

$$f'_r = \left[18{,}000 - 70 \frac{h}{R} \right] F \qquad (39c)$$

Wherein f'_r = allowable stress in the steel pipe section.
h = unsupported length of column.
R = radius of gyration of steel pipe section.
$F = \dfrac{\text{tensile yield point of pipe material}}{45{,}000}$

If the yield point is not known, the factor F shall be taken as 0.5.

If the concrete strength f'_c is not known it shall be assumed at 2,500 pounds per square inch.

8. Long Columns

(a) The maximum allowable load P' on axially loaded reinforced concrete or composite columns having a length, h, greater than 10 times the least lateral dimension, d, is given by Formula (39d).

$$P' = P \left[1.3 - .03 \frac{h}{d} \right] \qquad (39d)$$

Wherein P = the allowable axial load on a short column as given by Formulas (36) and (38).

(b) The maximum allowable load P' on eccentrically loaded columns in which $h \div d$ exceeds 10 is also given by Formula (39d) in which P is the allowable eccentrically applied load on a short column as determined by the provisions of Articles 307 (10) and (11). In long columns subjected to definite bending stresses, as determined in Article 307 (9), the ratio $h \div d$ should not exceed 20.

9. Bending Moments in Columns

The bending moments in the columns of all reinforced concrete structures should be determined on the basis of loading conditions and restraint and should be provided for in the design. When the stiffness and strength of the columns are utilized to reduce moments in beams, girders, or slabs, as in the case of rigid frames in general, the need for recognizing column moments is obvious; in other forms of continuous construction where column moments are unavoidable, they should also be provided for in the design. In building frames, particular attention should be given to cases of unbalanced floor loads on both exterior and interior columns and of eccentric loading due to other causes. Wall columns should be designed to resist moments produced by: (a) Loads on all floors of the building, (b) loads on a single exterior bay at two adjacent floor levels, or (c) loads on a single exterior bay at one floor level. Resistance to bending moments at any floor level should be provided by distributing the moment between the columns immediately above and below the given floor in proportion to their relative stiffnesses and conditions of restraint.

10. Combined Axial and Bending Stress

(a) In reinforced concrete columns subjected to bending moments, the recognized methods of analysis should be followed in calculating the stresses due to combined axial load and bending. The maximum fiber stress in compression and (in the case of large eccentricities of loading) the tensile stress in the vertical bars will govern the design. The gross area of both spiral and tied columns should be used in the computations.

(b) For preliminary designs it will usually give satisfactory results to compute the combined fiber stress in compression on the basis of an uncracked section of the column using Formula (39e).†

$$f_c = \frac{P}{A_g} \frac{\left[1 + \frac{ec}{R^2}\right]}{1 + (n - 1)p_g} \qquad \text{(39e)}$$

Wherein e = eccentricity of resultant load, measured from the gravity axis.
c = distance from gravity axis to extreme fiber in compression.
R = radius of gyration of equivalent concrete section.
n = as given in Article 301 (4).

Other terms as in Article 307 (4).

The term $\frac{ec}{R^2}$ may be replaced by the value $6e \div t$ for rectangular columns and $8e \div t$ for round columns without appreciable error (t = overall depth of section). This design may then be analyzed by more accurate methods to insure that allowable stresses are not exceeded.

11. Allowable Combined Axial and Bending Stresses

(a) For spiral and tied columns, eccentrically loaded or otherwise subjected to combined axial compression and flexural stress, the maximum allowable compressive fiber stress, f_c, is given by Formula (39f).

$$f_c = f_a \frac{1 + \frac{ec}{R^2}}{1 + C\frac{ec}{R^2}} \qquad \text{(39f)}$$

† This will result in a fairly accurate design if the eccentricity is less than ½ the overall column width, and the value of $p_g n$ is 0.3 or more.

Wherein the notation is that of Articles 307 (4) and (10), and in addition, f_a is the average allowable stress on an equivalent axially loaded concrete column, and C is the ratio of f_a to the allowable fiber stress for members in flexure. Thus, $f_a = \frac{0.225f'_c + f_s p_g}{1 + (n - 1)p_g}$ for spiral columns, and 0.8 of this value for tied columns.

$$C = \frac{f_a}{0.45f'_c}.$$

(b) The allowable tensile stress in the longitudinal reinforcement may equal that specified for flexural members, provided however that splices in the tensile steel at or near the section of maximum column moment are capable of developing fully the yield point strength of the reinforcement.

12. Wind or Earthquake Stresses

When columns are subject to wind or earthquake stresses in addition to combined axial load and bending, the column section need not be increased unless the allowable stress given by Formula (39f) is exceeded by more than one-third.

Report on Assignment 3

Progress in Science and Art of Concrete Manufacture

Needed Adjustments in Field Practice To Use Present Day Cements to Best Advantage

C. P. Marsh (chairman, subcommittee), F. W. Capp, R. Hayes, L. M. Morris, W. M. Ray, G. E. Shaw, C. H. Splitstone, L. W. Walter, C. A. Whipple.

In considering this subject the subcommittee has limited its studies and this report to the types of Portland cement for which ASTM specifications have been published, and has assumed that study and report on the use of calcium-aluminate cement, masonry cements and blended cements were matters outside of its assignment.

The new ASTM specifications which bear the title Tentative Specifications for Portland Cement, ASTM Serial Designation (C–150–40T) cover five types of cement which are intended to embrace all of the engineering uses of Portland cement. While these specifications are only tentative and do not supersede current standards for Portland and high early strength Portland cements (C9–38 and C74–39, respectively), it is anticipated that some engineers may wish to take advantage of the wider range in types which they afford. The following comments are offered as an aid in selecting the type of cement which is best adapted to a particular structure or group of structures.

Type I.—This cement, except for some differences in requirements and the incorporation of the autoclave test for soundness, is the same as those called for by the current ASTM standard specification C9–38 and by the federal specification SS–C–191a.

This type of cement is adapted for general concrete construction where the special properties specified for types II, III, IV and V, are not required. Owing to the fact that this cement is more finely ground and in general has a higher lime content than the normal Portland cement of some 12 to 15 years ago, it develops strength and heat of hydration more rapidly and the total heat of hydration in any period is greater. These changes cause heat to be generated more rapidly and produce higher temperatures in the concrete. Due to the higher temperature, larger temperature differentials within the mass and a greater loss of moisture are encouraged, which in turn aggravate the tendency to crack. Consequently, what was considered good practice in placing concrete 12 or 15 years ago must be revised in respect to limiting the temperature of the concrete when placed and the rate of placing, and in providing ample moisture for curing during the first few days after placing. Because the strength develops more rapidly the curing period may be shortened somewhat from the seven days usually specified. If an ample supply of moisture is assured a limit of five days is recommended.

Type II.—This cement is adapted for use in general construction where the special properties specified for types III, IV and V, are not required, and when the chemical and physical test requirements prescribed for this type are desired. In rate of hardening, this cement is intermediate between that of Type I and the low heat cement of Type IV, and is similar to the cement used by the Tennessee Valley Authority in dam construction.

It is recommended particularly for structures of considerable size where low heat cement is not necessary but where the use of cement of moderate heat of hardening will tend to minimize temperature rise and the resulting tendency to shrinkage cracking, as in the case of large piers, heavy abutments, heavy retaining walls, etc., when such structures are placed in warm weather. In cold weather, when the heat generated during hardening is of advantage, Type I cement may be preferable.

Type II cement, because of greater sulphate resistance as compared with Type I, is recommended for places where added precaution against sulphate attack is a factor of importance, such as in mine and drainage structures where the sulphate concentrations are not unusually severe. Where the sulphate concentrations are severe, Type V cement is recommended, as noted below.

Type II cement is suitable for concrete roads and architectural concrete structures. It can be used equally as well as Type I for many other structures for which no preference as between the two types is justified. It is recommended that the curing period when using Type II cement, be not less than seven days when an ample supply of moisture is assured.

Type III.—This is a high early strength cement. The requirements for this type are in most respects the same as those in the present ASTM Specifications for High Early Strength Portland Cement, C74–39, and in even closer agreement with those in the Federal Specifications for High Early Strength Portland Cement, SS–C–201. This type is recommended where high strength concrete at early periods is desired, which can be obtained more satisfactorily or more economically by the use of a high early strength cement than by resorting to richer mixes.

Owing to the quicker hardening, the heat due to hydration develops rapidly in the early period. The total heat evolved is also greater, and because of this greater care must be taken to avoid temperature cracks. Where Type III cement is used the curing period should be not less than three days.

Type IV.—This is a low heat cement which has not been covered previously by ASTM Specifications, although cement of this type has been used by the Bureau of Reclamation and other government bodies under specifications having similar requirements. Type IV cement is a slow hardening cement which should not be used for general work. It is recommended for use only in extremely large masses of concrete where the temperature rise resulting from the heat generated during hardening is a critical factor. Because of the special characteristics of this cement, it will not be generally available.

It is doubtful that its use would be found necessary in railroad construction. As it gains strength slowly, the curing period should be prolonged to four weeks.

Type V.—This is a special cement intended to provide a very high degree of sulphate resistance. Like Type IV this cement will not be generally available, and because of its slow hardening characteristics, should never be considered for any but the special purpose for which it is intended.

Its use is recommended only in structures exposed to severe sulphate action, such as is encountered in some of the western states having soils or waters of high alkali content. The slow hardening of this cement requires a longer period of moist curing at normal temperatures.

Report on Assignment 6

Methods and Practices of Lining and Relining Tunnels

Collaborating With Committee 1—Roadway and Ballast

I. L. Pyle (chairman, subcommittee), G. E. Boyd, Maurice Coburn, G. F. Eberly, W. A. Kingman, Roscoe Owen, O. V. Parsons, G. R. Smiley.

The following specifications are submitted as information with the object of presenting them later for adoption and publication in the Manual.

SPECIFICATIONS FOR LINING RAILWAY TUNNELS WITH METAL LINER PLATES AND SHOTCRETE

I GENERAL

101. Scope

These specifications cover the lining of new tunnels and the relining of old tunnels through ordinary formations which involve no special features.

102. Metal Lining

The side walls shall consist of metal liner plates, not less than 1/8 inch in thickness, secured between I-beams used as columns for supporting wall plates and arches.

The arch shall consist of liner plates alone or, when necessary, supplemented with ribs of I-beams, T-shapes or flat bars, supported on H-beams of the required size used as a wall plate.

II DESIGN

201. Interior Dimensions

The interior dimensions of the clear space provided for single and double track tunnels shall not at any point be less than the tunnel clearance recommended by the AREA, pages C1–4 and C1–5 of the Manual.

202. Floor and Ballast Walls

In all new tunnels, a concrete floor and ballast walls for ballast track section, or a floor for solid track section, shall be installed in accordance with AREA Specifications for Lining Railway Tunnels with Plain Concrete, page 8–103 of the Manual.

203. Foundations for Side Walls

A concrete footing shall be provided for the side walls. The concrete shall be made and placed in accordance with the AREA Specifications for Portland Cement Concrete, Plain and Reinforced.

The bottom of the concrete footing, in hard, durable material, shall be at least 6 inches below the bottom of the gutter for ballast track sections and 6 inches below the intersection of the surface of the floor and the side walls for solid track sections. In other material, it shall be carried to suitable foundation.

204. Side Wall and Arches

Side walls and arches shall consist of metal liner plates, properly supported and a protective covering of shotcrete not less than 3 inches thick, measured from the inside face of the liner plate.

The space between the liner plates and the face of the excavation shall be (a) firmly packed with durable stone, rammed into place and the voids filled with grout, or (b) entirely filled with "pea gravel" placed pneumatically and the voids filled with grout.

205. Refuge Niches

Refuge niches shall be at least 15 inches deep, 3 feet 6 inches wide and 7 feet high. Niches should be spaced approximately 100 feet apart and staggered with the opposite side so that there will be a niche every 50 feet in the tunnel. The bottom of niches shall be at the elevation of base of rail for ballast track sections and at the intersection of the surface of the floor and the side walls for solid track sections.

206. Drainage Openings

Rectangular tile drains, 3¾ inches by 5 inches, shall be installed as necessary in the rear of the lining, with outlets through the side walls to provide adequate drainage.

Weep holes shall be placed through the side walls at intervals of 20 feet unless drainage conditions require them to be placed at shorter intervals. The weep holes should be of pipe not less than 4 inches in diameter and placed on a slope of 45 degrees. The outer end of the outlets or weep holes shall be not less than 12 inches above the bottom of the gutter. Sub-drains shall be provided under the floor as necessary. Round tile drains 4 inches in diameter, or openings of similar area, shall be installed in each 10 feet of ballast walls to provide drainage for the section of the floor between the ballast walls.

III SHOTCRETE

301. Specifications

The shotcrete for the lining shall be made and placed in accordance with the AREA Specifications for Shotcrete, page 8–95 of the Manual, together with the additional provisions given herewith.

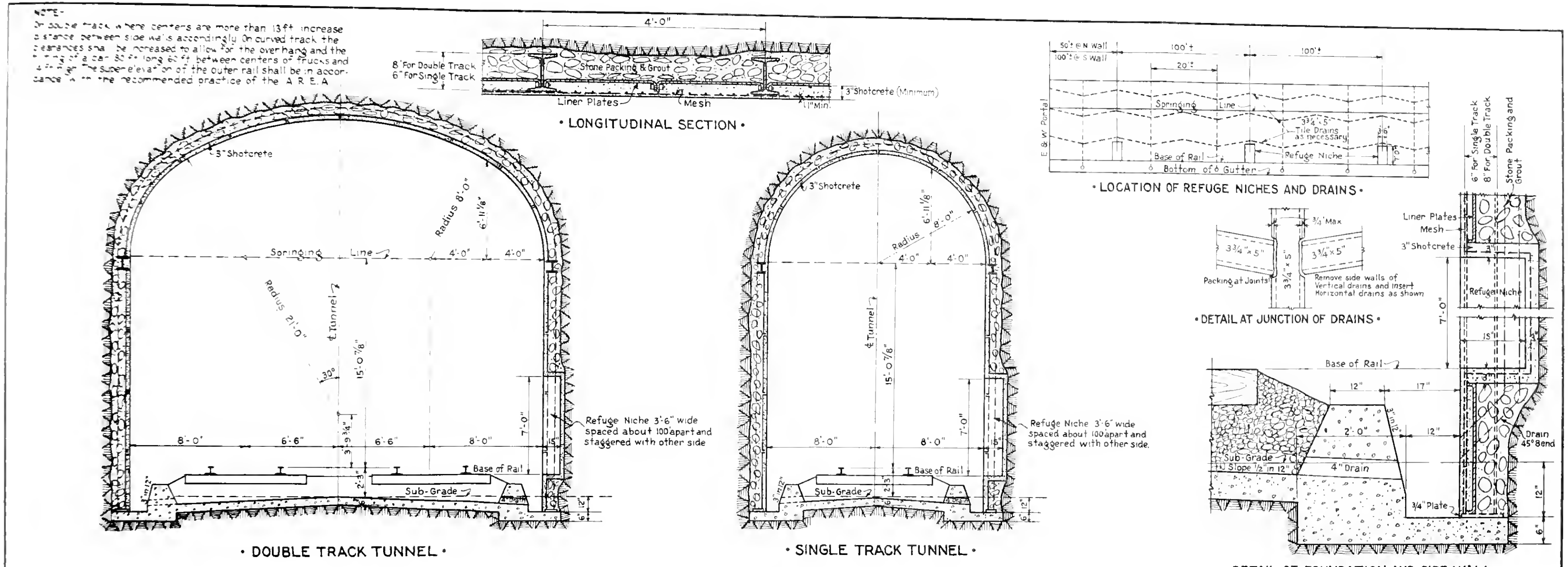
302. Cement

Portland cement shall conform to the requirements of the AREA Specifications for Portland Cement, page 8–9 of the Manual.

303. Aggregate

Aggregate shall consist of fine granular material composed of hard, strong, durable mineral particles that are free from injurious amount of saline, alkaline, organic or other deleterious substances.

Aggregate shall be well graded. The particles shall range in size within the limits below, percentage by weight and shall have a fineness modulus which shall be between 2.25 and 2.75:



• METHOD OF LINING TUNNELS WITH SHOTCRETE ON LINER PLATES •

Sieve Size	*Percent Retained*
No. 4	0
No. 8	5–30
No. 16	15–40
No. 30	35–55
No. 50	65–85
No. 100	92–98

304. Steel Reinforcement

Shotcrete shall be reinforced by galvanized electric welded wire fabric 3 × 3 inch mesh No. 10 A.S.W.G. Sheets shall be securely and properly fastened together and wires stretched tight.

305. Curing

The shotcrete lining shall be kept wet for at least 7 days after placing.

Revision of the Manual

Your committee recommends changes in the Specifications for Lining Railway Tunnels with Plain Concrete, adopted in 1936 and appearing on page 8–103, for the purpose of including an alternate for solid floor track section, with center drain, along with the present standard for ballast section.

Change the title of Section 202 from its present form to:

202. Floor and Ballast Walls for Ballast Track Section

Add the following new section:

203. Floor for Solid Track Section

The track rails shall be supported on creosoted tie blocks 8 inches by 10 inches by 2 feet 6 inches, spaced 19½ inches on center, embedded in the concrete floor, with a double-shoulder tie plate fastened to the tie block with suitable lag screws. Superelevation shall be provided for curve track by increasing the thickness of the tie blocks under the high rail.

The concrete floor shall extend at least 1 foot 4 inches below the bottom of the tie blocks. The surface of the floor shall slope ¾ inch in 12 inches from the center of the drain, 7 11/16 inches below the top of the tie block for double track and 4 inches below the top of tie block for single track, up to the side walls. (See supplement to Figures 835 and 836.)

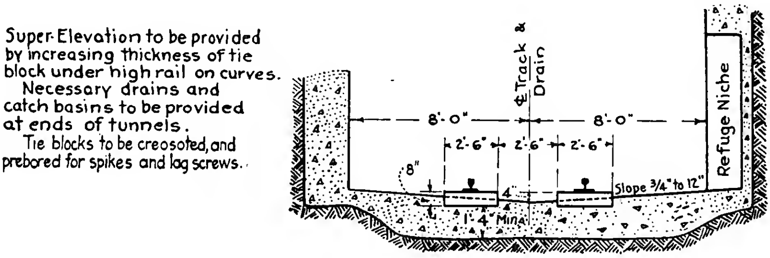
Make the necessary changes in the remaining section numbers.

Change the first paragraph in present Section 203 (new No. 204) to read as follows:

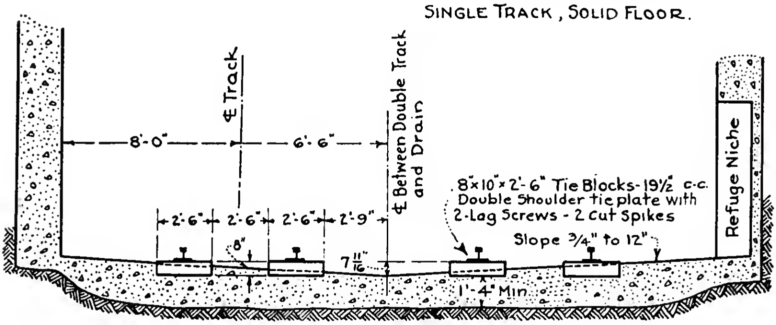
The depth of the side walls, in hard, durable material, shall be at least 6 inches below the bottom of the gutter for ballast track section and at least 6 inches below the intersection of the floor surface with the side walls for solid track section. In other material, the side walls shall be carried down to stable foundation and at least to below the frost line.

Change the last sentence of the first paragraph of present Section 205 (new No. 206) to read as follows:

The bottom of the niches shall be at the elevation of the bottom of the track ties for the ballast track section and at the elevation of the intersection of the floor surface with the side walls for the solid track section. (Figures 835, 836 and supplement.)



SECTION
SINGLE TRACK, SOLID FLOOR.



SECTION
DOUBLE TRACK SOLID FLOOR.

Supplement to Figures 835 and 836.

Report on Assignment 8

Progress in Cement Manufacture and Testing

C. P. Marsh (chairman, subcommittee), F. W. Capp, Maurice Coburn, L. M. Morris, L. W. Walter.

Supplementing the report presented last year, the committee reports as follows:

At the June, 1940, meeting of the American Society for Testing Materials, that society adopted "Tentative Specifications for Portland Cement, (C150–40T)", which are in effect a tentative revision of, and are intended to replace, when adopted, the present Standard Specifications for Portland Cement (C9–38), and for High Early Strength Portland Cement (C74–39).

These new specifications of the ASTM provide for five types of Portland cement, as follows:

Type I.—For use in general concrete construction when the special properties specified for types II, III, IV and V are not required.

Type II.—This cement is adapted for use in general concrete construction when the special properties specified for types III, IV, and V are not required, and when the chemical and physical test requirements prescribed for this type are desired.

Type III.—For use when high early strength is required.

Type IV.—For use when a low heat of hydration is required (Note).

Type V.—For use when high sulphate resistance is required (Note).

Note—Attention is called to the fact that cements conforming to the requirements for type IV and type V are not usually carried in stock. In advance of specifying their use purchasers or their representatives should determine whether these types of cement are, or can be, made available.

The specifications for these five types of cement correspond closely with the five federal specifications given in the table accompanying the committee's report of last year as printed in the Proceedings for 1940, Vol. 41, page 383.

They are related as follows:

Type I—Federal, Portland
Type II—Federal, moderate heat of hardening Portland
Type III—Federal, high early strength Portland
Type IV—Boulder dam low heat Portland
Type V—Federal, sulphate resisting Portland

The chemical and physical requirements are shown in tables I and II.

It will be noted that the table of physical requirements includes an autoclave soundness test. At its June, 1940, meeting, the American Society for Testing Materials adopted as tentative a Method of Test for Autoclave Expansion of Portland Cement (C151–40T).

While the present ASTM Standard Specifications for Portland Cement contain no requirement for fineness, the new tentative specifications contain a requirement for fineness as determined by the turbidimeter for types I, II, IV and V cements. The society adopted tentative methods for this test in 1939 under the serial designation C115–38T.

During the past year, investigations by 7 laboratories of mortars for the plastic mortar cube test for compressive strength and studies by 30 laboratories of various types of test for volume change and soundness, have been carried on under the sponsorship of working committees of ASTM Committee C1 on Cement. The working committee on the plastic mortar tests reported that none of the mortars covered by the investigation showed sufficient superiority over that specified in the Tentative Method of Test for Compressive Strength of Portland Cement Mortars (C109–37T) to warrant a change in type of mortar and recommended that this specification be retained as tentative for another year in order that the committee might study suggestions for improvement resulting from a study of the effect of different types, capacities, etc., of testing machines, and in order to investigate the high frequency vibration method for moulding cubes suggested by the National Bureau of Standards. The working committee on volume change and soundness reported:

1. That for 206 (94 percent) of 221 cements tested, the autoclave expansion of neat bars at 14 days was either approximately the same or was less than the expansion of companion bars at 1 day.

2. That the method used in moulding the 1 × 1 × 11¼-in. neat bars did not affect the 1-day autoclave expansion appreciably.

3. That sound autoclave pats may be obtained with cements which show autoclave expansions up to 4 or 5 percent.

4. That pats in the ASTM steam test were reported as sound for nearly all of the cements except those having excessively high autoclave expansions at 1 day. (The committee commented that "the results confirm those of many other tests in showing the inadequacy of the standard pat test as a test for soundness of cement".)

Chemical and Physical Requirements of Proposed Tentative Specifications for Portland Cement—1940

Chemical Limits:
Portland Cement of each of the five types shown in Section 1 shall conform to the requirements prescribed in Table I.

Table I—Chemical Requirements

	Type I	*Type II*	*Type III*	*Type IV**	*Type V**
Magnesium oxide (MgO) Max., percent	5.0	5.0	5.0	5.0	4.0
Sulfur trioxide (SO_3) max., percent	2.0	2.0	2.5	2.0	2.0
Loss on ignition, max., percent	3.0	3.0	3.0	2.3	3.0
Insoluble residue, max., percent	0.75	0.75	0.75	0.75	0.75
Silica (SiO_2) min., percent	----	21.0	----	----	24.0
Alumina (Al_2O_3) max., percent	----	6.0	----	----	4.0
Iron Oxide (Fe_2O_3) max., percent	----	6.0	----	6.5	4.0
Ratio of Al_2O_3 to Fe_2O_3		0.7 to 2.0			0.7 to 2.0
Tricalcium silicate (3 CaO. SiO_2)† max., percent	----	50	----	35	----
Dicalcium silicate (2 CaO. SiO_2)† min., percent	----	----	----	40	----
Tricalcium aluminate (3 CaO. Al_2O_3)† max. percent	----	8	15	7	5

* See Note, Section 1.

† The expressing of chemical limitations by means of calculated assumed compounds does not necessarily mean that the oxides are actually or entirely present as such compounds.

The percentages of tricalcium silicate, dicalcium silicate, and tricalcium aluminate shall be calculated from the chemical analysis as follows:

Tricalcium silicate=
(4.07 x percent CaO)—(7.60 x percent SiO_2)
—(6.72 x percent Al_2O_3)—(1.43 x percent Fe_2O_3)—(2.85 x percent SO_3)

Dicalcium silicate=
(2.87 x per cent SiO_2)—(0.754 x percent 3 CaO. SiO_2)

Tricalcium aluminate=
(2.65 x percent Al_2O_3)—(1.69 x percent Fe_2O_3)

Oxide determinations calculated to the nearest 0.1 percent shall be used in the calculations. Compound percentages shall be calculated to the nearest 0.1 percent and reported to the nearest 1 percent.

Physical Requirements:
Portland Cement of each of the five types shown in Section 1 shall conform to the requirements prescribed in Table II.

Table II—Physical Requirements

	Type I	*Type II*	*Type III*	*Type IV**	*Type V**
Fineness, specific surface sq. cm. per g.:					
Average value, min.	1,600	1,700	------	1,800	1,800
Minimum value, any one sample	1,500	1,600	------	1,700	1,700
Soundness:					
Autoclave expansion, max., percent	0.50	0.50	0.50	0.50	0.50
Time of setting (alternate methods)**					
Gillmore test:					
Initial set, min., not less than	60	60	60	60	60
Final set, hr., not more than	10	10	10	10	10
Vicat test:					
Initial set, min., not less than	45	45	45	45	45
Final set, hr., not more than	10	10	10	10	10
Tensile strength, psi.:† The average tensile strength of not less than three standard mortar briquets composed of 1 part cement and 3 parts standard sand, by weight, shall be equal to or higher than the values specified for the ages indicated below:					
1 day in moist air	------	------	275	------	------
1 day in moist air, 2 days in water	150	125	375	------	------
1 day in moist air, 6 days in water	275	250	------	175	175
1 day in moist air, 27 days in water	350	325	†	300	300
Compressive strength, psi.:† The average compressive strength of not less than three mortar cubes composed of 1 part cement and 2.75 parts fine testing sand, by weight, shall be equal to or higher than the values specified for the ages indicated below:					
1 day in moist air	------	------	1,300	------	------
1 day in moist air, 2 days in water	1,000	750	3,000	------	------
1 day in moist air, 6 days in water	2,000	1,500	------	800	1,000
1 day in moist air, 27 days in water	3,000	3,000	†	2,000	2,200

* See Note, Section 1.

** The purchaser should specify the type of setting time test required. In case he does not so specify, the requirement of the Gillmore test only shall govern.

† The purchaser should specify the type of strength test required. In case he does not so specify, the requirements of the tensile strength test only shall govern. The strength at any age shall be higher than the strength at the next preceding age. Tests at 28 days on Types I and II cement may be waived at the option of the purchaser. If, at the option of the purchaser, a 28-day test is required on type III cement, the strength at 28 days shall be higher than at 3 days.

5. That ratios of the strengths of autoclaved neat and standard mortar briquettes to the 30-hour strengths of companion moist-cured briquettes showed a general trend toward lower values as the autoclave expansion of the cement increased.

Prior to 1936, the ASTM specifications did not permit the use of grinding agents or plasticizers in the manufacture of Portland cement. The decrease in strength which resulted from their use was probably the reason they were not permitted to be used.

In recent years there has been an increasing realization that other qualities of concrete, such as plasticity, prevention of bleeding, resistance to the action of frost and corrosive waters, have been neglected and in attempting to effect improvement in these qualities the use of additions to Portland cement during manufacture has been re-examined. Some of these additions are primarily manufacturing aids. We believe that this development is of sufficient importance to justify a report at this time.

Comments upon some of these additions follow:*

Stearic Acid.—This is an effective grinding agent. The addition of about 0.1 percent of it improves grinding efficiency from 15 to 25 percent. It is effective in preventing ball coating. It is a fair plasticizer, introduces considerable air into mortar and reduces bleeding.

Stearic acid is one of the best waterproofing agents, but for effective watertightness not less than one percent must be used. Mortars containing interground stearic acid are lower in strength than similar mortars not containing stearic acid. The reduction will amount to about 10 percent when small amounts of 0.1 percent or less are used and may amount to as much as 30 percent when 1 percent is used.

Materials which are less refined than stearic acid but have essentially the same properties are tallow and crude packing house grease.

To a lesser extent, tankage flakes may be placed in the same category. They have been found to be even more effective than stearic acid or the greases in contributing to fatness and water retention to mortar. The strength reduction resulting from the use of tankage flakes is greater than that obtained with the greases and the improvement in grinding efficiency is less.

Metal soaps of Stearic Acid.—This group consists of calcium stearate, aluminum stearate and magnesium stearate. The behavior of these materials is similar to that of stearic acid except that larger amounts are required to produce the same result.

Vegetable and Animal Oils.—In this group may be placed fish oil, hydrogenated fish oil, oleic acid, and cottonseed oil foots. These materials are effective grinding agents, 0.1 percent being sufficient to improve grinding efficiency from 10 to 20 percent. They are moderate plasticizers which introduce air into the mortar or concrete and reduce bleeding. They have not been found to be as effective waterproofers as the greases.

Rosin.—This has been found to be one of the most effective of all the grinding agents, 0.1 percent being sufficient to improve grinding efficiency from 20 to 30 percent. Rosin is also one of the most effective of plasticizing or fattening agents and will practically eliminate bleeding in workable concrete. It introduces a large amount of air into the mix, and once introduced the air tends to remain until the mix has hardened. The water retention of mortar containing rosin is high. Mortars containing rosin also show greatly improved resistance to freezing and thawing.

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* The information presented on additions to Portland cements is based on an unpublished paper by Mr. L. A. Wagner, chief research chemist, Missouri Portland Cement Company, presented at the meeting of ASTM Committee C1 on Cement held on March 18 and 19, 1940.

A decrease in strength results from the introduction of rosin into the cement. However, because of improved plasticity, the water requirement of a mix containing rosin is decreased, which partially offsets the strength reduction brought about by the decrease in mortar density.

Vinsol resin, which is a processed wood rosin, exhibits essentially the same properties as gum rosin except that it is not so potent either as a grinding agent or as a plasticizing agent. Owing to commercial reasons, (cheapness and powdered form) this is the form of resin most used.

Paraffin Wax.—This material was found to have no value either as a grinding agent, plasticizing agent or waterproofer.

Waste Sulphate Liquor and Sulphonated Sludge.—Waste sulphate liquor is a by-product of the paper industry and is marketed by one manufacturer as Raylig. Sulphonated petroleum sludge is a by-product resulting from the sulphonation of petroleum in the manufacture of white oils. The Standard Oil Company of Indiana markets this material under the trade name of XGA soap oil. Both are effective grinding and plasticizing agents, about 0.1 percent of Raylig and 0.25 percent of soap oil being required for effective results. That a larger amount of soap oil is required is probably due to the fact that it contains about 50 percent water. These materials introduce a large amount of air into the mortar or concrete and reduce bleeding. However, the air is not retained to as large an extent as in similar mixes containing rosin.

Coal and Carbon Black.—Soft coal has long been known as a grinding agent and has been used by cement producers to clean out grinding mills in which the balls have been badly coated. Carbon black is somewhat more effective than coal as a grinding agent. These materials have little, if any, plasticizing value and do not reduce bleeding. It has also been reported that mortars containing these materials do not stand up well under freezing and thawing.

TDA.—This is a proprietary product, a combined catalyst and dispersing agent. It is a mixture of triethanolamine salts and highly purified soluble calcium salts of modified lignin sulphonic acids. According to the ASTM it is not harmful when used as an addition to Portland cement. It is reported to be a powerful grinding aid and has a marked effect in increasing the durability of concrete as measured by freezing and thawing.

Bentonite (finely divided clay) and Hydrated Lime.—These materials do not have any value as grinding agents but are often recommended as plasticizers. Bentonite is an effective plasticizer but for a given consistency it requires more water in the concrete mix and this reduces the strength. The addition of 3 percent of Bentonite has been found to greatly reduce the resistance to freezing and thawing.

Additions of dry hydrated lime were found to contribute little, if any, to the plasticity of mortar mixes. However, aged lime putty showed greater plasticity and fatness in mortar than the other materials tested.

Inert Fillers.—Inert fillers, such as limestone dust, various forms of silica, clays, slags, and fly ash are widely used as plasticizers in mortar and concrete. These materials are generally added in amounts of 10 to 25 percent by weight of the cement. If these materials are interground with Portland cement, the resulting products are more properly classified as blended cements and are considered to be outside the scope of this report.

Report on Assignment 9

Specifications for Culvert Pipe

Theodore Doll (chairman, subcommittee), A. N. Laird, J. A. Lahmer, R. L. Mays, J. L. Rippey, F. B. Robins, E. O. Sweetser, Jamison Vawter.

The following specifications were presented as information last year, and the committee now recommends that they be adopted for publication in the Manual.

SPECIFICATIONS FOR THE PLACEMENT OF CONCRETE CULVERT PIPE

1. Scope

These specifications cover the placement of concrete culvert pipe for railway culverts.

2. Bedding

The pipe shall be placed on a cushion of earth or other finely granular material, or on a cast-in place concrete cradle, as illustrated in Figs. 1, 2, and 3. The surface on which the pipe rests shall be so shaped that the reaction will be distributed as nearly uniformly as possible over a horizontal width of not less than six-tenths of the outside diameter and all possibility of concentration of the reaction at or near the vertical diameter eliminated. If pipe having a projecting bell is used, the surface on which the pipe rests shall be shaped to fit the bell, as well as the barrel of the pipe. The acceptable methods of bedding are illustrated in Figs. 1, 2, and 3, and the Engineer shall specify which method is to be used, depending on the superimposed load and the strength of the pipe.

3. Foundation and Camber

(a) If the material under the bedding cushion or cradle is sufficiently firm to maintain the culvert on the established line and grade, cambering of the pipe line will not be required.

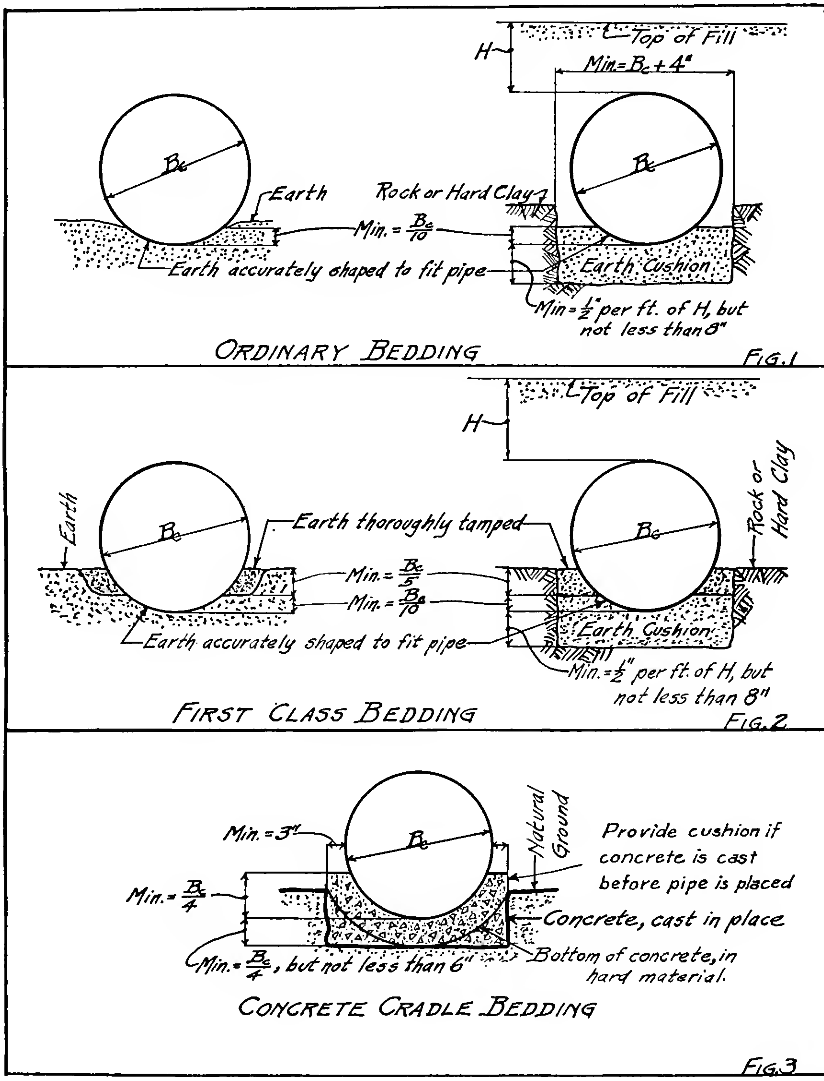
(b) If the foundation is such that it may be expected to yield a limited amount, which can be estimated with reasonable accuracy, the culvert shall be placed with sufficient camber to ensure that it will not have a sag at the end of the settlement. The camber shall be constructed by laying approximately one-half of the length of the culvert at the upstream end horizontally, or on a grade equal to about half of the average grade of the culvert, and the remainder on a sufficient grade downstream to provide the necessary camber or additional grade required. No section of pipe shall be placed higher than the one at the upstream end.

(c) If the foundation is soft or spongy, an adequate support shall be supplied by excavating the unstable soil and backfilling with firm material, by laying a timber mat on the unstable soil, or by such other means as may be specified or approved by the Engineer.

(d) If the foundation is muck, or similarly yielding material, the pipe shall be bedded above a continuous platform supported on piling, or by such other means as may be specified or approved by the Engineer.

4. Backfill and Embankment

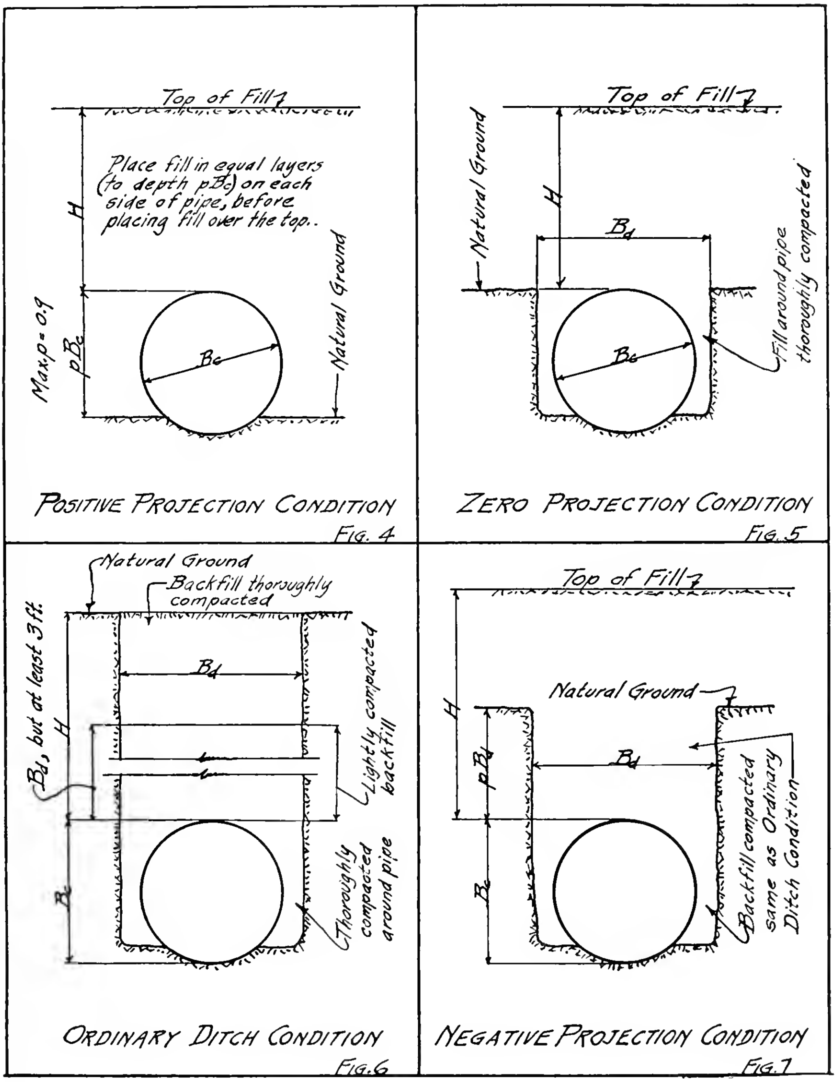
The filling around and over the culvert shall be placed in accordance with one or more of the methods outlined in Figs. 4 to 9, inclusive, as specified by the Engineer. The



filling shall in all cases be placed alternately on each side of the culvert, in approximately equal layers, and necessary care shall be taken to avoid displacing the pipe. Rock fill shall not be dumped over the culvert without a sufficient cushion of earth to prevent breakage.

5. Jacking Pipe Through Fills

Pipe used for jacking through fills shall be without projecting bells. The tongue shall preferably be at the downstream end. A ring of tarred or bitumen-coated rope shall be placed around the tongue of each pipe section at the joints, to prevent the



entrance of water during construction and to form an annular space for sealing with mortar from the inside after the jacking has been completed.

Jacking frames shall be so constructed as to avoid breaking the pipe or forcing it out of alinement. The pipe shall preferably be jacked upgrade to provide drainage at the heading during excavation. Satisfactory means shall be provided for maintaining the lead pipe in the correct grade and direction. If the line shows signs of developing excessive resistance to movement, jacking shall be carried on continuously until the jacking of the entire culvert has been completed.

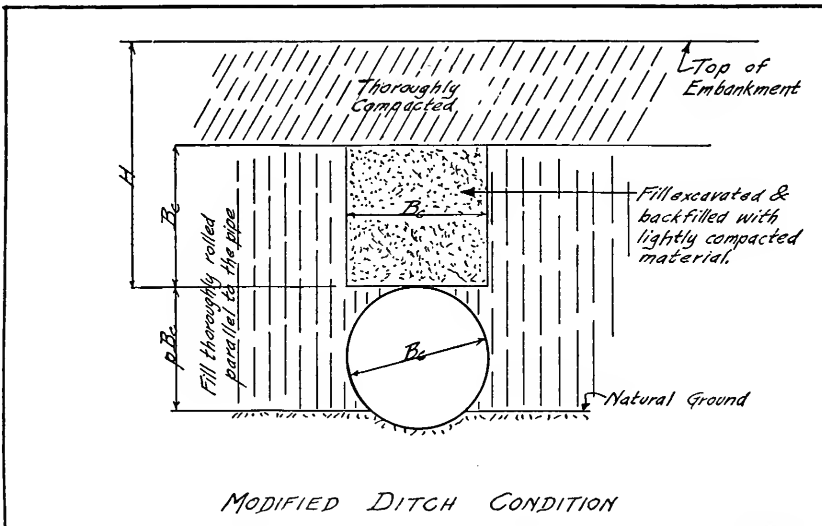


FIG. 8

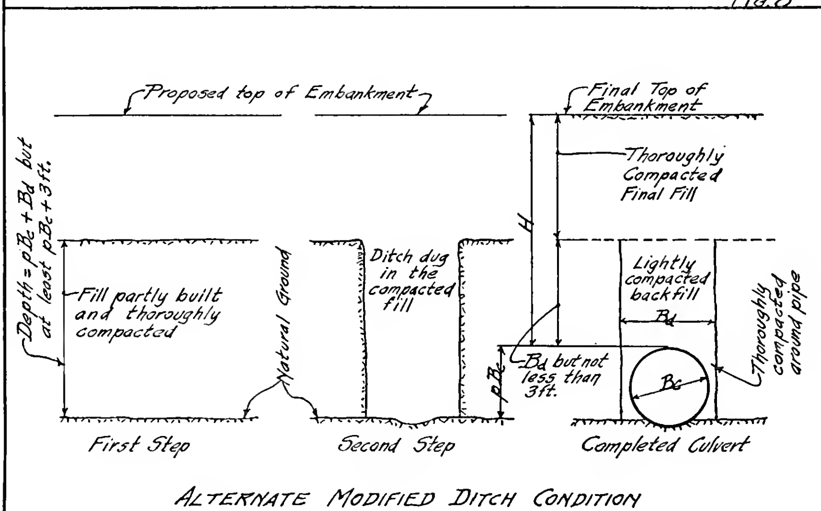


FIG. 9

6. Constructing Culverts in Tunnel

When it is necessary to place pipe culverts by tunneling, plans shall be prepared for the construction procedure and timbering.

7. Joints

(a) Bell and spigot pipe shall preferably be bedded with the bell end upstream. The interior surface of the bell shall be thoroughly cleaned and wetted, and the lower portion filled with a stiff mortar of sufficient thickness to make the inner surfaces of the abutting sections flush. The spigot end of the next section shall also be cleaned and wetted, and fitted into the bell so that the sections are closely matched. The annular space in the bell shall then be filled with mortar and the inner surface of the pipe brushed smooth at the joint.

(b) Tongue and groove pipe shall preferably be laid with the groove upstream. A shallow excavation shall be made underneath the pipe at the joint, and filled with stiff mortar into which the next section of pipe is laid. The groove end of the first pipe shall be cleaned and wetted, and a layer of mortar applied to the lower half of the groove. The tongue end of the next section shall also be cleaned and wetted, and a layer of mortar applied to the upper half of the tongue. The tongue shall then be fitted into the groove and shoved in place so that part of the mortar is squeezed out, and the sections closely matched. The inner surface shall then be brushed smooth at the joint.

(c) Joints in pipe that is jacked in place shall not be sealed with mortar until the jacking of the culvert has been completed.

The committee recommends that the subject be continued under the following designation: "Maintain contact with ASTM Committee C–13, Concrete Pipe."

Report on Assignment 11

Pressure Grouting

W. M. Ray (chairman, subcommittee), F. W. Capp, Maurice Coburn, G. F. Eberly, W. A. Kingman, Roscoe Owen, O. V. Parsons, I. L. Pyle, G. E. Robinson, C. H. Splitstone.

Your committee offers the following specifications as information with the intention of recommending their adoption and publication in the Manual next year.

SPECIFICATIONS FOR SOLIDIFICATION OF MASONRY STRUCTURES BY PRESSURE GROUTING

1. Drilling

Before undertaking a grouting project, it may be advisable to drill holes of a minimum diameter of 1½ inches to develop the conditions and extent of the required operation, these holes to be used later in the application of grout. The number of such holes shall be sufficient to permit observation and insure the filling of all voids and shall be approved by the Engineer.

2. Description

Grout.—The grout shall consist mainly of neat Portland cement and water in proportions varying usually according to local requirements from a minimum of 5 gallons to a maximum of 12 gallons of water per sack of cement. Operations shall be started with a definite water-cement ratio, introducing 50 percent of the water into the mixer before the dry ingredients, and the remaining water during mixing. If required by the Engineer in charge, fluidity must be controlled by tests through a standard flow cone.*

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* Standard flow cones described by Portland Cement Association, 33 West Grand Avenue, Chicago, Ill. See Concrete for Railways, Vol. 3, No. 1, page 9.

3. Materials

(a) Cement.—The cement shall be finely ground Portland cement of which not less than 90 percent shall pass a No. 200 sieve, as coarse particles may prevent the desired penetration, and shall in other particulars comply with AREA Specifications for Portland Cement (AREA Manual, page 8–9—Same as ASTM Designation C–9–38).

(b) Sand.—Sand may be added, at the direction of the Engineer, where satisfactory penetration can be secured in varying proportions up to 1 : 1 mix by volume. All sand should pass a No. 28 mesh sieve and have large proportions of fines passing 50 and 100-mesh sieves, and shall in other particulars comply with AREA Specifications for Fine Aggregate (Manual page 8–1, 2).

(c) Water.—The water shall comply with requirements for mixing water, for Portland Cement Concrete, AREA Manual page 8–2.

(d) Admixtures.—No admixture shall be used unless approved by the Engineer.

4. Apparatus

The apparatus shall consist of a mixer discharging to a receiver supplied with a suitable agitator from which the grout may be discharged.

(a) By Gravity.—Grout may be deposited directly through an open funnel or spout or may be conveyed up to 50 feet through a 2½-inch fire hose.

(b) By Pneumatic Pressure on the Receiver.—For this method an air tight receiver, equipped with an air driven agitator, shall be supplied. The grout mixed either in a mechanical mixer or by hand shall be delivered to the receiver and air pressure applied to expel the contents through suitable transmission pipes to the point of application through sealed connections at the drill holes. When used in cold weather, the entire apparatus should be heated to maintain the delivery temperature of grout up to 80 degrees F. A shotcrete gun may be remodeled readily for this pressure operation.†

(c) By Pump.—When pumps are used for ordinary quantities and conditions, efficient hand pumps are available which have the advantage of direct control of pressure and quantities applied. Grout may be drawn into the cylinders of a reciprocating pump and propelled directly into the discharge pipe. Delivery shall be as nearly continuous as possible, which is best attained by a rotary pump, satisfactory types of which have been developed.

5. Pressures

Required pressures may vary widely depending on the application desired and the character of the structure and shall be strictly under the direction of the Engineer in charge. The range of probable requirements is as follows:

(1) Small unit masonry jobs—gravity to 30 lb. per sq. in.
(2) Structural repairs by drill holes 30 to 50 feet deep—gravity to 100 lb. per sq. in.

6. Payment

Including furnishing, operation and maintenance of all equipment and supplying all materials required.

(1) Lump sum price for equipment moved to and from the job.
(2) Drilling .... diameter holes at .... per lineal foot.
(3) Grout cement in place at .... per sack.
(4) Sand .... cubic yards in place at .... per cubic yard.

† Engineering News Record, June 22, 1939, pages 61 and 62.

Report on Assignment 12

Specifications for Concrete and Reinforced Concrete Railroad Bridges and Other Structures

C. H. Splitstone (chairman, subcommittee), F. E. Bates, Hardy Cross, G. H. Dayett, Meyer Hirschthal, L. H. Hornsby, M. L. Johnson, J. E. Kalinka, J. A. Lahmer, A. N. Laird, C. P. Marsh, J. L. Rippey, G. E. Robinson, C. P. Schantz, G. E. Shaw, G. R. Smiley, A. W. Smith, J. H. Titus, W. R. Wilson, J. J. Yates.

Your committee reports progress as follows:

A skeleton outline for the specifications has been prepared and the subject matter is being developed by comparing the present specifications, topic by topic, with those of 25 or 30 railroads and public bodies, utilizing the material therein insofar as it is found to be of value in specifying modern concrete construction. Of special value in this procedure is the report of the Joint Committee on Specifications for Concrete and Reinforced Concrete. This is the most comprehensive and up to date work on the subject available to the committee, which is giving it corresponding weight in its work.

It is the purpose of your committee to separate the subject matter as between specifications and recommended practice, as has been done by the Joint Committee. The greater part of the specifications has been developed and a start has been made on the recommended practices.

Report on Assignment 13

Specifications for Test Borings

Collaborating with Committee 1—Roadway and Ballast

W. R. Wilson (chairman, subcommittee), G. H. Dayett, Theodore Doll, R. Hayes, W. A. Kingman, R. L. Mays, Roscoe Owen, O. V. Parsons, C. H. Splitstone. Jamison Vawter.

The following report is submitted as information. The table on page 323 and the Specifications for Test Borings are presented with the intention of submitting them in 1942 for adoption and publication in the Manual.

To be of any value, subsurface exploration must determine the location and thickness of each stratum of soil encountered for the required depth of the bore, and also classify the type of soil in each strata.

The following are the methods which will furnish such data and suitable samples of the types of soil encountered:

Test Pits

The best method for determining subsurface conditions is to dig a test pit. With a test pit it is possible to examine soil conditions in the natural state and to locate accurately any strata of running sand. The ground water elevations can also be more exactly determined than by any other means. Undisturbed samples of plastic soil can be secured for laboratory analysis. Due to the difficulty of controlling the water, the cost of removing the soil and the heavy sheeting required to protect the walls, test pits are not practical in most cases. Exploration of the site by other methods may indicate the need for test pits to solve adequately the foundation problem.

Augers

Auger borings can be used for shallow depths and in cohesive soils. Where soil conditions are found by other methods to be uniform, a check of the uniformity can be made by auger borings at intermediate points between test borings spaced relatively far apart. Samples are difficult to obtain in granular soils or where ground water is encountered. The cost is high for deep auger borings. Samples taken from the auger are disturbed and in plastic material care must be taken in classifying the samples so secured.

Dry Sample Borings

Dry sample boring is the method most used for underground exploration in soil. The term "dry sample" is the common name for this process. This name is misleading in that, when taken in wet soils or below the ground water line, the sample is not dry.

The method of procedure is to sink a hole by means of wash boring, i.e., where water under pressure goes through a wash pipe equipped at the lower end with a chopping bit. The wash pipe is churned up and down and rotated, thus loosening the soil at the bottom of the hole, the loosened soil then being carried out of the hole by the upward flow of the wash water. The casing is driven as the boring progresses. The nature of the soil carried to the surface by the wash water has been completely changed due to the action of the chopping bit and the wash water, therefore, it is valueless in determining the characteristics of the strata encountered. "Dry samples" are taken whenever the characteristics of the soil, as indicated by the wash water and the feel of the wash pipe, change. They are taken by pumping out the loosened soil in the hole, removing the string of wash pipe and substituting a sampling spoon or open piece of pipe for the chopping bit. The wash pipe and sampling bit are then lowered in the hole and driven into the soil. The spoon is removed and the sample taken from it, identified, placed in a container, completely labeled and retained as part of the record. The ordinary sample so obtained has been disturbed but it contains the same proportions of grains as does the strata sampled. To determine the consistency of the strata, a record is kept of the weight of hammer and number of blows required to drive the spoon for one foot. A casing as small as two inches in diameter may be used with corresponding samples 1⅛ in. in diameter.

Undisturbed sampling is the term used for the method of obtaining undisturbed samples of plastic soil for laboratory investigation, however, it is impossible to obtain completely undisturbed samples. Many types of sampling spoons have been used with varying degrees of success. The minimum size of sample that can be investigated in the laboratory is 4¾ in. The method of boring the test hole is the same as for dry sample boring. Due to the large size of casing required for undisturbed samples and the care with which they must be taken, the cost of such investigation is high.

Core Borings

To secure samples of rock or boulders it is necessary to take core borings. The term core boring refers to the securing of samples of rock by means of rotary drilling tools equipped with special cutting tools. The cutting tools are of three types, namely; black diamond, shot drills and toothed steel cutters. The nature of the rock to be sampled and the size of core required will determine the type of cutting tool to be used on the particular job. Cores ⅞ in. in diameter can be made with a diamond drill but the smallest commercial size is 1⅛ in. Cores more than four inches in diameter are seldom made with diamond tools. Shot drill cores less than two inches in diameter are difficult to make. Cores up to 52 in. in diameter have been taken. Steel toothed cutters have

TABLE I - METHODS OF UNDERGROUND EXPLORATION AND SAMPLING *

Common Name of Method	Materials in Which Used	Method of Advancing the Hole	Method of Sampling	Approx. Cost per ft.	Value for Foundation Purposes
Wash Sample Borings	All soils. Cannot penetrate boulders or rock.	Washing inside a driven casing.	Samplee recovered from the wash water.	$0.50 to $1.25 per ft. 2 1/2" oasing.	Almost valueless and dangerous beoause results are deceptive.
Dry Sample Boring	All soils. Cannot penetrate boulders or rock.	Washing inside a driven casing.	Open end pipe or spoon driven into soil at bottom of bore hole.	$0.65 to $1.75 per ft. 2" and 2 1/2" casing.	Most reliable of inexpensive methods. Data on compaction of soil obtained by measuring penetration resistance of spoon.
Undisturbed Sampling	Samples obtained only from oohesive soils.	Usually washing inside a 6" casing. Augers may be used.	Special sampling spoon designed to reoover large samples.	$8.00 to $12.00 per ft. 6" oasing.	Used primarily to obtain samples of oompressible soils for laboratory study.
Auger Boring.	Cohesive soils and oohesionless soils above ground water elevation.	Augers rotated until filled with soil and then removed to surface.	Samples recovered from soil brought up on augers.	$0.75 to $2.00 per ft. 1 1/2" auger.	Satisfactory for high way exploration at shallow depths.
Well Drilling	All soils, boulders, and rook.	Churn drilling with power machine.	Bailed sample of churned soil or samples from "clay socket".	$5.00 to $15.00 per ft. 6" to 8" hole.	"Clay socket" samples are dry samples. Bailed samplos are valueless.
Common Name of Method	Materials in Which Used	Method of Advancing the Hole	Method of Sampling	Approx. Cost per ft.	Value for Foundation Purposes
Rotary Drilling	All soils, boulders, and rock.	Rotating bits operating in a heavy circulating liquid.	Samples recovered from circulating liquid		Samples are of no value.
Core Borings	Boulders, sound rock and frozen soils.	Rotating coring tools: diamond shot, or steel-tooth cutters.	Cores cut and recovered by tools.	$3.50 to $35.00 per ft. 1-1/8" to 36"	Best method of determining character and condition of rook.
Test Pits	All soils. In pervious soils below ground water level pneumatic caisson or lowering of ground water is necessary.	Hand digging in sheeted or lagged pit. Power excavation occasionally used.	Samples taken by hand from original position in ground.	$10.00 and up depending on plan size, depth, water and soil condition.	Soils can be inspected in natural condition and position.

Notes:

1. Test rods, sounding rods, jet probings, geophysical methods, etc., are not included in this table, because no soil samples are obtained.
2. The approximate costs per foot of the various methods vary between wide limits because of the large number of factors which govern the cost. A few of those factors are: character of soil, depth of hole, number of obstructions encountered, total footage of boring or drilling at given site, accessibility of site, etc.

* From Exploration of Soil Conditions and Sampling Operations, by H. A. Mohr, Second Edition, February 1940, Publication No. 269, Graduate School of Engineering, Harvard University.

proved successful only in certain of the softer types of rock. The size of cores so taken is the same as for the diamond drill.

Miscellaneous Methods

Various other methods are used for drilling holes in the earth. These methods are valueless for exploration work in that samples are not taken, or if taken, are so changed that it is impossible to identify the class of soil from them. Some of these methods are: Wash borings, well drilling and rotary drilling, such as is used for oil wells.

Test rods, sounding rods and jet probings are useful means for determining the elevation of rock or boulders but they do not give any indication of the kind of rock or the type of soil overlying the rock. Care must be used in forming conclusions from the results of such soundings.

Geophysical methods of exploration have been developed for preliminary exploration of large areas. These methods are the electric resistivity method and the seismographic method. The results of exploration by these methods when used for design and construction must be checked by test borings, hence these methods are not practical for ordinary exploration for specific projects.

The accompanying table is a summary of the present methods of underground exploration and sampling.

Field Identification of Soils

Pages 1–6.1 to 1–6.5 of the Manual, present a discussion of physical properties of earth materials, including descriptions necessary for the identification of soils of the sizes of sand and finer. The following notes, submitted as information, supplement the material given and will assist in making the proper identification of the soil encountered in test borings.

Fill is man-made deposits of natural soils and waste materials. The classification of fills should be made to show the predominating material, such as clay fill; cinder fill, etc. Trouble may result from placing a foundation on fill if it overlies other material, hence care should be taken to explore the underlying soils.

Inorganic silt or rock flour is a fine grained inorganic earth, consisting of grains which will pass through a 200-mesh sieve. It is a treacherous soil and the source of trouble as a foundation material. In the wet state it is often misclassified as soft clay. When wet, it can be molded or rolled in the fingers without breaking, but it crumbles as it drys slightly. The material that dries on the hands can be easily dusted off. A small pat of wet inorganic silt placed in the palm of the hand and shaken in a horizontal plane will become wet and shiny. When compressed between the fingers the water disappears from the surface and the surface appears dull. If water does not appear on the surface, the material is lean clay.

Organic silt and organic clay are silts and clays with a content of visible organic material or of organic colloids. These materials will be compressible, plastic and pervious. They are identified by their color—dark grey or black. They often have a perceptible odor of decomposition. When molded, they exhibit a soft feeling, very different from the feel of inorganic silt or clay.

Sand, Gravel and Boulders

Fine Sand can be classified as that of which the greater portion will pass a No. 65 mesh screen.

Medium Sand is that of which the greater portion will pass a No. 28 mesh screen and be retained on a No. 65 mesh screen.

Coarse Sand will pass a ¼-in. diameter screen and be retained on a No. 28 mesh screen.

Gravel will be retained on a ¼-in. diameter screen and its size ranges to six or eight inches.

Small Boulders range in size from 8 in. to ½ cu. yd. in volume.

Large Boulders are more than ½ cu. yd. in volume and may contain as much as 15 to 20 cu. yd.

Compactness of Granular Soils.—Compact sand or gravel requires the use of a pick for its removal. It offers considerable resistance to the progress of earth boring tools. Loose sand or gravel can be excavated by shoveling. Rapid progress with earth boring tools is possible.

Suspension of Granular Soils.—Any fine granular soil the grains of which are of nearly uniform size may be subjected to a flow of water through it in such a manner as to cause each particle of soil to be suspended in the water. Such a condition is called quicksand and is a granular phenomenon and not a type of soil.

Classification of Clay.—Clay may be classified in part by color. Locally the color classification will have a bearing on its consistency and assist the designer in determining its safe bearing load.

Hard clay cannot be remolded by the use of the fingers and requires a pick to excavate.

Medium clay can be remolded by applying considerable pressure with the fingers and can be excavated with a spade.

Soft clay can be easily remolded with the fingers and can be readily excavated with a shovel.

Hardpan is a compacted mixture of clay, sand or gravel, difficult to remove with a pick and often requiring pneumatic tools or explosives for excavation. It should be identified as hardpan and the description of the soil composition should also be given.

Shale is highly consolidated clay, the minerals of which have been essentially unaltered since being deposited. In slate the original clay minerals have been altered. When water is added to shale the mass will become plastic. When shale has been dried it can be easily shattered by a light blow or by hand. In slate there will be no change.

For further information regarding identification of Soils see:

Exploration of Soil Conditions and Sampling Operations, by H. A. Mohr, Second Edition, Feb. 1940, Publication No. 269, Graduate School of Engineering, Harvard University.

Description and Identification of Soil Types, by P. C. Rutledge, pages 124 to 129 incl., Proceedings of Purdue Conference on Soil Mechanics and Its Application, Purdue University, July 1940.

Records

The importance of making a complete record of all the information regarding the test boring cannot be too highly stressed. The boring report to be of value should furnish the following information.*

1. The starting grade of each boring. The grade should be referenced to a definitely established datum. This is just as important as is an established datum

* From Exploration of Soil Conditions and Sampling Operations, page 5.

plane for a contour survey. In many instances actual construction is undertaken several years after the borings have been made. During the interval the area might have been filled or it might have been leveled off. Then, too, as is constantly the case, years after the borings have been made, alterations or additions are undertaken. If the starting grades are given with respect to an established datum the borings are of permanent value. Otherwise they are of no value after a short period of time.

2. A true cross-section of the ground showing the depth below the starting grade to the top of each stratum or the thickness of each stratum. It seems needless to advise that the report should identify the soils encountered in consecutive order starting at the surface.

3. The results plotted to scale and to true elevation.

The engineer knows the type of the proposed structure, its weight, the number of points of support and their spacing, the loads it will transmit to the soil and the elevation of the basement floor or the lowest elevation of some controlling requirement. With these data, a line drawn across the boring report at the controlling elevation, will often give at a glance the answer on the proper type of foundation to use. In most instances a few hours' study, which may include estimates of the cost of two or three types of foundations, will determine the answer. Occasionally, however, a difficult and interesting problem is encountered and a great deal of time and study are required before the proper solution is arrived at.

4. Ground water level. If there is any indication of an unusual water condition it should be noted. The usual indication of a porous stratum is a loss of wash water. The voids in the porous stratum may be completely filled with water and the loss be caused by a positive hydrostatic head in a downward direction. On the other hand the voids may contain no water and the loss of wash water can still be from the same cause. If there is a question of the true condition, the bore hole should be bailed for a definite answer. Every iota of evidence pertaining to water conditions should be noted as construction work below water level is the bane of a builder's existence.

5. Some indication of the compactness of granular soils and the degree of hardness of plastic soils. To record "compact sand" or "loose sand" or "hard clay" or "soft clay" is not explicit. Those are relative terms and will have a different meaning with different individuals. A positive resistance basis to penetration under an applied weight, or blows of a constant height of fall of a given weight, should be established and used.

6. A proper soil classification of every stratum encountered. The practice of designating the different soils by various types of cross-hatching or letters or numbers or by any other legend merely confuses the one attempting to interpret the report, and introduces unnecessary chance for error in translating from the original report or notes to the unreadable and then back again. Anyone studying a boring report does so to learn what the ground conditions are. This purpose can be accomplished easily and intelligently when the report shows the classification written in the proper location. Boring reports should never be made or shown otherwise.

7. Every indication of the presence of boulders, rip rap, and obstructions of every kind.

8. A record in full of every trial or uncompleted boring in the same manner as completed borings are reported.

9. A plot plan showing the location of each boring referenced to definite survey lines. The boring numbers should be marked on the plan.

10. Identification as to owner, engineer or architect, location, date and job number. The report should be filed so that it may be easily located for future reference.

THE NORTH & SOUTH RAILROAD CO.

Office of Chief Engineer Chicago, Ill.

TEST BORING DATA

Bridge No. 56.74, First District, Eastern Division

TEST HOLE NO. 4

Station or M.P.+ Sta. 468+37.0

Rt. or Lt. of ℄ 23.5 ft. Lt.

Borings made by X. Y. Z. Co. Date Started 4-4-40 Time 9:30A

Inspector Wm. Jones Date Completed 4-5-40 Time 4:20 P

Base of Rail Elev. 222.47

Inside Diam. of Casing $2\frac{1}{2}$"

" " " Spoon 2"

Weight of Hammer 150#

Drop of Hammer 30"

Ground Line Elev. 210.6

Depth	Material	Sample
4'-3"	Sand & Clay Fill	
10'-0"	Stiff Peat	Sample 41
16'-6"	Fine Dirty Sand	" 42
Water 17'-2"		
20'-9"	Firm Coarse Sand	" 43
28'-4"	Firm Yellow Clay	" 44
31'-10"	Hardpan, Clay	" 45
37'-0"	Fissured Limestone	Core 46
42'-3"	Hard Limestone	" 47

Bottom of Test Hole

DRY SAMPLE DATA

Sample No.	Elev. of bott. of spoon	No. of blows per ft.	Total penetration of spoon	Length of sample obtained
41	4'-3"	3	18"	15"
42	10'-0"	6	15"	$4\frac{1}{2}$"
43	16'-6"	15	14"	8"
44	20'-9"	18	16"	14"
45	28'-4"	122	6"	$5\frac{1}{4}$"

Type of Core Drill Diamond

Core Diam. $1\frac{1}{8}$"

CORE DATA

Sample No.	Elevation Top	Elevation Bott.	Core recovered	Rate of Boring ft. per hour
46	31'-10"	37'-0"	2'-10"	8
47	37'-0	42'-3"	4'-2"	4

REMARKS:
Water stood at 16'-8" below ground 24 hours after test was completed
28' of casing used

Sheet 4 of 6

A Sample Page of Test Boring Data.

The foreman should be furnished a notebook printed especially for recording his findings. The blank spaces to be filled in will keep him from forgetting items of importance. The illustration shows a sample page of test boring data as recorded in such a notebook.

When making a report do not elaborate. State the positive facts found. For instance, if the boring is stopped abruptly by an impenetrable object, stop the report at the top of that object. To identify it as bed rock is an unwarranted assumption, as a small boulder in hard pan will stop progress with earth boring tools. The only way to identify such an object is to drill it with core tools and reclaim a sample. Any boring report definitely identifying material below the bottom of the bore hole should raise suspicion.

Usually, when a boring is stopped abruptly and the work is not too deep, efforts are made to determine if a boulder or ledge rock stopped the tools. Additional borings are made at distances of four or five feet from the location of the original boring. If all borings at that location are stopped at about the same elevation, it is often assumed that bed rock has been encountered. Regardless of the number of trials and the results obtained, nothing has been definitely proved regarding the nature of the material that stopped the tools. By no line of reasoning can anyone justify a positive identification of the material below the bottom of the bore hole.

SPECIFICATIONS FOR TEST BORINGS

I SCOPE

These specifications cover the procedure for making borings through soil and rock to determine their characteristics for foundation purposes.

The specifications are written to cover a variety of methods of exploration, but only those methods will be used which are consistent with the information it is desired to obtain on a particular job.

II GENERAL

1. Number and Location of Test Holes

The number and location of the test holes shall be as indicated upon the drawings.

Additional test holes may be required to delimit erratic soil areas should radical soil changes be disclosed by the original borings.

2. Plant

All plant, equipment and methods to be used shall be approved by the Engineer before the work is begun. However, approval of the equipment shall not be construed as including approval of the performance thereof or that additional equipment and methods will not be required to perform the work satisfactorily according to the specifications.

3. Depth of Borings

At locations where the rock stratum is at such a depth that it is not practical to reach it, the boring shall extend below the proposed foundation, or foot of piles, to such a depth as will adequately determine the characteristics of the underlying materials.

Where the borings reach rock, all borings shall be carried at least 5 feet into solid rock. If cores indicate that the rock is seamed or broken, or in thin layers, all borings shall be carried to the depth considered necessary.

4. Permits

All permits shall be secured by the owner or contractor before the work is started and as provided by the contract.

III EXPLORATION METHODS

1. Test Pits

Where required, test pits will be made to bedrock or to such depth as ordered. Excavation shall be by hand methods and excavation materials of each class shall be kept in separate piles as far as practicable. Ordinarily, samples of the formations shall be taken progressively from the natural formation where requested by the Engineer and placed in quart jars and properly labeled.

2. Hand Augers

Hand augers may be used for test borings of moderate depth in plastic materials, in granular materials above the ground water line or in granular materials containing sufficient clay to make them cohesive. The auger shall be not less than 2 inches in diameter. The strata shall be determined by the samples secured when the auger is pulled from the ground.

3. Dry Sample Borings

(a) *Casings.*—Casings for penetrating soil shall be not less than 2 inches inside diameter. Casing for penetrating rock shall be not less than 2½ inches inside diameter. Water may be used to facilitate the driving of the casing.

(b) *Procedure.*—Where required, dry sample borings will be made to bedrock or to such a depth as ordered to obtain samples suitable for determining accurate soil profiles and furnishing material for certain laboratory tests not requiring large-diameter undisturbed samples.

Dry samples shall be taken at every change of formation, and in any case at intervals not exceeding 5 feet. Continuous samples may be required through thinly stratified formations. Samples may be taken with a solid spoon from which the sample may be pushed with a piston or with a split spoon where the formation is such that part of the sample will not adhere to each half of the spoon when separated. Core retainers will be used with the sampler when necessary to hold the sample.

The use of water for cleaning out the casing between samples will generally be allowed, but when the moisture content of the material below the casing, of which a sample is desired, might be altered by introducing a head of water in the hole, the casing must be cleaned dry by means of augers, a drive pipe, or other method.

(c) *Dry Samples.*—Dry samples of the material penetrated shall be at least 1⅛ inches in diameter and obtained by pushing a sample spoon of approved design not less than one foot below the bottom of the casing into the material. If a sample is not obtained the first time, the spoon shall be driven again to a depth of two feet below the bottom of the casing. Should the material be so incohesive that the second driving of the spoon fails to secure a sample, a spoon with a flapper valve shall be driven as specified above. Should this last procedure fail to secure a sample, an auger or sand trap shall be used until the required sample is obtained. Data shall be recorded and samples marked and preserved as specified in Sections IV and V.

(d) *Determination of Ground Water Level.*—Where required the elevation of the ground water level shall be accurately determined by the following procedure, or equal. Immediately after taking the last sample from the boring, the casing shall be pumped dry and then withdrawn a vertical distance of 2 feet from the maximum penetration, and allowed to stand for 30 minutes before measuring the level to which the water has risen. If the water fails to rise in the hole within 30 minutes the casing shall be withdrawn one foot higher and allowed to stand for 10 minutes. If the water fails to rise the second time, and the casing is in material which may be impervious, the casing shall be withdrawn until its bottom is one foot higher than the elevation at which such material was first encountered and the hole allowed to stand for another 10 minutes. If water still does not appear and the boring has penetrated one or more layers of impervious material above the elevation at which the casing stands, the casing shall be withdrawn above each succeeding impervious strata as specified above until the water rises in the hole or no more impervious strata are above the bottom of the casing.

If the boring is located where the ground water level may be influenced by a tidal body of water, a record of the exact stage and direction of the tide at the time of taking the elevation of the ground water shall be made.

During the above described determination of ground water level an accurate record shall be made of the times and elevations of each successive withdrawal of the casing and also of the elevation to which water rose in the hole.

(e) *Determination of Running Sand.*—At any time that sand, coarse or fine, is encountered, the following test shall be made to determine if the water content and the pressure upon the material is sufficient to cause it to run. Upon striking sand, a sample of the material shall be obtained by the dry sample method. The casing shall then be driven into the sand 2 feet below the elevation at which the sand was encountered and carefully washed out to the bottom. The hole shall then be allowed to stand 10 minutes, and the elevation at which the sand then stands in the casing measured. The water in the casing then shall be removed sufficiently to produce an unbalanced hydrostatic condition at the bottom of the casing and the elevation of the top of sand measured.

3. Core Borings

(a) *Plant.*—Drilling into bed rock shall be done with a diamond, shot or other approved bit which will obtain a core from the rock penetrated of not less than 1⅛ inches in diameter.

(b) *Starting Core Bit.*—Before starting the core bit in the hole, the chopping bit shall be used to break up all disintegrated rock and the casing seated firmly on hard rock by driving and washing out.

(c) *Procedure.*—The core bit shall be started in the hole and the hole drilled to a depth of 5 feet. The drill shall then be withdrawn, the core removed, labeled and stored as specified in Article 2, Section V. After the core is recovered the drill shall be replaced in the hole, and another 5 feet of depth drilled, the drill withdrawn, the core removed as noted above. Drilling shall continue in this manner until the required depth has been reached.

IV RECORDS

The following data shall be recorded on a permanent form.

1. General

(a) Date.

(b) Names of railroad, engineer, contractor and inspectors.

(c) Location and identifying number of test boring and reference to survey data.

(d) Ground elevation at hole and base of rail elevation.

2. Borings—Dry Sample

(a) Elevation of top of each different material penetrated.
(b) Diameter and description of casing.
(c) The elevation of the bottom of spoon at start of driving for each sample.
(d) The elevation to which the spoon was driven.
(e) The weight and drop hammer used to drive the spoon and number of blows required to drive it one foot, for each sample.
(f) The length of sample obtained.
(g) The distance from the bottom of the spoon to the lower end of the sample when the spoon is not filled to the bottom, and any other circumstances of obtaining the sample.
(h) The stratum represented by the sample.
(i) The weight, number of blows and drop of hammer used to drive the casing to each successive elevation.
(j) The soil shall be described in accordance with the following classifications:
  1. Kind: Top soil, fill, loam, clay, sand, gravel, etc.
  2. Color: Light, dark, blue, red, etc.
  3. Moisture: Dry, moist, wet, very wet, etc.
  4. Consistency: Loose, medium, compact, stiff, etc.
(k) Elevation of ground water.
(l) Elevation of running sand and thickness of strata.

3. Borings—Core

(a) Elevation of bottom of casing when seated on rock according to Article 3 (b) Section III.
(b) Type of core drill, including size of core.
(c) Length of core recovered for each 5-foot length drilled.
(d) Elevation of bottom of core hole.
(e) Elevation of each change in type of rock.
(f) The rock shall be described in accordance with the following classification:
  1. Shale, slate, limestone, sandstone, etc.
  2. Condition: Broken, fissured, laminated, solid, etc.
  3. Hardness: Soft, medium, hard, very hard, etc.
(g) Rate at which each 5-foot section was bored in feet per hour.

V SAMPLES

1. Dry Samples

All dry samples shall be immediately placed in suitable air-tight, wide-mouthed, clear-glass jars of sufficient size to hold a section of the sample intact. These jars shall be permanently and clearly labeled to show the date, number of the test hole, elevation at which taken, and kind of material. These samples shall be carefully preserved as a part of the record.

When undisturbed samples are required for investigation in a laboratory, extreme care must be taken in the recovering, sealing and handling of such samples so that they are delivered to the laboratory in as good condition as when taken.

2. Cores

A label shall be placed on each piece of core more than 6 inches in length, stating the number of the hole, the original length of the piece and the original elevation of the top of the run. The pieces of core shall be placed in the order in which they were removed from the core barrel in a 5-foot narrow box. The box shall be securely labeled showing the number of the test hole. These cores shall be carefully preserved as a part of the record.

VI INSPECTION

No drilling shall be done except in the presence of the Engineer or his Inspector. No more than two drilling crews working in the same vicinity at the same time shall be covered by one inspector. The Inspector shall establish bench marks for the determination of the required elevations, check the log of the boring to determine that the information designated in Section IV is being obtained; and see that all soil samples and cores are properly boxed and stored in a suitable place or shipped to the designated destination.

VII CLEANING SITE

After completing the work, the casing shall be withdrawn, the plant and other material removed and all holes closed as directed by the Engineer.

Report on Assignment 14

Specifications for Concrete Placed Under Water

T. L. Condron (chairman, subcommittee), F. E. Bates, G. E. Boyd, F. W. Capp, I. L. Pyle, G. R. Smiley, J. J. Yates.

In its study of "underwater concrete" or "depositing concrete under water", your committee has gathered a mass of information from engineers in all parts of the United States who are experienced in this particular use of concrete. From the information received and from the definite recommendations of these engineers, the committee has prepared the following section of a specification for underwater concrete.

Accordingly, your committee recommends that Section 206, Depositing Concrete Under Water, paragraphs 1 to 6, inclusive, pages 8–26 and 8–27, of the Specifications for Portland Cement Concrete, Plain and Reinforced, be withdrawn from the Manual, and that the following Section 206—Special Requirements for Concrete To Be Deposited Under Water, paragraphs 1 to 13, inclusive, be adopted as a substitute therefor.

It is also recommended that Sections 212 and 213 be renumbered 207 and 208, and that Sections 207, 208, 209, 210 and 211 be renumbered 209, 210, 211, 212 and 213, respectively, for greater clarity and easier reference.

The method of "pumping concrete" when deposited under water, has not been included in the requirements embodied in the proposed Section 206, as the committee has not obtained sufficient information or evidence of the successful and economical application of that method to warrant specific reference to it. The three methods included in the proposed Section 206 seem adequate at this time.

206. SPECIAL REQUIREMENTS FOR CONCRETE TO BE DEPOSITED UNDER WATER

1. General

(a) The methods specified in Section 204, for Depositing Concrete in Air, shall be used except when the space to be filled with concrete contains water which cannot be removed in some practical way. In such cases, and when authorized by the Engineer, concrete shall be deposited under water in accordance with the following paragraphs of this section.

(b) The methods, equipment and materials proposed to be used, shall be submitted first to the Engineer for his approval before the work is started. The methods used shall be such as will prevent the washing out of the cement from the concrete mixture, minimize the segregation of materials and the formation of laitance, and prevent the flow of water through or over the new concrete until it has fully hardened.

2. Capacity of Plant

Sufficient mixing, transporting and placing equipment shall be provided to insure that the depositing of all underwater concrete for each predetermined section or unit of the work to be done, shall be continuous until completion.

3. Standard Specifications

The materials, proportions and methods to be used in making concrete to be deposited under water shall all conform to the requirements of the AREA Specifications for Portland Cement Concrete, Plain and Reinforced, except as modified or supplemented by the following paragraphs.

4. Cement

Not less than 6 sacks, or 564 pounds of cement per cubic yard of concrete shall be used.

5. Coarse Aggregates

Preference will be given to gravel rather than crushed material. The maximum size of aggregate preferably shall be 2 inches and shall not exceed 3 inches. The coarse aggregate shall be well graded, the weight of the coarse aggregate shall be not less than one and one-quarter, nor more than twice that of the fine aggregate.

6. Mixing

The cement and aggregates shall be mixed for a period of 2 minutes with sufficient water to produce a concrete having a slump of not less than 6 inches nor more than 8 inches for concrete placed by tremies, and not less than 3 inches nor more than 6 inches for concrete placed by bottom dump buckets or for concrete placed in sacks.

7. Caissons, Cofferdams or Forms

Caissons, cofferdams or forms shall be sufficiently tight to prevent loss of mortar or flow of water through the space in which the concrete is to be deposited. Pumping will not be permitted while concrete is being deposited, nor until 24 hours thereafter.

8. Leveling and Cleaning the Bottom to Receive Concrete

(a) The surface of the bottom, whether of clay, rock, or other material, shall be leveled as directed by the Engineer, before depositing concrete under water.

(b) Where the bottom on which concrete is to be deposited under water is, or is likely to be, covered with silt, such material shall be removed down to solid material before any concrete is placed. The method to be used to clean the bottom of silt or similar material, shall be subject to the approval of the Engineer.

(c) Before starting to deposit concrete under water, the condition of the bottom shall be examined and reported upon to the Engineer by a competent diver, and shall be approved by the Engineer.

9. Continuous Work

Concrete shall be deposited continuously until it is brought up to the required elevation. While depositing, the top surface shall be kept as nearly level as possible, and the formation of laitance planes avoided.

10. Methods of Depositing

One of the following methods of depositing shall be used:

(a) Tremie.—When concrete is to be deposited under water by means of a tremie, the top section of the tremie shall be a hopper large enough to hold one entire batch of the mix or the entire contents of the transporting bucket, when one is used. The tremie pipe shall be not less than 8 inches diameter and shall be large enough to allow a free flow of concrete and strong enough to withstand the external pressure of the water in which it is suspended, even if a partial vacuum develops inside of the pipe. Preferably flanged steel pipe should be used, of adequate strength to sustain the greatest length and weight required for the job. A separate lifting device shall be provided for each tremie pipe with its hopper at the upper end. Unless the lower end of the pipe is equipped with an approved automatic check valve, the upper end of the pipe shall be plugged with a wadding of gunnysacking or other approved material, before delivering the concrete to the tremie pipe through the hopper, which plug will be forced to and out of the bottom end of the pipe by filling the pipe with concrete. It will be necessary to slowly raise the tremie in order to cause a uniform flow of the concrete, but the tremie shall not be emptied so that water enters above the concrete in the pipe. At all times after the start of placing the concrete and until all concrete is placed, the lower end of the tremie pipe shall be below the top surface of the plastic concrete. This will cause the concrete to build up from below instead of flowing out over the surface, to avoid formation of laitance layers. If the charge in the tremie is lost while depositing, the tremie shall be raised above the concrete surface, and unless sealed by a check valve it shall be replugged at the top end, as at the beginning, before refilling for depositing concrete.

(Note: Experience has shown that tremie concrete can be placed as above specified, so that it will build up the flow as much as 50 feet horizontally from the discharge end of the tremie with a slope of less than 3 feet in 50 feet.)

(b) Bottom Dump Bucket.—Where concrete is to be deposited under water by means of a bottom dump bucket, the bucket shall be of the type that cannot be dumped until after it has rested, with its load, on the surface upon which the concrete is to be deposited. The bottom doors shall be so equipped as to be automatically unlatched by the release of tension on the supporting line or cable of the bucket, and the bottom doors shall then open downward and outward as the bucket is raised. The top of the bucket shall be fitted with double, overlapping canvas flaps, or other approved covers, to cover the contained concrete and to protect it from wash when it enters the water and as the bucket descends to the bottom. The bucket, preferably should be so designed that the hinged bottom doors will operate inside of a steel skirt, which skirt will surround the bucket while the bottom doors are shut and will extend below the bucket as the bottom doors open and hence minimize turbulence and motion while the concrete is being deposited. The bucket shall be submerged slowly until it is completely under water. The normal line speed after that shall not exceed 200 feet per minute. After the bucket has reached the surface on which the concrete is to be deposited, it shall be raised slowly for the first 6 or 8 feet while the concrete is being deposited.

(c) Placing Sacks of Concrete.—Where a relatively small amount of concrete is to be placed that does not warrant the equipment required for either tremie or open bottom bucket methods, concrete may be placed under water in sacks or bags. In such case the

space shall be filled with sacks of concrete carefully placed by hand in header and stretcher formation, so that the whole mass becomes interlocked. Sacks used for this purpose shall be made of jute or other coarse material, free from deleterious materials, and shall be filled about two-thirds full of concrete and the sack openings securely tied.

11. Soundings

During the time that concrete is being deposited underwater soundings shall be continuously taken to the surface of the deposited concrete and recorded. The surface of the deposited concrete shall be maintained relatively level over the area being covered.

12. Removing Laitance

Upon completing a unit or section of underwater concrete, any laitance or silt collecting on the upper surface of the same shall be removed and the concrete surface thoroughly cleaned, if additional concrete is to be deposited on that surface.

13. Concrete Seals

Under favorable conditions it will be possible to place underwater concrete of a limited thickness in the bottoms of caissons or cofferdams and so completely seal the structures that after the concrete has set, all water can be pumped out. In such cases, if it is economical to do so, the water shall be pumped out, the exposed surfaces cleaned and the balance of the concrete deposited in air.

Report on Assignment 15

Durability of Concrete

L. M. Morris (chairman, subcommittee), F. W. Capp, Maurice Coburn, M. L. Johnson, J. E. Kalinka, C. P. Marsh, I. L. Pyle.

Introduction

The purpose of this report on the durability of concrete is to give the members of the Association a summary of the present status of knowledge on this very important subject.

In reviewing the literature of the last ten years relating to durability of concrete, one cannot but be impressed with the enormity of the subject and how little is really known definitely and with finality. This condition, of course, results from the many variables which enter into the production of good concrete. These numerous variables may be classified under six main elements: Cement, water, aggregate, time, temperature, and the methods of mixing and placing.

This discussion, necessarily, cannot possibly be complete, but an effort has been made to summarize some of the more important ideas on the subject from recent literature. Papers by McMillan,[1 6] Scholer,[2] Carlson,[3] Bates,[4] Voss[5] and Young[7 8] have been used principally. These and other references used are shown in the bibliography at the end of the paper.

Your committee has endeavored (B) to discuss the various major factors affecting durability from the standpoint of materials and manufacture; (C) to outline the principal defects in concrete which lead to disintegration; (D) to consider the most important weathering actions and other disintegrating forces affecting durability; and (E) to discuss various tests for predicting durability.

The variables involved and the many divergent opinions make it impossible to express the relative importance of the numerous contributing factors, and, therefore, no significance should be attached to the order in which the various items are discussed.

B. Major Factors Affecting Durability from the Standpoint of Materials and Manufacture

The major factors affecting the durability of concrete from the standpoint of materials and manufacture can be outlined very briefly in three items:

1. Nature of the aggregates
2. Nature of the cement
3. Watertightness of the concrete

1. Nature of the Aggregates

Consideration of the first item—Nature of the Aggregates—discloses an amazing number of conflicting ideas, but from the mass of literature several properties emerge which form, at least, bases for discussion: Chemical composition, size, gradation, shape, surface characteristics, porosity, strength, soundness, elastic properties, thermal expansion, volume constancy under wetting and drying, and specific gravity.

The chemical composition of the aggregate is considered important in that it either provides minerals which are complementary to the process of cementation, are inert to it, or detract from its efficiency. Aggregates such as limestone appear to aid in the process of cementation, quartzes and dense igneous rocks of high silica content are practically inert, while some cherts, micas, feldspars and the like are thought to have eventually deteriorating effect under certain exposure conditions. There seems to be some evidence to support the contention that certain combinations of cement and aggregate cause unsoundness in the resulting concrete. Whether this is due to some unusual chemical action between the particular materials or whether due to other causes, is not known.

As to the maximum size of aggregate, the evidence seems to be rather definite that neither very large nor very small aggregate is best. Not only are the harmful effects of bleeding magnified when aggregates are large, but internal cracking due to volume change is also worse. A lesser overall volume change is found with the use of large aggregates, but at the expense of greater internal stresses and cracking. Thus it appears that some moderate maximum size aggregate is best, but it is difficult to say exactly what this size may be. In all probability, it will not be the same for all materials. The maximum size of aggregate must be adapted to the structure in which it is used.

Likewise, there appears to be an optimum gradation of aggregate. The general result of most methods of proportioning aggregate is that the combined aggregate is made as coarse as possible within the range of proper workability. This result can be obtained in several ways. Present indications are that the best gradation is such that the sieve analysis plots as a smooth curve, but even this does not fully define the gradation. There is no general agreement on the particular smooth-curve gradation which is best. Washed sand, as we know it in many localities, is almost entirely devoid of fines. This is considered to result in particle interference, unless excesses of cement are available.

Particle Shape and Surface Characteristics

The effect of particle shape and surface characteristics of aggregate on durability remains in the controversial stage. The shape of particles undoubtedly has considerable bearing on the density of the mix. It seems to be the consensus that an excess of thin, flat or elongated pieces will materially decrease the workability for a given water-cement ratio and hence adversely affect durability. Smooth, rounded particles undoubtedly help workability. Surface texture may have a marked effect on the strength of bond with the cementing matrix. Some maintain that the surfaces should be rough. Others argue that the aggregate should have sufficient porosity to help in removing excess water from the cement paste. Some view the problem as chiefly a matter of mechanical anchorage, sometimes due to roughness, and often resulting from adhesion caused by suction of the paste into the surface pores of the aggregate. Some types of seemingly smooth aggregate may therefore bond more strongly than those with a rougher surface texture. On the whole, the shape and surface texture of aggregate particles have a marked effect upon the concrete-making properties, particularly with respect to water, cement requirement and workability, all being important factors from the standpoint of durability.

Strength of aggregate is, of course, very important for durable concrete; however, soundness is even more important. Since the aggregates form nearly three-quarters of the mass of hardened concrete, they are of necessity an important consideration in the production of durable structures. Aggregates which disintegrate under the influence of weathering agencies cannot be expected to endure indefinitely, even though protection be afforded by a durable cement paste.

Elastic Properties

The elastic properties of aggregates vary widely and the elastic properties of the resulting concrete will follow rather closely the properties of the aggregate of which it is chiefly composed. The thermal coefficient of expansion of aggregates likewise varies widely, and again the chief variable in concrete as to its thermal deformations is found in the aggregate rather than in the cement. The engineer is usually in ignorance of what particular aggregate will be used and he designs for average conditions. But it must be borne in mind that these properties may constitute very important factors in determining the satisfactory life of a concrete structure. This is particularly true if the structure, like a pavement, requires the building of expansion joints to relieve such deformations. If adequate provision is not made, the resultant high stresses develop a type of failure often mistaken for material disintegration.

Volume constancy under wetting and drying is another important quality for aggregates. Just as low thermal expansion is desirable in an aggregate from the standpoint of induced stresses, low volume change due to wetting and drying is important in reducing internal stresses.

While specific gravity has no direct effect on the properties of normal freshly mixed concrete, a natural or crushed stone aggregate with a specific gravity of less than 2.50 should be investigated thoroughly before it is used in concrete. Some of the adverse properties often associated with low specific gravity are porosity, softness and high absorption, any of which may lead to breakdown under weathering action.

2. Nature of the Cement

If we are left with a feeling of inadequate accurate knowledge by the preceding survey of those properties of aggregates which result in durable concrete, we are brought up against an almost blank wall of ignorance when we try to list those properties of cement which will without question produce durability. However, from the present very incomplete technology of cement, certain properties stand out as bases for discussion of this most essential element in the concrete mix: Chemical composition, fineness, cement-water combination, bleeding characteristics and plastic properties, cement content, strength, soundness, resistance to aggressive waters, volume change characteristics, and heat of hydration.

Cements of different chemical compositions, of course, perform quite differently as regards strength development, heat of hydration and other properties. This is reflected in the new ASTM tentative specifications covering five types of cement: Normal, moderate heat of hardening, high early strength, low heat and sulphate-resistant.

The different properties of these various cement compositions probably do affect the durability of the resulting concrete to various degrees; however, there are few aspects of this problem upon which the experts agree. It is now rather generally accepted that high tricalcium aluminate in a cement produces concrete having lower resistance to sulphate waters and sea water than cement with low percentages of this compound. The effects of the principal compound compositions—tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium alumino-ferrite—on strength, volume change, resistance to freezing and thawing tests, resistance to sulphate solutions, heat of hydration and other properties, are known to a considerable degree. A summary of this phase of the subject can be found in the 1940 report of the Masonry committee, AREA Proceedings, Vol. 41, page 378.

It is now known that the compound compositions, as at present calculated from the oxide analyses, may be greatly altered by the heat treatment of the clinker after burning, principally in that if the clinker is cooled quickly, a large percentage of "glass" may be formed. At times, the "glass" thus formed may constitute the third in amount, constituent of Portland cement. Unfortunately very little is yet known concerning the influence of "glass" on cement properties. Uncertainty also remains as to the nature of the role of the so-called minor oxides, such as MgO, Na_2O, K_2O, FeO, TiO_2, Mn_2O_3 and P_2O_5, which will average a total of about four percent for the cements of the entire country, but in some cases will amount to six percent.

The influence of "glass" and the minor oxides renders the usual calculation of compounds from the oxide composition, a questionable procedure; however, in lieu of more adequate tests for physical properties, this method serves a useful purpose, provided it is used with discretion.

Properties of Compounds

It is desirable to summarize the setting properties attributed to each of the principal cement compounds. Tricalcium aluminate reacts rapidly, attaining all its physical effect in about 24 hours. Its total heat of hydration is approximately 200 calories per gram and practically all of this is evolved in 24 hours. The tetracalcium alumino-ferrite evolves about half this heat and requires roughly one month to do so. The tricalcium silicate in about one month evolves all its total heat of 120 cal. per gram, while the dicalcium silicate has generated but little heat at the end of 7 days and requires a year to develop all of its total heat of approximately 60 cal. per gram.

From such data it is possible to estimate roughly the heat of hydration of any cement from its chemical analysis. For instance, if the cement is high in alumina and lime and low in silica and iron oxide, it will contain predominately tricalcium aluminate and tricalcium silicate and hence will generate a large amount of heat.

Likewise, many tests have been made to determine the physical properties of the four main compounds, as previously mentioned. As a result, many data are at hand for use in predicting the physical characteristics of a hydrated cement from a chemical analysis of the non-hydrated material. From such data we know that tricalcium aluminate and tetracalcium alumino-ferrite develop so little strength that the alumina and iron oxide may be ignored in this respect. Tricalcium silicate, and consequently a high-lime low-silica cement, attains the greater part of its strength in a month; while dicalcium silicate, unless extremely finely ground and in the presence of other materials which act somewhat catalytically, at the same age has developed hardly a tenth of the strength of the other silicate. By the end of a year, however, the strength of the two types of silicates shows little difference.

While the previous discussion on cement and its compounds bears indirectly on durability, direct evidence of relative durability of the various types of cement is more limited. In his Marburg lecture before the ASTM last June, Bates[4] said:

> Here our data are much more meager than in the case of strength or heat of hydration. But they do show such a trend that we may conclude that many of the commercial cements would be improved as to durability if the alumina and iron oxide were reduced to a minimum that in some cases would cause manufacturing difficulties. The relative value of the two silicates in respect to durability is known with less assurance. Possibly if all concrete, regardless of whether made of a high or low-silica cement, could be protected for six months and ideally cured, it would be found that thereafter the two silicates would deport themselves alike in regard to permanency.

Before leaving the subject of cement composition, it should be stated that the use of Portland-puzzolan cement is increasing. Puzzolanic material possesses the property of combining with lime in the presence of moisture to form stable cementitious compounds, and for this reason it is claimed to have a "healing" effect with the progress of time, especially with the high lime content cements. Federal Specification SS-C-208 covers cement of this type.

Fineness

As regards the fineness of cement, there are many varying ideas. The physical properties mostly affected by fineness are time of set and strength. Many believe that fineness is intimately related to volume changes during hardening. Too finely ground cements are believed to require undue amounts of water and, consequently, undue shrinkage and cracking may result. Others feel that the coarse particles of the less finely ground material may hydrate later and cause disruptive expansion. Some question whether the very fine particles do not hydrate so promptly during mixing and placing that they confer nothing to the strength and may tend to be concentrated in any laitance formed or on surfaces against forms where they rather promptly cause map cracking or crazing, or unsightly weathering. R. W. Carlson[3] reasons as follows:

> Regarding the fineness of cement, there appears to be a limit for best results. It was reasoned at one time that the main effect of finer grinding was to facilitate hydration. In other words, a lean mix with a very fine cement was considered to be about equal to a richer mix with a coarser cement. But recent studies of thin sections of concrete reveal a significant difference not acknowledged before. It has always been known that a large percentage of the grains of fine cement hydrate completely. In the case of the coarser cement, the numerous unhydrated cores of cement grains become the solid cores for the many little cells of unstable hydration products. The uninterrupted dimensions of the gel appear actually to be less in the case of the coarser cement because of the stabilizing cores. In concrete subject to drying, therefore, at least a part of the advantages of finer grinding may be offset by a greater degree of internal cracking. The actual optimum fineness of cement must be dependent on composition, because only one compound (dicalcium silicate) can be relied upon not to hydrate completely under ordinary conditions. It is somewhat ironical that a good cement could not be made from

this compound alone, even though it has wonderful long-time cementing ability and low heat of hydration. Besides having insufficient early strength, it produces nothing but gel upon hydrating and therefore it causes great drying shrinkage Neither could any all-purpose cement be made from any other one compound in Portland cement. Even the most desirable compounds, the calcium silicates, have an optimum proportion one to the other.

Cement in combination with water serves two functions: To make the mixture workable and to properly set and harden the finished concrete. Both functions are important and have a bearing on durability. There seems little question but that different cements have different plastic properties, depending somewhat upon fineness of grinding, possibly chemical composition and upon other properties not yet known. Certain admixtures such as some of the grinding and plasticising agents (TDA, Vinsol resin and others) have marked influence upon the plasticity of the resultant mixture as well as increasing the resistance to freezing and thawing. Closely related to plasticity and workability are the bleeding characteristics of a concrete mixture. Different cements have different bleeding characteristics, and there is reason to think that this is intimately associated with the problem of durability.

Bond Between Mortar and Aggregate

Many concrete failures consist of loss of bond between the mortar and the coarser aggregate. The sufficiency of this bond is apparently in some way closely associated with that property of the cement which gives plasticity to the mixture, and which prevents bleeding. On the other hand, there is also reason to believe that the ability of a concrete mixture to lose its water may be advantageous; for example, in the use of absorbent molds and vacuum concrete. Evidently, in these methods the evil effects of bleeding, which is a form of segregation, can be almost wholly, if not completely, offset by the proper manipulation of the mass before final set occurs. An important difficulty pointed out by Pearson in this connection in a paper given at the ASTM 1940 Symposium on Cement,[24] is that with concrete mixtures of low bleeding characteristics, the use of overwet consistencies is not easily recognized because plainly visible segregation is not apparent, and yet serious segregation may occur with this kind of a mix in the usual placing and finishing operations.

The subject of admixtures is fast becoming very important in its prospect for marked improvement in the workability and durability of concrete. Bates in his Marburg lecture before the ASTM last June stated, in effect, that with cements as they are now produced, there seems to be no brighter prospect of improving these cements throughout their entire useful life in concrete than by the use of admixtures, such as grinding agents and plasticisers, in their manufacture.

In the 1940 symposium of ASTM Committee C1 on Cement, Wagner[24] presented an unpublished discussion on this subject, in effect, as follows:

> The fact that most of these agents—grinding, wetting, dispersing, foaming, plasticising—or what have you, introduce air into the concrete mix has long been taken as prima facie evidence that the resulting concrete would be less durable than similar concretes not containing air. Recent studies in many laboratories reveal, with few exceptions, that concretes plasticised with foaming agents are far more durable than similar unplasticised concretes. Probably the best explanation of this very interesting phenomenon yet given may be found in Power's report on bleeding.[23]

> Reduced to its simplest terms, it appears that when concrete is placed it immediately proceeds to take itself apart. Water works its way upward, cement and aggregate settle until the larger pieces of aggregate bridge upon one another, after which the cement particles and finer sand continue to settle away from the undersides of the bridged aggregate. The spaces beneath the aggregate from which the cement and fine sand have settled become filled with water, producing the condition known as "water gain". Furthermore, some of the trapped pockets of water find outlets to the surface and in rising produce threadlike passages before the cement has time to set. When it does set, the mass is solidified in an inhomogeneous condition, with many water pockets and threadlike capillaries leading to the surface. These remain as excellent entrance points for water and consequent weathering action at later periods in the life of the structure.
>
> With a foaming agent present, however, the concrete is intermixed with countless uniformly distributed tiny air bubbles. The buoyant effect of these air bubbles is sufficient to retard the settling of the aggregate. These are present in such countless numbers that they retard even the movement of the sand grains and cement particles. Settlement of these particles is restrained; formation of water pockets and capillaries is reduced or eliminated. The concrete cannot take itself apart because the instant the tiniest grain of cement or aggregate starts to move it bumps into an air bubble and is halted. The concrete must remain in a homogeneous mass until it hardens.
>
> When the concrete has hardened it is true that it still retains the countless air bubbles and because of the reduced density of the mass its strength may be somewhat reduced. However, the bubbles are not interconnected and each has a shell of hardened cement paste. Water cannot re-enter such concrete with the same ease that it can re-enter an unplasticized concrete. Perhaps the air bubbles even serve a useful purpose of providing expansion chambers which may relieve some of the pressure of frost action.

Another view of this most important and live subject was presented by Swayze at this same symposium[24] in relation to water-repellant additions, such as mineral oils, animal fats and oils, and natural resins, in effect, as follows:

> We believe that the high resistance of concrete to freezing and thawing, when these admixtures are present, is not due to the water-repellent nature of the admixture, but instead to the influence of the fat or resin on the microstructure of the cement gel formed on hydration of the cement. We believe that in normal concrete the gel capillaries must be considerably larger in size than with treated cements. The presence of air voids is not believed to be the real cause of higher durability, but only an incidental characteristic produced by the admixtures under consideration. The basic reason underlying the action of the admixtures in promoting greater resistance apparently is their effect on concrete permeability.

From considerations of permeability, resisting to freezing and thawing, and shrinkage, Swayze[24] concludes that of the three classes of admixtures considered, the natural resins, such as Vinsol resin, offer the greatest promise for improvement of concrete durability.

As to the cement content, neither very rich concrete nor lean concrete is best. Neat cement disintegrates far more rapidly in freezing and thawing tests than does concrete. And yet, very lean concretes do not withstand this durability test as well as do moderately rich concretes. The conclusion appears to be that there is some intermediate mixture with some moderate cement content that is best. Just as the inert portions of hydrated cement dilute the gel beneficially, so does sound aggregate beneficially dilute the cement paste. Unfortunately, it is difficult to say what proportions are best because we are not yet certain about what constitutes a dependable test for durability. From later discussion we shall see that minimum cement content is desirable from the standpoint of shrinkage and heat evolution, but higher cement content is ordinarily required to obtain good workability with low water-cement ratios. Hence, we see that minimum cement content and low water-cement ratio are opposing factors which must be balanced in obtaining placeable concrete. This much, however, can be said. The quantity of cement cannot safely be reduced below a certain limit even though the strength resulting from the leaner mixtures may be adequate for the load requirements of the structure.

In this connection we should not forget that with present day cements it is now taking less cement to produce concrete of a certain 28-day compressive strength than it did with former cements, with the result that durability as indicated by such strength tests is not the same today as then. Therefore, impermeability and durability must govern cement content rather than strength requirements.

Age-Strength Relation

The age-strength relation which a cement will develop is very important from the standpoint of durability. While reasonable early strength is desirable in most work, long-continued strength and soundness are even more important. The discussion given above under cement composition is pertinent in this connection. For many years cements which satisfactorily passed the usual steam test were considered to be sound, but cases of delayed expansion brought the subject to the fore again recently with the result that the autoclave test has been adopted. It seems to be the consensus that cement which will meet the new tentative autoclave test will be a more durable cement.

The knowledge in regard to the action of aggressive waters such as sulphates and sea water is limited. As previously indicated under "cement composition", cements of low tricalcium aluminate content are considered to be more resistant to these waters. The newly adopted ASTM tentative specification provides for a cement of this type; however, there are cases of higher alumina cements which have given good performance under exposure to such sulphate action. Other factors not yet known are undoubtedly involved in this question.

Portland puzzolan cements are finding considerable favor for their greater resistance to sulphate action; however, these cements vary in performance depending on the particular puzzolanic addition used in manufacture.

There is considerable evidence that alkalies (Na_2O and K_2O), averaging about 0.75 percent for cements of the entire country, produce a swelling effect with subsequent disintegration when used with aggregates containing certain minerals.

The volume change characteristics of a cement due to changes in temperature, changes in moisture content, and freezing and thawing are of great importance in relation to durability; however, these characteristics are so tied up with the characteristics of the other components of concrete that discussion of this item will be given later under "weathering actions". Suffice it to say at this point that there is reason to believe that the shrinkage of concrete is affected by the cement used. If the actual loss of water and consequent shrinkage which does occur should approach the ultimate which might occur, if completely dried out, variations in cement might produce concretes of significantly different qualities as regards shrinkage and durability. In all except rather unusual conditions of exposure, concrete sections of any appreciable size will reach their ultimate possible shrinkage due to water loss so very slowly, that maximum drying shrinkage will never occur.

Heat of hydration characteristics were briefly discussed under "chemical composition". This property of cement has assumed great importance in the construction of mass concrete, such as dams, to avoid cracking. For this purpose, low heat and moderate heat of hardening cements have been developed. Lately this latter type of cement has come into use for other work, such as for pavements. Its use is rapidly expanding and is reflected in the Type II cement adopted recently by the ASTM as a tentative standard. Certain Portland-puzzolan cements have also come into use for mass concrete construction.

3. Watertightness of the Concrete

Of course, many of the quality factors for aggregate and cement already discussed, have a definite relation to watertight concrete; however, under this heading we shall consider mainly the important role of the water-cement ratio, the mix, methods of concrete manufacture and strength. Most of these items are so well known that it would seem almost useless to mention them; however, it is safe to say that a majority of our troubles in obtaining durable concrete have their origin in the neglect of these fundamental constructional procedures.

Watertightness, as all students of the problem will agree, is the most important requirement for concrete to meet the destructive effects of weathering. Concrete behaves as do the natural rocks under exposure to the various weathering agencies. It is particularly susceptible to the freezing and thawing of entrapped moisture and to the solvent action of percolating water.

Requirements Defined

The requirements for water tight concrete can be very simply stated as "impervious aggregates incorporated in a cement-water paste which is itself impervious". One most important property of the cement-water paste which we have not discussed is the water-cement ratio. The effect of the water content on the strength of concrete is now universally recognized. The early experimental work of Abrams showing a fairly definite relation between the compressive strength of plastic concrete and the water-cement ratio, for given materials and conditions, has been widely confirmed. The influence of the water content on the watertightness of concrete is not as thoroughly established experimentally, but the relation is fundamental and various investigations have shown the important effect of a proper water-cement ratio, proper cement content, plastic and workable consistency, and thorough curing for watertight or impermeable concrete. These same items have also been found to be of great importance for resistance to sulphate waters. For a given set of materials and conditions, most authorities agree that the water-cement ratio is the most significant factor affecting the strength, impermeability and the durability of hardened concrete.

A most important item which is intimately associated with water-cement ratio is that the concrete must be plastic and workable. It is very important to have the proper amount of cement paste for impermeable and workable concrete. Since the water which passes through a concrete member must find its way between the aggregate particles and through the cement paste, it is evident that if the entire space is not filled with paste, there is little to resist the passage of water. In order that the space between the aggregate particles be completely filled, it is essential that concrete mixtures be of plastic consistency so that the material can be worked readily into the forms and completely incorporate the reinforcement.

To obtain a plastic consistency there must be sufficient paste to actually float the aggregate particles; otherwise the concrete will be harsh and result in honeycombing, bleeding and laitance, all of which are detrimental to durable concrete. Thus, we see that the water-cement ratio is a major influence on the watertightness of concrete in two important respects; first, through its influence on the imperviousness of the paste, and second through its influence on workability.

Of course, the design of the concrete mix involving not only the water-cement ratio, but the cement-aggregate ratio, aggregate gradings, maximum aggregate size, etc., is extremely important, but evidently cannot be covered in this resumé.

Method and Time of Mixing

The method and time of mixing have a most important bearing on obtaining a uniform and workable concrete, and deserve more attention than they ordinarily receive. Thorough mixing is essential to durable concrete. Some of our older concrete structures which are making such an excellent showing as to durability even under adverse conditions, were constructed with the old-fashioned method of ramming and tamping concrete into place. The mixture was neither plastic nor workable in the modern sense, but in the type of construction in which it was used, reinforcing, forms, and other details were such that it was possible to force the concrete into position and compact it properly. The result was a low water-cement ratio, a minimum of voids, and a high degree of impermeability. The speeding up of concrete operations, mechanical mixing, spouting and flowing into place from a common point brought a whole train of evils in their wake. Much as the cement and cement industry has changed, the changes in our methods of mixing, handling, placing, and finishing concrete have been even greater, and all of these are elements which enter into the durability of the resultant concrete structure.

On many jobs we are using too short mixing time; we are using methods which cause agglomerations of cement and water in the mixer; we are placing concrete in ways that cause segregation, that condition probably more responsible for concrete disintegration than any other factor; we have changed to watertight forms of steel or plywood which with excesses of cement and water may accentuate segregation; we are using vibrators in ways which may increase segregation and thereby vitiate whatever else may be advantageous in their use; and finally we are treating newly exposed surfaces in such a way as to cause excessive surface strains. Segregation is inherent in concrete, inasmuch as a coarse aggregate with a specific gravity of about 2.65 cannot remain suspended in a cement-sand-water mortar of about 2.2, if excessive vibration is allowed.

Time, temperature and moisture are elements which enter into the hardening of a concrete mixture. It is difficult to separate the three, but without doubt, the proper relation of time and temperature with moisture plays a primary part in developing a durable concrete. If satisfactory temperatures and curing precautions for the proper hydration of cement are not maintained for sufficient time to permit proper hardening, it is almost certain that the full strength and durability of the concrete will never be developed.

As already indicated under the discussion of cement strength, the compressive strength of concrete can never, of itself, safely be taken as a measure of impermeability or durability, for while it is true that for a given set of materials and conditions, the greater the strength the better the impermeability and watertightness, it is far from true that a certain degree of watertightness will exist in all concretes of the same strength regardless of aggregate, cement content and other variables.

C. Principal Defects in Concrete Which Lead to Disintegration

Although the preceding discussion of the various factors affecting the durability of concrete from the standpoint of materials and manufacture has served to indicate a large number of the known underlying causes for concrete disintegration, it will clarify the situation if we list the principal resultant defects in concrete which lead to disintegration under weathering action.

Of course, in this enumeration of defects we are not considering those most important structural items, such as inadequate provision for drainage, defective construction joints, unequal settlement of foundation, or failure to provide for volume changes due to shrinkage or temperature variables. These design features are fundamental and failure to make proper provision may result in subsequent conditions of cracked concrete and percolating water which will result in early disintegration no matter how good the inherent quality of the concrete.

Some of the more important defects or defective conditions are:

1. Unsound or faulty materials—any of the components of the concrete.
2. Segregation, resulting mainly from undersanded or harsh poorly designed mixes, improper placing, and overworking.
3. Excess water in the mix.
4. Water gain in placement, or bleeding.
5. Laitance at joints or work planes.
6. Improper or insufficient curing.
7. Cracks from whatever cause: Structural; improper curing; volume change due to drying shrinkage, temperature variations, repeated wetting and drying, and freezing and thawing of entrapped moisture. All cracks from whatever cause permit easy ingress of water with subsequent leaching, corrosion of steel and concrete, and accelerated disintegration when simultaneously exposed to freezing and thawing action.
8. Scaling, due to improper finishing, use of chlorides in ice removal, freezing during construction, bleeding, etc.
9. Improper embedment of reinforcement resulting in corrosion of steel, with consequent cracking or spalling of the surrounding concrete.

D. Principal Weathering Actions and Other Disintegrating Forces Affecting the Durability of Concrete Other Than Design Loads and Abrasion

Of all the disintegrating forces to which concrete is subjected, the most important, of course, is natural weathering action. Natural weathering forces involve four principal actions:

1. Freezing and thawing of entrained moisture.
2. Volume changes due to several causes.
3. Solution action of normal percolating water.
4. Action of aggressive waters.

In regard to the first two phases of weathering action R. W. Carlson[3] has presented a very interesting analysis, from which the following is quoted:

> The destruction of concrete by weather is a type of fatigue action. Changes in temperature and moisture cause alternations of stress which the concrete must be able to withstand easily if it is to endure. Some parts of a concrete structure are being stressed and restressed repeatedly due to continued changes in temperature and moisture. The following explanation of the causes of these stresses is admittedly meager, but it may provide a suitable background for later discussions.
>
> Firstly, temperature change causes stress, even when the change is uniform throughout a body of concrete. Whenever the temperature changes, the different constituents of the concrete tend to expand or contract by different amounts,

causing highly localized stresses that may in turn cause invisible, internal cracks. In general, cement paste tends to expand and contract with temperature much more than does the aggregate. When the temperature change is not uniform through the concrete, additional stresses are caused by one part of the concrete tending to expand or contract more than another. The latter stresses may be more extensive and are likely to result in visible cracks.

Change in moisture content, especially loss of moisture, readily causes stress and cracking in concrete. The gel, which is the main cementing material that forms upon hydration of the cement, tends to contract greatly, while the other constituents tend to remain more or less constant in volume. If the gradation of particle sizes in the fresh concrete has been such that the gel has formed as a very thin skeleton surrounding inert grains of unhydrated cement and fine aggregate, the gel may not be damaged by the volume change. The mortar may then tend to contract as a unit. The contraction of the mortar is in turn restrained by the larger particles of aggregate and it is believed that the mortar is generally cracked between large particles of aggregate in concrete which has been allowed to dry in ordinary air. If the concrete is well proportioned, however, the internal cracks are likely to be extremely small, probably less than one-thousandth inch wide, and susceptible of being healed in time. A few remarks about this healing may be appropriate before proceeding to the consideration of other volume changes. The possible healing of fine cracks seems to justify the otherwise wasteful common practice of using fairly rich mixes and coarse cement, rather than lean mixes and extremely fine cement, so that there is always an abundance of unhydrated cement left in reserve. Unfortunately, the unhydrated cement is not readily available except as the cracks by chance open up the grains and expose the interiors to further hydration. The addition of a moderate amount of puzzolanic silica to concrete would seem to be better than to depend on unhydrated cement if healing of internal cracks were to be a major consideration. The puzzolanic silica, and the lime necessary for its gelation, would always be available and the healing of cracks would seem to be facilitated.

A third major cause of volume change is the freezing of water in the pores of concrete. The expansion of the water upon freezing causes localized expansions somewhat analagous to the localized contractions of the gel upon drying. It is believed that water in the majority of pores in the gel of good concrete does not freeze, because the pores are of molecular dimensions. On the other hand, water in large, visible pores usually drains before freezing occurs and thus causes little damage. The dangerous pores seem to be those of intermediate size, probably invisible, such as are abundant in the gel of poor concrete and in many aggregates. In a recent series of freezing and thawing tests involving a number of variables, the most resistant concrete proved to be that which when mixed contained more than 10 percent of air voids. The air voids were produced by adding less than 0.1 percent of a wetting agent to the cement before mixing. Attempts were made to saturate the specimens before freezing, and although it seemed that the concrete was more nearly saturated than concrete in service, there was some doubt about the saturation. This result, therefore, is only offered to show that visible voids are not necessarily detrimental.

No discussion of voids in concrete would be complete without reference to bleeding. Undoubtedly the control of bleeding offers a means of improving durability. The pores on the undersides of aggregate particles that result from bleeding are likely to be of all sizes, including those that are damaging. Furthermore, the lack of bond to the undersides of aggregate particles has other bad effects. This subject has been treated so well in the paper by Powers that reference is made to that paper rather than to discuss the subject fully here.

When cement hydrates, the calcium silicate gel that forms, substantially fills the spaces originally occupied by the mixing water. Attempts have been made again and again to make sizable specimens of such gel in the laboratory, for the purpose of measuring their properties. Invariably such specimens crack extensively soon after being exposed to ordinary air and they usually crumble upon a single drying. But hydrated cement is not all gel. The gel is interspersed largely with grains of unhydrated cement and crystals of calcium hydroxide, both of which are relatively volume constant. Thus, as a result, larger specimens of neat cement can be made without cracking, because the gel has been diluted with the grains and crystals. The gel is still a problem, because, unless the water-cement ratio is extremely low so as to keep the gel skeleton light, ordinary drying will cause plenty of cracking even in specimens only a few inches thick.

The solution action of normal percolating water on concrete is many times not recognized due to its being obscured by frost action. Water alone will destroy concrete through its solvent action on certain elements of the cementitous binder, but more important, water is the medium through which many other enemies of concrete carry on their attack. Sea water, sulphate-bearing waters, acid waters, and bog waters are merely waters carrying impurities that render their destructive action more severe, and all act through the intimate contact that the water has with the concrete through absorption into its pores. The solvent action of water is not confined to leaking joints or cracks, as porous concrete is particularly susceptible to such action.

The solvent action of water is regularly found wherever concrete has been in contact with soft pure water for any length of time or where drainage conditions are such that rain water runs over the surface of concrete. While this etching action is not serious, it indicates that if we give a quantity of this same water a chance to penetrate the concrete, serious impairment may result.

Investigation of supposedly normal waters that have proved most corrosive to concrete, revealed the interesting fact that, whereas the hydration products of cement are soluble in any water, those that are most destructive are relatively pure waters carrying so little CaO in solution that they are lime-hungry, having an acid reaction as indicated by a hydrogen-ion concentration below 7.

Effects of Certain Salts

The addition of certain salts to water will increase its destructive action. Sea water and sulphate-bearing waters are the more important cases, and in both, the salts involved are principally the sulphates of magnesium, sodium and calcium. The action of these compounds on the concrete appears to be both chemical and mechanical. The chemical action is partly corrosive and partly an interference with the normal processes of hydration, while the mechanical action, due to the disruptive effects of the by-products of the chemical reactions forming compounds within the cementing matrix of the concrete, results in an expansive process similar to freezing water.

The foregoing discussion may appear unduly alarming in regard to the solution action of normal and aggressive waters. With the exception of thin concrete sections subjected to high heads of water, the permeability of properly controlled concrete is sufficiently low to be of little practical concern. It is the cracks, improperly prepared constructions joints, porosity and other imperfections which make permeability and the solution action of water an important problem. The white deposit or "efflorescense" so commonly seen on concrete surfaces is the result of leaching with subsequent carbonation and evaporation.

It is clear that watertightness and low volume change will result in reduced leaching effects. The use of sulphate-resisting cement such as the tentative specification recently adopted by the ASTM, will materially reduce the corrosion of concrete by alkali waters. Attention has been lately directed toward "Portland-puzzolan" cements as effective in producing concrete with improved resistance to sulphate and acid waters.

Aside from the natural weathering forces discussed above, there are several other important disintegrating actions which should be mentioned, such as the delayed expansion of unsound materials, corrosion of embedded steel, exposure to chemical wastes, corrosive atmosphere of certain industries, dehydration in stacks and fire hazard. Some of the factors involved in these various deteriorating forces have been covered previously in this report, while others are of so specialized a nature that it is not considered desirable to discuss them further in this summary.

Exposure Conditions Vary

One important aspect in connection with weathering action which we are prone to forget is the extreme variation in exposure to which different structures may be subjected. Two structures otherwise identical and located not far apart may be showing radically different degrees of deterioration due to the fact that one is so located with respect to the terrain that it is continually subjected to the action of water seepage, while in the case of the other structure the drainage is such that the concrete has never been subjected to this condition. In fact, conditions of exposure can vary widely even in the same structure due mainly to differences in drainage and the action of percolating water.

We are all, of course, cognizant of the varying exposure conditions throughout the country due to temperature variations. In this connection it should be remembered that while concrete, when saturated with water, may resist one freezing or several, yet the continued repetition of this action will in time destroy it. Further, only a few degrees of frost are required to cause freezing of the contained moisture in the surface layer. It would seem, therefore, that the effects of frost should be more severe in those sections of the country that have the greatest number of alternate freezings and thawings, and while this is not subject to statistical proof, it seems to be borne out in a general way by observation. It certainly is a fact that as soon as one enters those sections having more than a few annual frosts, the evidence of frost action is almost as common as in districts further north.

E. Tests for Predicting Durability

In view of the many variables involved in the production of good concrete, the engineer has been led to develop various tests in an effort to predict durability under different conditions of exposure. As already indicated, it does not seem that a simple and reliable procedure for testing concrete for durability has yet been found.

A brief resumé of the principal tests which have been suggested and used for predicting durability, both for hardened concrete and for its component parts, is given below:

1. Accelerated Freezing and Thawing

There seems to be fair agreement among engineers that some type of accelerated freezing and thawing test constitutes probably the most dependable criterion for durability. However, there is as yet no general agreement on test methods. An analysis of freezing and thawing tests in comparison with varying exposure conditions develops so many variables that engineers have been hesitant in setting up standard test procedures until research is more complete on the subject. Space permits naming only a few of these variables: Degree of water saturation, effect of previous drying, velocity of cooling, type and size of specimen, freezing temperature, duration of cold, and manner of thawing. The ASTM has a specification (C4–24) covering a freezing and thawing test method for drain tile. In 1938 ASTM adopted a tentative method (C137–38T) for soundness of aggregates by freezing and thawing, and in 1939 a freezing and thawing test (C67–39T) for brick was adopted as tentative.

In measuring the results of freezing and thawing tests, various methods have been used, such as mere visual examination, loss in weight, and decrease in strength. Lately, certain experimenters have found flexural strength tests to be more indicative of deterioration than compressive strength tests. All such strength test procedures, however, require a large number of specimens. Another method which seems to offer promise, but which is, as yet, in the experimental stage, is the use of sonic vibration in predicting change in modulus of elasticity and thereby the degree of deterioration of the specimen being tested.

From the present state of knowledge, it would appear that some procedure of freezing and thawing, combined with cycles of wetting and drying, and possibly cycles of heating and cooling above average outside temperatures, will constitute a reasonable solution of this problem. However, it appears self-evident that no one test procedure could possibly be indicative of the many varied conditions of natural weathering exposure. A great amount of research work is in progress on this important subject and it is hoped that some reasonably reliable and simplified procedure may result from these efforts.

2. Sodium Sulphate and Magnesium Sulphate Tests for Soundness of Aggregates

The ASTM has a tentative specification (C88–39T) which has been the basis for most salt crystallization testing for several years. The disruptive salt crystallization tests have been used in this country as an accelerated measure of resistance to freezing and thawing and not as an indication of the resistance to actual salt crystallization action as occasioned near the surfaces of exposed concrete due to percolating solutions. The use of this test in this country on other kinds of structural products seems to have had as its object the latter purpose in many cases rather than a simulation of freezing and thawing action. Likewise, English and Continental investigators have stressed these tests from the latter standpoint. Relatively little attention is apparently paid to salt crystallization as a natural agency of disintegration in freezing climates, although the Bureau of Reclamation emphasizes this action in its Concrete Manual.[27]

The evidence is rather clear that these tests detect obviously unsound particles of the nature of those which cause pitting in concrete surfaces, such as shales, ochers, soft sandstones, "water-lime", certain argillaceous sandstones and limestones, certain cherts, etc. However, it is also recognized that these tests may cause the disintegration of certain sedimentary rocks, particularly those having fairly high absorption, which have shown good service in concrete. The sodium sulphate test has been in use for many years, while the magnesium sulphate test has recently found favor with various experimenters due to its lesser sensitivity to temperature change and greater severity of attack. There does not seem to be any consistent agreement between various authorities as to the existence of definite relationships between the two sulphate tests and accelerated freezing and thawing tests. The conclusion seems to be that these salt tests are useful in detecting unsound aggregates, but the results have to be interpreted with discretion, giving due weight to actual experience with similar aggregates in concrete structures. Most aggregate specifications incorporate clauses to this effect.

3. Steam and Autoclave Test for Soundness of Cement

As previously mentioned the ASTM has adopted the autoclave test in its new tentative specifications for Portland cement. The older steam test is considered as satisfactory for detecting free lime which is not in the hard-burned state, but it will not detect hard-burned free lime or crystalline magnesia, to which constituents most authorities attribute delayed expansion of some concrete structures. The more severe autoclave test will detect these two constituents and for that reason is favored as providing a more durable cement.

4. Permeability Tests

Permeability tests of concrete have been used in various research projects with specimens made up in the form of a bomb or disk, and the quantity of input or output water measured. Such methods would seem from theoretical considerations to give a reliable indication of probable durability; however, examinations of existing structures and data from permeability tests are not so convincing. Most of the evidence of lack of adequate watertightness in most structures seems to indicate that the distress shown has been largely due to segregation in handling and placing rather than to a fundamental defect in the mix. Tests of any properly cured concrete which was so designed that a plastic workable mix was secured, show very little permeability even under high pressures. Based on these results it is questionable whether this type of permeability test is of such significance as to justify its inclusion in a general concrete specification.

5. Simulated Aggressive Water Tests

Many research projects have been made which included the performance of mortar and concrete specimens under the simulated action of various aggressive waters, such as sulphate, acid and sea waters. However, no general specification covering these procedures has been adopted. There is little doubt that this type of test, if properly conducted, is very effective in predicting the durability of concrete under the action of the particular aggressive water used.

6. Water Absorption

This is an old test which has been used for many years on various masonry and other materials. The test is generally made at normal temperatures, but sometimes it is made in boiling water. The ASTM has test methods covering water absorption tests on various concrete products such as drain tile, pipe, masonry units and brick.

The absorption test is considered to indicate the general durability of concrete with reference to weathering action. If water does not readily enter the pore spaces of a concrete, it will, in general, be less affected by freezing and thawing, the possibility of percolating or aggressive water action is much reduced, and volume change due to variations in water content is decreased.

7. Fire Tests

The methods of determining fire resistance as described in ASTM Specifications C19–33 are applicable to concrete and are believed to be dependable for concrete as a material. They are not readily adaptable for studying particular samples of concrete, but are adapted to testing specific portions of a structure such as columns, beams or walls which may be built of the concrete to be tested.

8. Strength

The fact that strength has been mentioned last does not mean that it is not important; however, many engineers feel that in recent years too much importance may have been attached to early strength and too little thought given to long-continued strength or durability.

While the preceding tests are the principal ones used to date in attempting to predict durability of concrete or concrete materials, several other tests have been proposed and used by various investigators. Some of the more prominent of these methods are:

1. Heat tests, involving alternate heating and cooling of concrete specimens, sometimes combined with alternate wetting and drying. This type of test has never gone any farther than the research stage.

2. Sugar solubility test on Portland cement to detect underburned and prehydrated cements, as proposed by the late Thaddeus Merriman.[4] This test has received only limited acceptance. Merriman believed it to be indicative of a cement which would give durable hydration products.

3. Sodium sulphate test on Portland cement, made on slabs of neat cement, to determine sulphate resistance. This test was used by Merriman, but has attained only limited acceptance.

4. Water, or "floc" test, on Portland cement, proposed by Ira Paul.[4] This test has as yet received little acceptance. It gives very different results on different cements, which is believed to have some connection with durability.

5. The autoclave test on Portland cement clinker, recently proposed by Paul.

This test is considered to have possibilities.

F. Conclusion

The committee desires to warn against undue alarm at the foregoing enumeration of the many ills to which concrete may be heir under various exposure conditions. Our purpose is to widen the appreciation of concrete technology and thereby hasten the day when all concerned will give proper attention to those precautions which are necessary in securing durable concrete. When we consider the various unfavorable conditions under which many of our concrete structures have been completed in years past, we must agree with Bates[4] by paraphrasing the closing remarks of his Marburg lecture last June in regard to the many uncertainties still remaining as to the true nature of Portland cement, by saying that the many uncertainties still remaining regarding the production of durable concrete in no way detract from the proved findings of its tremendous use and that "the results are startlingly satisfactory".

Lacking any generally accepted test for predicting durability of concrete, it behooves the engineer and constructor to make full use of proved methods for producing durable concrete as given in various authoritative publications, probably the latest one of which is the Joint Committee Report on Concrete and Reinforced Concrete, published in June, 1940.[28]

To indicate only the high points in this procedure:

1. Use materials—cement and aggregates—which by test and experience have proved durable under the expected exposure conditions.

2. Select a water-cement ratio which will give a paste of a high degree of impermeability and resistance to expected exposure.

3. Use such proportions as will produce a plastic and workable mixture.

4. Mix and place the concrete in a manner to insure a homogeneous mass without segregation.

5. Provide thorough curing.

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Report of Special Committee on Waterproofing of Railway Structures

J. A. Lahmer, *Chairman,*	J. P. Gallagher	F. P. Turner
F. E. Bates	A. C. Irwin	L. W. Walter
G. E. Boyd	L. H. Laffoley	H. T. Welty
C. H. Chapin	F. J. Pitcher	C. A. Whipple
A. C. Copland	G. E. Robinson	O. G. Wilbur

Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

Change heading of Section 203 to read:

203. Asphalt for Saturant and Mopping Below Ground

Add following paragraph immediately below heading of Section 203:

Asphalt for saturant below ground shall meet the requirements of Section 202.

Change first paragraph of Section 207 to read:

1. Fabric shall consist of high-grade cotton cloth saturated thoroughly and uniformly with asphalt specified in Section 202 or either type of coal tar pitch specified in Section 204.

These revisions do not change the meaning of the specifications and are recommended for the purpose of avoiding ambiguity.

2. Waterproofing of railway structures.

A study is being made of the Specifications for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing, ASTM Designation D 173–40T, and of the Specifications for Coal-Tar Pitch for Roofing, Dampproofing and Waterproofing, ASTM Designation D 450–38T, in comparison with AREA specifications and it is probable that agreement will be reached after additional information is received with reference to certain requirements.

Progress has been made toward harmonizing differences between ASTM Specifications for Asphalt for Dampproofing and Waterproofing, ASTM Designation D 449–37T and corresponding requirements in AREA Specifications for Membrane Waterproofing. Two of the larger oil companies have informed your committee that they are prepared to furnish waterproofing asphalt which will meet all requirements of AREA specifications. The ASTM committee on bituminous waterproofing and roofing materials has indicated that during the coming year it will endeavor to obtain cooperation of the Federal Specifications Board, the American Association of State Highway Officials and the AREA in an effort to adopt uniform specifications for waterproofing materials.

The Special Committee on Waterproofing of Railway Structures,

J. A. Lahmer, *Chairman.*

Bulletin 422, January, 1941.

Report of Committee 15—Iron and Steel Structures

R. A. Van Ness, *Chairman,*
James Aston
F. E. Bates
R. N. Brodie
A. W. Carpenter
C. H. Chapin
O. F. Dalstrom
R. P. Davis
R. L. Eason
Herbert Ensz
W. G. Grove
G. A. Haggander
F. S. Hales
Shortridge Hardesty
C. S. Heritage*
Otis E. Hovey
J. B. Hunley
Jonathan Jones
A. R. Ketterson
A. M. Knowles
B. R. Leffler
H. S. Loeffler
F. M. Masters
C. H. Mercer
C. T. Morris
O. K. Peck
F. J. Pitcher
Albert Reichmann
O. E. Selby
T. C. Shedd
I. L. Simmons
C. E. Sloan
J. E. Bernhardt, *Vice-Chairman,*
G. L. Staley
H. C. Tammen
G. H. Tinker
G. H. Trout
F. E. Turneaure
F. P. Turner
T. M. von Sprecken
C. E. Webb
E. Weidemann
H. T. Welty
C. D. Williams
A. R. Wilson
W. M. Wilson
Committee

* Died August 31, 1940.

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

Report on revision of Specifications for Steel Railway Bridges and of Rules for Rating Existing Iron and Steel Bridges .... page 356

Report on Instructions for Maintenance Inspection of Steel Bridges, with recommendation for inclusion in the Manual .... page 358

2. Specifications for fusion welding and gas cutting for steel structures, collaborating with ASTM Committee A-1 on Steel, and the American Welding Society Conference Committee on Bridges.

No report.

3. Non-ballast type metal-floor steel bridges.

Final report, submitted as information .... page 363

4. Design of expansion joints involving iron and steel structures.

No report.

5. Relation between fatigue of metal and bridge design.

No report.

6. Review specifications for overhead highway bridges of American Association of State Highway Officials insofar as they relate to steel construction, conferring with that association.

No report.

7. Progress in design of bridge details.

No report.

8. Rigid frame design.

No report.

The Committee on Iron and Steel Structures,
R. A. Van Ness, *Chairman.*

Bulletin 422, January, 1941.

Report on Assignment 1

Revision of Manual

O. E. Selby (chairman, subcommittee), R. N. Brodie, O. F. Dalstrom, Herbert Ensz, Shortridge Hardesty, O. K. Peck, G. H. Trout, F. E. Turneaure, C. E. Webb, H. T. Welty.

The following revisions of the Specifications for Steel Railway Bridges are recommended:

301 (b) p. 15–10

Delete the words "shoes and pedestals" in the first line.

425 p. 15–15

Add a paragraph to read:

For stringers, the gage of the outstanding legs of the connection angles over the top one-third of the stringer depth shall be not less than the quantity $\sqrt{\frac{Lt}{8}}$

L = length of stringer span, in feet
t = thickness of angle, in inches

432 p. 15–16

Revise to read:

Stiffeners at Points of Bearing

432. There shall be stiffeners at the points of bearing of plate girders and at the points of bearing of concentrated loads on the girders.

There shall be stiffeners at the corresponding points of rolled beams if the reaction or the concentrated load, as the case may be, exceeds the value given by the formulas:

$$R = ft\left(B + \frac{d}{4}\right)$$

$$W = 2\,ft\left(B_1 + \frac{d}{4}\right)$$

R = safe reaction
W = safe concentrated load
t = thickness of web, in inches
d = unsupported depth of web, in inches
B = distance over which reaction is applied
B_1 = half of distance over which concentrated load is applied
f = safe unit resistance of web to buckling $= 15{,}000 - \frac{3}{4}\frac{d^2}{t^2}$

The section of the stiffeners shall be such that the unit bearing stress on the combined effective bearing areas of the stiffeners and the web will not exceed that allowable.

Even though the web of the beam is sufficient to meet the requirements of the foregoing formulas, the flanges shall be stiffened, if necessary, to give effective distribution.

The stiffeners shall extend as nearly as practicable to the edges of the flange angles or the beam flanges and shall be connected to the web by enough rivets to transmit the stress. Such stiffeners shall not be crimped. Only the part of the stiffener section beyond the fillet of the flange angle or of the beam flange shall be considered effective in bearing.

504–5–6 p. 15–20

Revise to read:

Preparation of Holes

504. Holes shall be cylindrical and perpendicular to the member. They shall be clean-cut, without torn or ragged edges.

Holes in material not more than ⅞ inch thick used for lateral, longitudinal or sway bracing, lacing, stay plates, diaphragms, inactive fillers, and stiffeners not at bearing points, may be punched full-size, except that holes through assembled material shall not consist of both reamed holes and holes punched full-size. Holes in material more than ⅞ inch thick used for such parts shall be sub-punched and reamed or sub-drilled and reamed.

If there are not more than three plies of main material and if no ply is more than ⅝ inch thick, holes in the main material may be punched full-size.

If there are more than three plies of main material or if the thickness of any ply of main material is more than ⅝ inch but not greater than the nominal diameter of the rivet less ⅛ inch, holes in all plies of main material shall be sub-punched or sub-drilled, and reamed after assembly.

If the thickness of any ply of main material is greater than the nominal diameter of the rivet less ⅛ inch, holes in such ply of main material shall be sub-drilled. Holes in the other plies of main material may be sub-punched, or sub-drilled, and reamed after assembly.

Stiffeners and active fillers at points of bearing shall not be considered main material in determining the number of plies, but should any sub-punching, or sub-drilling, and reaming be required by reason of thickness of material, all holes in such stiffeners and fillers also shall be sub-punched, or sub-drilled, and reamed after assembly.

Size of Holes

505. The diameter of holes punched full-size and of finished holes reamed and drilled shall be $\frac{1}{16}$ inch greater than the nominal diameter of the rivets.

The diameter of the die for punched and sub-punched holes shall not be more than $\frac{3}{32}$ inch greater than that of the punch.

The diameter of holes sub-punched, or sub-drilled, prior to reaming shall be $\frac{3}{16}$ inch less than the nominal diameter of the rivets.

The diameter of sub-drilled and reamed holes shall be as required for sub-punched and reamed holes, or else the holes shall be drilled to finished size while all of the plies are assembled.

The diameter of holes for turned bolts shall not be more than $\frac{1}{32}$ inch greater than that of the bolt.

Reaming and Drilling

506. Reaming shall be done with twisted-flute reamers directed preferably by mechanical means. Drilling shall be done with twist drills.

703. p. 15–26.

Revise first sentence to read:

703. The weights of rolled shapes and plates shall be computed on the basis of their nominal weights and dimensions as shown on the approved shop drawings, deducting for copes, cuts, and open holes.

525 p. 15–22

Revise to read:

Fit of Stiffeners

525. The bearing ends of stiffeners on beams and girders shall be milled or ground to bear against the flange or else shall be welded to the flange, except that welding to a flange at a point where the tensile stress exceeds one-fifth of that allowable will not be permitted. The fit of other stiffener ends against the flange shall be such as to exclude water after being painted. Fillers and splice plates shall be made to fit within ¼ inch at each end.

XII. Steel Castings. p. 15–42

Change Serial A27–36 T in the reference to ASTM specifications to read "Serial A27–39".

1611. p. 15–48

Add a section to read:

Welding

1611. Welding of structural alloy steel will not be permitted.

The following revision of the Rules for Rating Existing Iron and Steel Bridges is recommended:

108 p. 15–123

Under (c) Hammer Blow Effect, Clause 3, substitute the numeral 5 for the quantity n^s in the denominator of the last term in both formulas (a) and (b).

Instructions for the Maintenance Inspection of Steel Bridges

In accordance with instructions to collaborate with Committee 12—Rules and Organization, on matters affecting bridges, Committee 15 in 1939 submitted to Committee 12, Instructions for the Maintenance Inspection of Steel Bridges, to replace corresponding material previously adopted for publication in Chapter 12—Rules and Organization, and published in the 1929 Manual. However, in accordance with the suggestion received from Mr. W. T. Dorrance, chairman of Committee 12, that these instructions would properly be a part of Chapter 15, Committee 15 submits the following instructions with the recommendation that they be adopted for publication in Chapter 15 of the Manual.

INSTRUCTIONS FOR THE MAINTENANCE INSPECTION OF STEEL BRIDGES

1. The inspection of steel bridges shall be under the general supervision of the Chief Engineer of Maintenance, the Bridge Engineer, or other general officer in charge of bridge maintenance. Direct supervision, on each maintenance unit, shall be under some designated officer herein called General Bridge Inspector.

2. One or more competent bridge inspectors for each maintenance unit, who are familiar with and have a general knowledge of steel bridges, shall be assigned for the inspection of bridges under the direct supervision of the General Bridge Inspector.

3. The General Bridge Inspector shall personally inspect all steel bridges in his territory at least once each year, and those requiring special attention more frequently.

4. Bridge inspectors shall forward promptly to the General Bridge Inspector, on the form provided, a report of each bridge inspected. The report shall state the conditions found in each individual part, regardless of what may have been reported previously.

5. When the bridge inspector finds defects that, in his opinion, are of such a nature as to make traffic at regular speed unsafe, he shall take the necessary steps to have the speed limited to that which he considers safe. Immediately after the inspector has taken steps to protect traffic, he must notify the Train Dispatcher by telegraph or telephone, sending copy to the Division Engineer and the Division Superintendent, giving the safe speed limit and briefly describing the necessary repairs. He shall follow this immediately with a written report to the General Bridge Inspector, giving in detail the defects found.

6. The General Bridge Inspector shall examine these inspection reports and if any defects of a serious nature are reported he shall take immediate steps to have the necessary emergency repairs made. After the General Bridge Inspector has examined the inspection reports, he shall forward one copy of each to his superior officer, calling attention to any defects which are not of an emergency nature but are serious enough to warrant the attention of such officer.

7. The General Bridge Inspector should be familiar with the capacity and stability of the steel bridges under his charge. If any defect should develop which, in his opinion, weakens the structure or any member, he shall report to his superior officer immediately after personal inspection with his inspector and the division officer charged with the direction of bridge maintenance, giving recommendations for remedying the defect. He may request that a special inspection be made of the structure by a representative of the Bridge Engineer.

8. In making inspection reports the following abbreviations are permissible:

A. B.	Anchor bolt	I.	Inner
Bbl.	Barrels	I. S.	Inside
Bot.	Bottom	L.	Angle
B. W.	Backwall	Lat.	Lateral
Br. S.	Bridge seat	Mas.	Masonry
Brkt.	Bracket	N.	North
Bm	Beam	O.	Outer
Chd.	Chord	O. S.	Outside
Concr.	Concrete	P.	Post
Conn.	Connection	Ped.	Pedestal
C. Pl.	Cover plate	Pl.	Plate
Diag.	Diagonal	Ptl.	Portal
Diaph.	Diaphragm	Reinf.	Reinforcing
E.	East	Roll.	Roller
E. B.	Eastbound	S. Pl.	Sole plate
Exp.	Expansion	S.	South
F. Bm.	Floor beam	Spl.	Splice
Fill.	Filler	Stiff.	Stiffener
Flg.	Flange	Str.	Stringer
Fdtn.	Foundation	U. C.	Undercoping
Fr.	Frame	Vert.	Vertical
G. R.	Guard rail	Wpg.	Waterproofing
Gen. Cond.	General condition	W.	West
Gir.	Girder	W. B.	Westbound
Guss.	Gusset	W. W.	Wing wall
Hor.	Horizontal	X.	Cross
Int.	Intermediate		

9. The bridge inspector, in his report, shall cover the following points:

(a) Deck

Size, spacing and minimum depth of ties.
Whether ties are treated or untreated.
Uniformity of bearing of ties.
Number and size of defective ties.
Size and condition of guard timbers and guard rails.
Fastenings of ties.
Fastenings of guard timbers and guard rails.
Condition of walks and railings.
Condition of refuge bays.
Condition of ballasted deck, and depth of ballast measured from base of rail at each end of bridge.
Whether waterproofing is effective or requires repairs.

(b) Fire Protection

Description and condition of fire protection.

(c) Track

Weight of rail and size of tie plates.
Condition of rails, joints, and fastenings.
Alinement of track and its location with reference to the steel structure, at ends and center of each span.
Surface of track on bridge and on approaches.
Where track is out of line or surface, the report shall show the location, amount, and probable causes.

(d) Shims and Blocking

Conditions of shims and blocking, giving description and location, making sketch if necessary.

(e) Bridge Seats

Condition and cleanness.

(f) Anchors and Bearings

Whether the superstructure is securely anchored to the masonry.
Whether bed plates, rollers, rockers, and pedestals are clean, in correct position and have full bearing.
Whether expansion bearings are functioning properly.
Whether bed plates are wearing into masonry.
Whether there are any flaws or breaks in bearings.

(g) Expansion

Clearance between expansion ends and masonry or adjoining spans.
Whether there is any apparent movement of the masonry.

(h) Paint

Condition of paint.
Date of last painting, number of coats and kind of paint, if stenciled on the bridge.
Whether spot painting or repainting is needed.

(i) Straightness and Alinement of Members

Condition of individual members as to bends and kinks.
Alinement of trusses, girders, floor members and towers.
Slackness of eye-bars and adjustment of counters.

(j) Damage From Blows

Parts damaged by blows from equipment, lading or floating objects.

Location and extent of damage, making sketch to show parts damaged and repairs suggested.

(k) Cracks and Breaks

Where parts or welds to be examined for cracks or breaks are in dark or poorly lighted places, examination should be made with flashlight or other artificial light.

Cracks and breaks, especially in floor connection angles, stringer flange angles under tie bearings, hangers, pin plates, fillets of angles of flanges and posts, and in end sections of lower chords or flanges over or near bearings.

Cracks in webs of floor beams where bottom flange angles do not extend under end connection angles.

Lateral bracing and cross frames, especially those of spans on curves.

Welds on lateral bracing and cross frames, stiffeners and other welded details.

(l) Pins, Pin Holes and Nuts

Condition of pins and pin holes, as to movement and wear.

Pins should be observed under traffic if practicable. The report shall give the location of pins observed, the amount of movement of the pins, and the wear of pins and pin holes if it can be determined.

Whether pin nuts are tight.

(m) Rivets and Turned Bolts

Location and number of rivets and turned bolts that are loose and of rivets that have badly corroded heads, giving special attention to floor connections.

(n) Corrosion

Condition of members as to loss of section from corrosion, noting extent of such action, with measurements of remaining section if members are badly corroded, paying close attention to loss of metal in plates and angles of lateral systems of spans on curves.

Damage from engine blast in spans over other tracks, and attachment of blast plates, where used.

Top chord splice and connection of portal angle to top of end post for rust distortion between stitch rivets.

(o) Cleanness

Collection of dirt on horizontal surfaces.

(p) Movable Bridges

(1) Rail Locks

Wear and condition of rail locks and rail ends and whether tolerances in Part 64, Signal Section Manual, are exceeded (vertical 1/4 inch, horizontal 3/16 inch).

Signal interlocking connections.

(2) Charts and Diagrams

Whether an operating diagram is posted.

Whether electrical wiring diagram is posted or is available.

Whether lubrication chart is posted and the instructions on it are followed.

(3) Lubrication

Whether moving parts have been kept sufficiently lubricated. They should be observed during operation. The report shall show whether lack of lubrication is due to inattention or to inadequate facilities. If facilities are inadequate, complete information shall be given with recommendation for improvement.

(4) Gears

Condition of gears as to:

Accurate meshing
Fit on shafts
Fit of keys
Breaks, flaws and excessive wear (on gear teeth and keys)
Protection against falling objects
Safety guards
Cleanness

(5) Bearings

Whether bearings have proper linings and good running fit.

Whether shafting is accurately alined, so as not to weave or wobble in bearings or between them; also whether collars and thrust bearings are in adjustment.

Attachment of caps to bases and of bearings to supports.

Alinement, fit, and wear of trunnions, rollers, and sheaves in their bearings.

(6) Cables

Adjustment of cables as indicated by slackness, inclination of equalizer bars, or uneven seating of spans.

Condition of cables as to rust and excessive accumulations of hardened grease.

Broken wires and broken strands.

Condition as to lubrication.

Working clearances.

End connections and clamps.

(7) Clutches and Brakes

Working condition and cleanness.

(8) Power Equipment

Condition of power unit for delivering the necessary power.

Whether properly maintained.

(9) Mechanical Features

Operating condition.

Condition and adjustment of balance wheels.

Condition and adjustment of wedges or other lifting devices.

Condition and adjustment of locking devices.

Adjustment of indicator devices.

Adjustment of toggle arms to form very nearly a straight line when wedges are fully driven.

Turntable of swing bridges, including rollers and treads as to breaks or flaws that might cause breaks.

Clearance through a complete cycle of operation.

Balance through a complete cycle of operation.

Safety devices—electrical and mechanical.
Lightning protection of power plant and superstructure.
Condition and adjustment of guides, centering devices, buffers, and bridge locks.
Condition and fastenings of racks, tracks and tread plates.
Condition of sheaves.

(10) Counterweights
Condition of counterweights and their supports.
Saftty of balance or counterweight box.

(11) Navigation Requirements
Condition of lights.
Condition of siren or other boat signalling devices.
Condition of fenders and other protection.
Clearances for navigation.

(12) Record of Openings
Whether a complete record is being kept of bridge openings, vessel movements, and happenings affecting the interests of the Railway Company.

10. The inspector shall report indications of overload or failure in any part of the bridge. He shall observe the behavior of the bridge during the passage of live load, if practicable, noting excessive vibration, deflection, and side sway.

11. Attachments of wires, pipes, etc., that may be harmful to the bridge, shall be reported.

Report on Assignment 3

Non-Ballast Type Metal Floor Steel Bridges

G. A. Haggander (chairman, subcommittee), James Aston, J. E. Bernhardt, A. W. Carpenter, F. S. Hales, A. R. Ketterson, H. S. Loeffler, F. J. Pitcher, G. L. Staley, F. P. Turner.

The non-ballast type of metal floor for steel bridges is adapted to places where the depth from base of rail to clearance line is small. It was widely used in early track elevation structures.

Figure 1 illustrates an early and simple type consisting of transverse I-beams, about 1 ft. 3 in. center to center, acting as floorbeams between the girders, with a longitudinal plate under each rail. These plates usually are stiffened by angles or Z-bars riveted to the edges to distribute the loads longitudinally. The space outside of these stiffened plates is covered by a thin deck plate to protect the I-beams and to shelter the area under the bridge. The rail is fastened to the longitudinal plate by cast clip washers and bolts.

This type of floor did not provide for track circuit insulation and was noisy. The bearing of the rail caused considerable wear in the longitudinal plate. It was impracticable to adjust the grade of the track or the rail if that became necessary.

To overcome these faults the construction shown in Fig. 2 was generally adopted. It is essentially the same as that shown in Fig. 1 except that a wood or fiber shim is inserted between the rail and the plate to provide insulation, prevent wear, and reduce noise. Fiber bushings and washers are provided for the clip washers and bolts to complete the insulation.

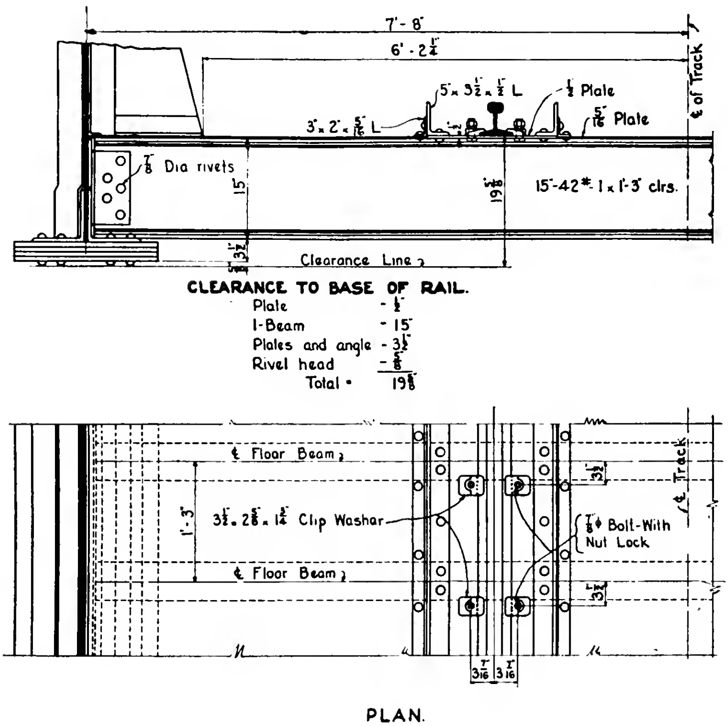

Fig. 1.

A great many bridges with floors of this type are in service. By varying the thickness of the shims, the rail may be surfaced. If wood shims are used, they should be placed with the grain transverse to the rail and laid continuous to reduce splitting and crushing. A tough wood without pronounced fiber is recommended.

Figure 3 illustrates a rail trough floor with the track on a nine-degree curve. One rail is elevated. A flangeway along the gage side of the low rail is provided by a pair of heavy angles with their vertical legs well braced and supporting a manganese steel wearing strip. These wearing strips are bolted to the angles and may be replaced easily. This particular design does not provide for insulating the rail, the circuit being carried around the bridge by a cable.

Figure 4 illustrates a conversion of the bridge shown in Fig. 1. This consists of replacing the rail trough with a heavy wide-flange beam and supporting the rail on this beam. This beam distributes the load more effectively over the floor beams. The rail is well fastened and insulated. This plan requires a raise of grade which also improves the clearances.

Figure 5 illustrates a rail fastening to a trough type floor. In the original construction the rail rested on a small steel plate riveted to the top trough section. This was replaced by the construction shown, which carries the load to the vertical trough plates and provides insulation.

Generally, the first cost and maintenance cost of these types are higher than for types with ballasted decks. To offset this, the reduced floor depth may result in lower cost of the approaches.

A floor of this type is not justified unless there is no alternative within reasonable first cost when all of the factors are considered.

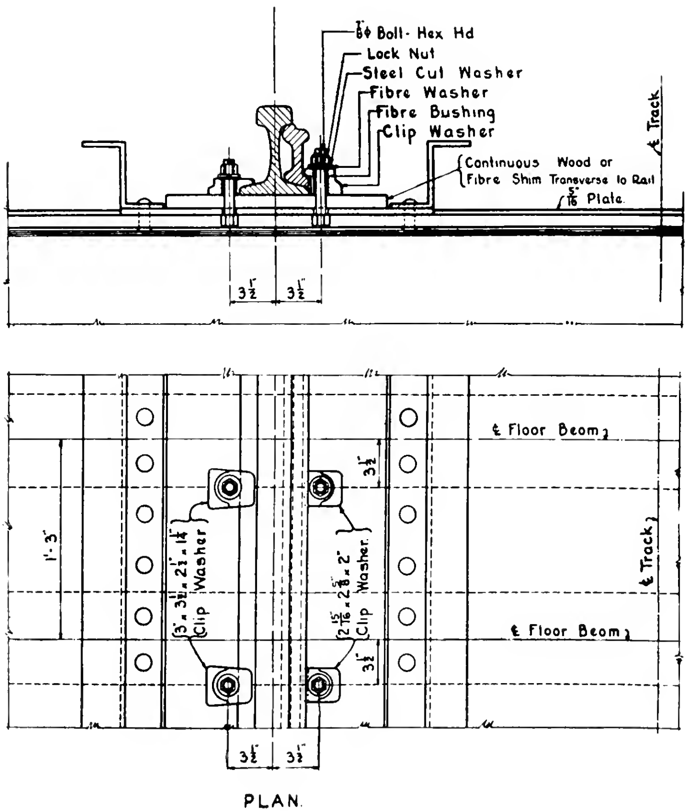

Fig. 2.

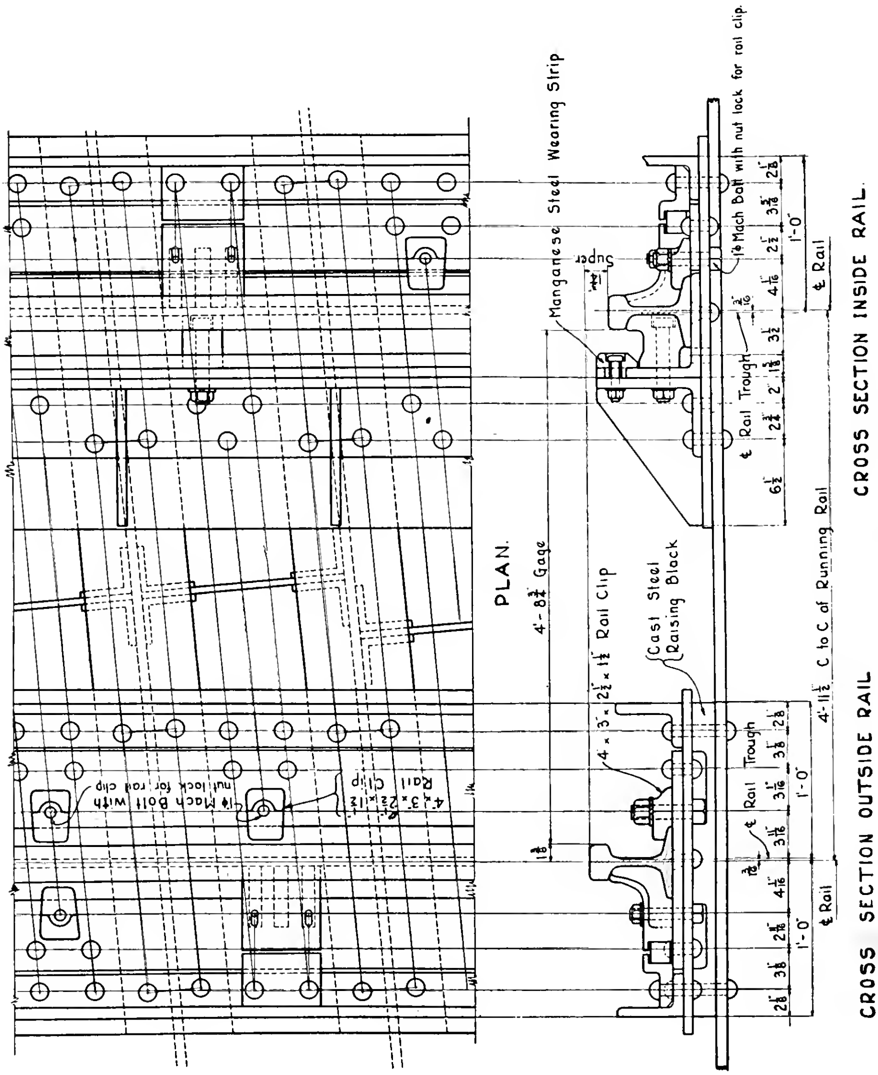
PLAN
4'-8½" Gage
Manganese Steel Wearing Strip
Super
1¼ Mach Bolt with nut lock for rail clip.
4"×3"×2½"×1½" Rail Clip
Cast Steel Raising Block
Rail Trough
℄ Rail
1'-0"
4'-11½" C to C of Running Rail
CROSS SECTION OUTSIDE RAIL
CROSS SECTION INSIDE RAIL

Fig. 3.

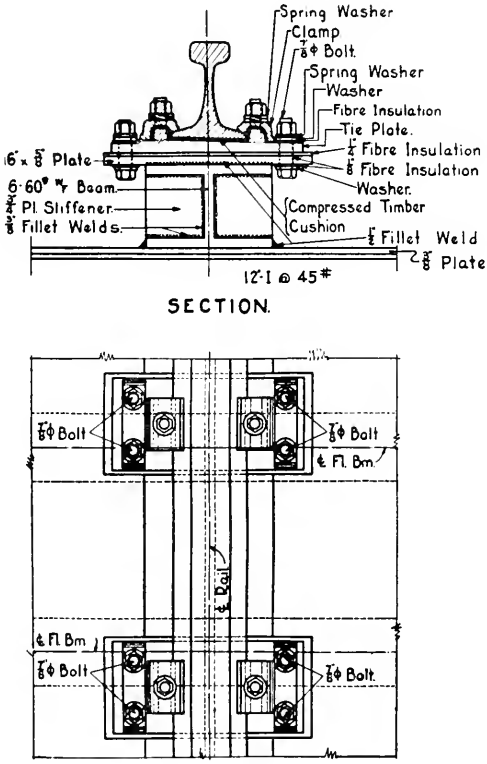
Spring Washer
Clamp
Bolt
Spring Washer
Washer
Fibre Insulation
Tie Plate.
Fibre Insulation
Fibre Insulation
Washer.
Compressed Timber
Cushion
Fillet Weld
Plate
Plate
Beam.
Pl. Stiffener
Fillet Welds.
12"-I @ 45#
SECTION.
Bolt
Bolt
℄ Fl. Bm.
℄ Rail
℄ Fl. Bm
Bolt
Bolt
PLAN.

Fig. 4.

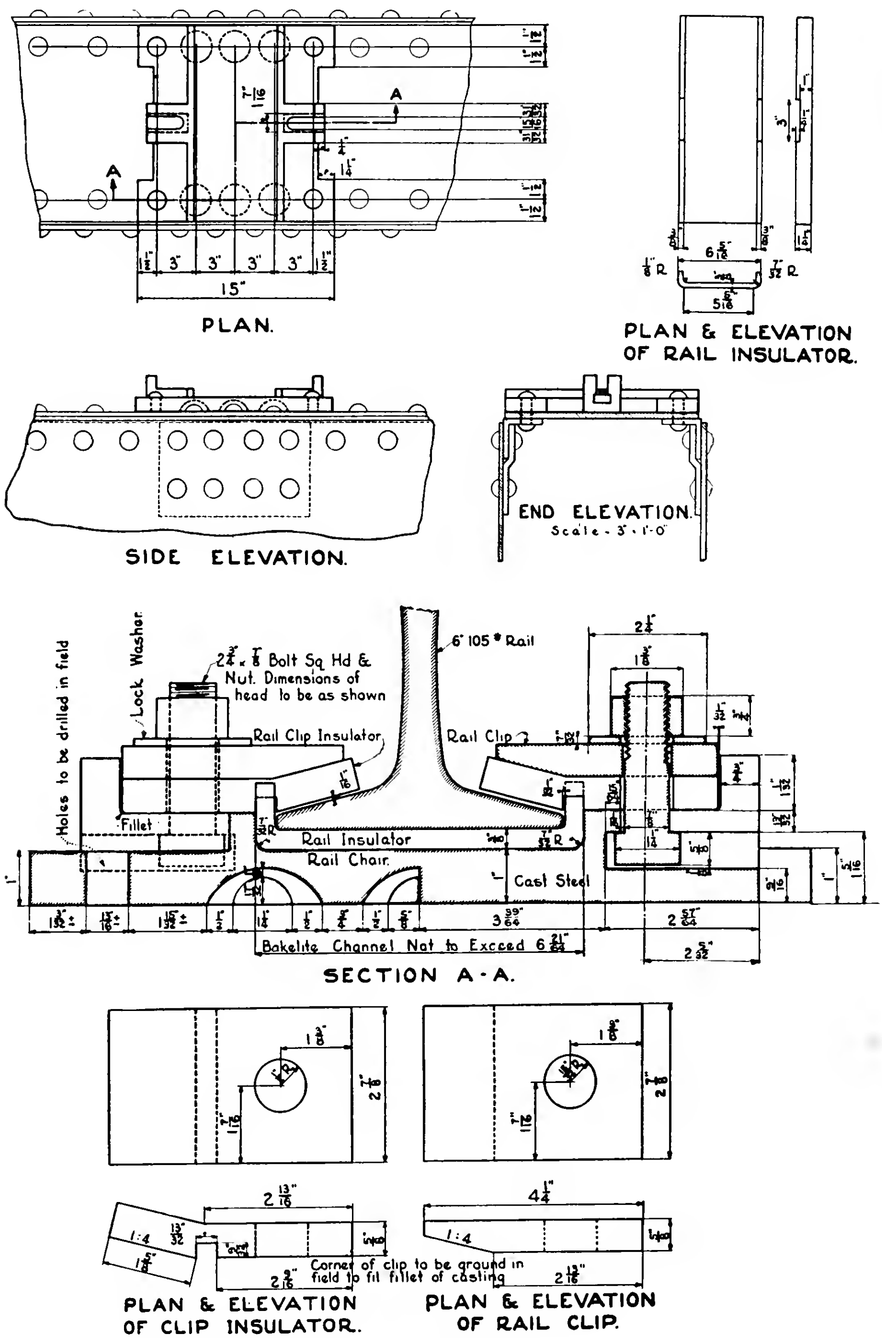
PLAN.
PLAN & ELEVATION OF RAIL INSULATOR.
SIDE ELEVATION.
END ELEVATION.
Scale - 3" = 1'-0"
6" 105 # Rail
Bolt Sq. Hd & Nut. Dimensions of head to be as shown
Lock Washer
Holes to be drilled in field
Rail Clip Insulator
Rail Clip
Fillet
Rail Insulator
Rail Chair
Cast Steel
Bakelite Channel Not to Exceed
SECTION A-A.
Corner of clip to be ground in field to fit fillet of casting
PLAN & ELEVATION OF CLIP INSULATOR.
PLAN & ELEVATION OF RAIL CLIP.

Fig. 5.

Report of Committee 11—Records and Accounts

C. A. Knowles, *Chairman,*
Anton Anderson
F. B. Baldwin
H. D. Barnes
S. H. Barnhart
B. A. Bertenshaw
W. C. Bolin
E. V. Braden
W. F. Cummings
V. H. Doyle
D. E. Field
C. C. Haire
H. N. Halper
J. H. Hande
R. J. Herring
A. T. Hopkins
C. D. Johnson
W. R. Kettenring
E. M. Killough
P. R. Leete
Henry Lehn
W. M. Ludolph
D. O. Lyle
W. S. MacCulloch
W. S. McFetridge
E. W. Metcalf
H. L. Restall, *Vice-Chairman,*
O. M. Miles
A. T. Powell
C. P. Richardson
F. M. Spiegel
H. J. Stroebel
D. C. Teal
V. P. Turnburke
H. C. Wertenberger
A. O. Wolf
Louis Wolf

Committee

To the American Railway Engineering Association:

Your committee respectfully reports on the following subjects:

1. Revision of Manual.

Progress report—presented as information .... page 370

2. Bibliography on subjects pertaining to records and accounts.

Progress report—presented as information .... page 371

3. Office and drafting room practices:

(a) Drafting equipment and tools;

(b) Specifications of materials to be used for drawings and drafting;

(c) Standard system for filing drawings.

Progress report—presented as information, with recommended conclusions for publication in the Manual .... page 373

4. Recommended practice to be followed with respect to maintenance of way accounts and statistical requirements.

Progress report—presented as information .... page 379

5. Construction reports and records:

Forms for recording complete descriptive statement of quantities and other physical characteristics of construction projects.

No report.

6. Valuation

(a) Resumé of developments of the current year in connection with regulatory bodies and the courts.

Progress report—presented as information .... page 379

(b) ICC Valuation orders, reports and records.

Progress report—presented as information, with a recommended addition to the Manual .... page 381

7. Report upon changes in, revisions and interpretations of, ICC accounting classifications.

Progress report—presented as information .... page 382

8. Methods for avoiding duplication of reports and for simplifying and coordinating work under the requirements of the ICC and other public authorities.

Progress report—presented as information .... page 385

9. Records of property leased and available for lease.

No report.

The Committee on Records and Accounts,
C. A. Knowles, *Chairman.*

Bulletin 422, January, 1941.

Albert Pierce Weymouth

Albert Pierce Weymouth, a member of the Committee on Records and Accounts since 1928, died November 13, 1940, at his home in Ben Avon, Pittsburgh, Pa. He was born in Dorchester, Mass., February 20, 1882, and was graduated from Massachusetts Institute of Technology in 1904. Following his graduation he entered the service of the Pennsylvania Railroad in the engineering department at Pittsburgh. He remained in that department during his entire service and through successive advancements became assistant engineer on the staff of the chief engineer at Pittsburgh, which position he had held for over twenty-five years at the time of his death.

He is survived by his widow, Mrs. May Myers Weymouth, a daughter, Frances G., and a son, Edward A. Weymouth, all of Ben Avon. Mr. Weymouth was devoted to his family, to the Ben Avon Presbyterian church, of which he was an elder, and to his profession. He was a student of the principles of engineering and valuation accounting, which prompted him to become a member of the Committee on Records and Accounts.

His experience on extensive engineering projects in the Pennsylvania's most difficult territory, combined with his zeal and earnestness in the pursuit of sound accounting and clear records, made him a valuable member of the committee. As a member and chairman of various subcommittees he rendered devoted, unselfish and capable service. Through his unobtrusive but effective manner and his pleasing personality he won and held the respect and friendship of his associates. It is with a sense of distinct loss to the Committee on Records and Accounts and the American Railway Engineering Association that the members of the committee here record his passing.

E. V. Braden
C. C. Haire
Committee on Memoir

Report on Assignment 1

Revision of Manual

D. E. Field (chairman, subcommittee), W. F. Cummings, J. H. Hande, R. J. Herring, W. R. Kettenring, P. R. Leete, Henry Lehn, E. W. Metcalf, A. T. Powell, F. M. Spiegel, H. J. Stroebel.

The work of the subcommittee this year has consisted of reviewing all forms in the Manual to determine those in need of revision, and those that should be deleted. This was accomplished by having each member of the subcommittee review that portion covering material handled by some other subcommittee, of which he is also a member. At this time the committee recommends no change.

During the next year the subcommittee will look into the possibility of a new arrangement of the material in Chapter 11 of the Manual, to the end that it may be put in more logical sequence, give a better numbering to forms, plates and pages, and simplify future revisions.

Report on Assignment 2

Bibliography on Subjects Pertaining to Records and Accounts

E. V. Braden (chairman, subcommittee), Anton Anderson, B. A. Bertenshaw, H. N. Halper, Henry Lehn, E. W. Metcalf, C. P. Richardson, D. C. Teal.

The practice of previous years has been followed in compiling the bibliography for the current year. Periodicals likely to contain important articles pertaining to railroad records and accounts were systematically reviewed, also reference lists of new books and pamphlets for items of special usefulness or interest to members of the Association. The following compilation is submitted as a result of such bibliographical review for the period from November 1, 1939 to November 1, 1940.

Bibliography

Books

1. Interpretations of ICC Accounting Classifications of Steam Railroads. By Accounting Division, Finance, Accounting, Taxation and Valuation Department, AAR, Washington, D. C. Loose Leaf. $1 per copy to member railroads. $1.25 to non-members.

   This book contains all the formal interpretations included in ICC Accounting Bulletin No. 15, also the informal interpretations issued by the ICC Bureau of Accounts and designated as "A" cases, all revised to March 1, 1940. When a sufficient number of additional interpretations or revisions of cases previously issued have been accumulated, the Department of Finance, Accounting, Taxation and Valuation, AAR, will issue loose-leaf supplements.

2. Code of Federal Regulations of the United States of America—Having General Applicability and Legal Effect in Force June 1, 1938.

   Title 49—Transportation and Railroads (Vol. 14, Book 1, Vol. 14, Book 2), two volumes covering the regulations and orders of ICC 1938 Supplement, containing amendments issued to Dec. 31, 1938. Price $2.25 per volume or supplement, Superintendent of Documents, Government Printing Office, Washington, D. C.

Pamphlets

1. Taxation of Railroads in the United States. 1936–1940. A list of references, arranged by years of publication by the Bureau of Railway Economics Library, AAR, Washington, D. C. 20 typed pp.

2. Railroad Reorganization, Practice and Policy; Some Aspects and Present Trends. By Joseph R. Warner. Savings Bank Journal, December 1939. pp. 7, 26–32.

3. Valuation or Historical Cost; Some Recent Developments. By George O. May. (partner,—Price Waterhouse Company). Dun's Review. May 1940. Published by Dun & Bradstreet, Inc., New York City. pp. 17–20, 49–50.

4. Railroad Construction Indices. Compiled by Engineering Section, Bureau of Valuation, ICC, Washington, D. C. 22 mimeo pp. Dated August 1, 1940.

5. Symposium on Railroad Reorganization. Published as the Summer, 1940, issue of Law and Contemporary Problems, Duke University Law School, Durham, N. C. Contains the following 13 articles relating to Railroad Reorganization:

   The Development of Railway Corporate Structures.

   J. W. Barriger, III, chief examiner, Railroad Division, Reconstruction Finance Corporation.

The Background and Techniques of Equity and Bankruptcy Railroad Reorganizations; A Survey.

Warner Fuller, professor, Washington University School of Law.

Progress and Delay in Railroad Reorganizations Since 1933.

F. D. Dembitz, attorney, Reconstruction Finance Corporation.

Some Financial and Economic Problems in Railroad Reorganizations.

Joseph R. Warner, railroad financial analyst, Newark, N. J.

The Relative Treatment of Securities in Railroad Reorganizations Under Section 77.

H. J. Friendly and L. M. Tondel, Jr., attorneys, Root, Clark, Buckner & Ballantine.

The Case for a Special Railroad Reorganization Court.

C. M. Clay, assistant general counsel, Reconstruction Finance Corporation.

The Judicial and Administration Mechanism of Section 77.

Leslie Craven, attorney, Miller, Owen, Otis & Bailly.

The Representation of Security Holders' Interests Under Section 77.

Wm. G. Fennell, attorney, Cadwalader, Wickersham & Taft.

Labor's Interest in Railroad Reorganization.

A. F. Whitney, president, Brotherhood of Railroad Trainmen.

Protecting the User Interest in Railroad Reorganization.

A. B. Rood, executive research director, Old Colony Commuters & Shippers League.

The Problems of the Leased Line.

John F. Meck, Jr., assistant professor, Yale School of Law.

The Voluntary Adjustment of Railroad Obligations.

Hubert L. Will, attorney, U. S. Department of Justice.

The Purchase by Railroads of Their Own Obligations.

R. T. Swaine, attorney, Cravath, deGersdorff, Swaine & Wood.

6. Recent Developments in the Field of Public Utility Valuation and Accounting. Report of Special Committee American Bar Association, 32 pages, 1140 North Dearborn Street, Chicago.

7. Rate of Capitalizing Railroad Earnings to Establish a Valuation for Property Taxation. N. H. Jacoby—Journal of Business, University of Chicago. 13: 158–71, April 1940.

8. Transition of Depreciation Accounting; How Public Service Commission and Wisconsin Utilities have met this problem. A. R. Colbert, Journal Land and Public Utility Economics, 16: 129–36. May 1940.

Report on Assignment 3

Office and Drafting Room Practices

D. C. Teal (chairman, subcommittee), B. A. Bertenshaw, D. E. Field, A. T. Hopkins, C. D. Johnson, W. M. Ludolph, E. W. Metcalf, F. M. Spiegel, H. C. Wertenberger.

The schedule of subjects assigned and reported on herein is as follows:

(a) Drafting equipment and tools

(b) Specifications of materials to be used for drawings and drafting

(c) Standard system for filing drawings

The basic information for these studies has been developed through the medium of a questionnaire submitted to 58 Class I railroads. In general, the practices described and recommended are those of the majority of the users.

(a) Drafting Equipment and Tools

A report on this topic was made at the March, 1940, convention and published in the Proceedings, Vol. 41, pages 454 to 456, as information. It contains a list of the drafting tools ordinarily owned by the draftsman and also the items of equipment usually furnished by the railroad. General recommendations were made for selection of new equipment.

After reviewing the subject matter again, your committee is of the opinion that the report submitted in 1940 adequately covers the assignment. It is recommended that the subject be discontinued.

(b) Specifications of Materials To Be Used for Drawings and Drafting

The most commonly used materials in drawing and drafting work are drawing, tracing and blueprint papers and cloths, pencils, inks, water colors and erasers.

To judge drawing materials correctly is very difficult as most of the important qualities can be measured only with the aid of special instruments constructed for this purpose. An experienced draftsman may be able to select a drawing paper in regard to its surface, erasing quality and transparency; however, for most of the other properties such as wearing quality and permanence, he is obliged to rely on his own past experience or trust that the material ordered will conform to the small sample he has been shown.

In choosing drawing materials, it is necessary to keep in mind whether they are to be used for pencil, ink, or water color work, for indoor or outdoor use, and whether the drawings are to be permanent or temporary records. As the materials used become an integral part of the finished drawing, in theory, their general quality should balance and be consistent with the permanence and importance of the work to be done. However, it is not practical in railroad work to keep large amounts or a wide selection of drawing supplies on hand. Regardless of initial good quality, most of them deteriorate to some extent with age. Although theoretically it would be well to have a selection that will cover all possible needs, in practice, this would necessitate keeping numerous items on hand which would be used infrequently. It is common practice and common sense to order drawing room supplies monthly, limiting the selection to those types whose general quality and properties are adapted to the major requirements of the work to be done.

The table lists the most commonly used drawing materials together with the special factors to be considered when ordering them, with general all-round utility in mind.

Factors Influencing the Selection of Drawing Materials

Item	*Properties to Consider*
Drawing papers and cloths	Surface (for taking pencil or ink) Erasing quality (to suit major requirements) Color (for eye strain and to suit other requirements) Wearing quality (to suit major requirements) Permanency (to suit major requirements) Formation (to suit major requirements) Cleanliness (to suit major requirements)
Tracing papers and cloths	Transparency (for tracing work and for making prints) Surface (for taking pencil or ink) Erasing quality (to suit major requirements) Wearing quality (to suit major requirements) Permanency (to suit major requirements)
Profile and cross-section papers and cloths	Surface (for taking pencil or ink) Permanency (special resistance to shrinkage or expansion to protect accuracy of engraving line work) Transparency (for making prints) Color of engraving lines (for eyestrain)
Print papers and cloths	Wearing quality (resistance to rough handling and folding) Permanency (body resistance to shrinkage or expansion to protect accuracy) Chemical treatment of surface (Permanency and retention of color of background or lines)
Drawing pencils	Ability to make clean black lines Strength and uniformity of lead Opaqueness of lines (for tracing work)
Colored pencils	Ability to make clean distinct lines Contrast and vividness of colors Strength and uniformity of lead Indelible versus other types (Indelible pencils should not be used on drawings or prints that are for outdoor service, because of possibility of getting wet.)
Waterproof drawing inks and water colors	Opaqueness (for tracing work) Ability to make clean, distinct lines Permeating tendencies Ease of erasing
Erasers	Ability to erase without damage to texture of paper or cloth Uniformity of materials Operating speed and effectiveness

According to questionnaire answers, it is universal practice among all American railroads to order drawing materials by requisitions on the general storekeeper, the stationery department or direct on the purchasing agent. Requisitions state the trade name and catalog reference of the brand preferred with a note to the effect that acceptable substitutes will be considered in order to allow competitive bidding. Everyday items such as drawing paper, tracing cloth, pencils, etc., are usually ordered on the basis of past experience, while innovations are selected from samples submitted by the manufacturer. The standardized commodities are usually purchased in sufficient quantities to obtain price advantages. Blueprint paper is often contracted for yearly at an agreed price, orders being placed from time to time as paper is needed.

A wide selection of drawing materials is now available from old established and reputable dealers. Prices are in keeping with the quality and are adequately controlled by the competition between the manufacturers.

Your committee has been unable to find any instance in either railroad work or other industries where specifications have been used for the ordering of drafting materials. In this connection, it should be noted that their production is highly specialized work which is confined to a relatively few reptuable manufacturers. All of the papers and cloths and most of the instruments are registered with the U. S. Patent Office. The special materials and patented processes used to produce these "trade mark" goods are in reality the specifications for them.

Conclusions

Except for requirements laid down to the paper mills by the drawing supply companies, no specifications are now in use or available for the ordering of drawing and drafting materials.

The present almost universal practice of ordering "trade name" materials by catalog reference and from samples, limiting the selection to standard types having general quality and properties suited to the major requirements of the office, is quite satisfactory for railroad work.

It is considered unnecessary and impractical to attempt the preparation of definite specifications at this time for the ordering of drawing materials.

The report is presented as information with the recommendation that the subject be discontinued.

(c) Standard System for Filing Drawings

Railroad drawings are the records of land ownership, tracks, bridges, buildings, equipment and other work. They are valuable as permanent records, and are also needed frequently for reference when planning new facilities and for handling routine business. It follows that they should be filed in a safe place as well as in a manner to make them easily accessible.

Drawings should be filed efficiently and systematically, but how? One railroad drafting room has one type of equipment, the next one another. Drawings are indexed alphabetically, geographically and numerically. They are stored in vertical filing cases, in flat horizontal drawer cabinets, and in pigeonhole tubes. The methods used depend partly upon the type of filing equipment that is available and, while systems may vary as to details, they are usually alike in certain essentials.

In the larger sense to which this report is dedicated, filing involves three things.

1. Numbering and coding
2. Indexing
3. Filing equipment

Numbering and Coding

As indicated by the phrasing, the numbering and coding of drawings are usually so combined and correlated that they have to be considered as one operation.

The drawing number serves two purposes, (1) for easy identification and (2) for locating in the storage files. As they are completed, the drawings are assigned numbers that embody code letters or symbols to indicate where they are to be kept. The number thus becomes the intermediary agent between the card index catalog and the filing cabinet. The storage equipment, of course, has to be identified and labeled in accordance with the system used.

Most offices number serially, starting from one. However, there are others that start new numbers with each individual file case.

The filing information may be placed at the beginning or it may be at the end of the main number. In the latter case, Drawing No. 1234–A–IV–a would indicate that Drawing 1234 belongs in cabinet "A", drawer "IV", compartment "a". In some cases only the drawers and their compartments are identified. Drawing No. 1234–A–1 would here belong in drawer A, compartment 1. This plan is feasible in smaller offices and when the equipment is suitable. The flat drawer, sectional type cabinets, to which new sections can be added as needed, are adaptable to this scheme.

One railroad with two types of filing equipment distinguishes between pigeonhole and drawer filing by prefixing a "Ph" or "Dr" to the number. The range of numbers contained is posted over each receptacle. In this manner Drawing Ph–2012 would be filed in the pigeonhole marked Ph–2000 to Ph–2025.

In another office, new numbers are started for each cabinet and the filing cases are identified by letters. Here, drawings with numbers prefixed by the letter "A" are filed in cabinet "A" and those with prefix "B", in cabinet "B". This scheme obviates the use of large numbers.

One railroad files its small letter-sized drawings in looseleaf type file binders. The drawings are identified by book and page numbers. Drawing No. B–5, P–100 is filed in book 5, page 100.

Besides identifying the drawing and locating it in the files, the drawing number often contains other coded information. Sometimes the prefix letters indicate the department in which the drawing was prepared. Symbols used by one railroad are:

C. E. = Chief engineer's office
B. = Bridge department
S. D. = Signal department
W. S. = Water supply department

When such prefixes are used, the filing information is necessarily placed last. Drawing No. S. D.–1000–D–2 would be a drawing prepared by the Signal department, filed in cabinet D, drawer or compartment 2.

On another railroad, where all drawings are under the jurisdiction of the chief engineer, prefix letters are used to indicate the general class of the drawing, for example:

A = Architectural drawing
B = Bridge drawings
C = Coaling plant drawings
D = Dams
S = Signal drawings

Here again the filing information appears at the end of the main number.

Another method used to indicate the general class is to allot a series of numbers to each. In one office, drawing numbers 0 to 9,999 are assigned to buildings, 10,000 to 19,999 are for bridge drawings, etc.

There is, however, one class of drawing for which all railroads use the same numbering system, namely, for the identification of right-of-way and track maps (valuation maps) as prescribed by the ICC in accordance with Section 19A of the Act to Regulate Commerce—second issue, effective January 1, 1933. The ICC instructions are included in the "Specifications for Preparation of Maps and Profiles", appearing as Article 207 on page 11–66 of the Manual.

Indexing

Filing always involves indexing and indexing means first of all, to catalog the drawings on index cards or in ledgers, in such a manner that they can be quickly found. This is usually accomplished by first listing the drawing on a "master" numerical index and then on other cards grouped according to location or by subject matter, recording the drawing number, title and other pertinent data, and making cross references where necessary. The master or numerical index is used principally for keeping track of the last number assigned. It is also indispensable for locating plans which have been referred to by number only.

The location and general subject indexes supplement the master numerical index. They are the ones most used for looking up drawings.

Building and track layout drawings are usually grouped and catalogued according to city or village location with the index cards arranged alphabetically. Bridge drawings, because of their "in between town" locations are indexed according to mile post location and district, subdivision or valuation section, with cards arranged serially or geographically. Profiles and track charts are also catalogued in this manner.

Standard drawings, which illustrate items of equipment and recommended construction methods, are best indexed by subject matter. Standard drawings as a rule require more cross references than the others.

One railroad uses a colored card system for grouping.

White cards are for station, track and right-of-way maps
Blue for contract plans
Green for lease plans
Yellow for deed plans
Buff for profiles

The ICC specifications for the preparation of right-of-way and track maps do not require that they be catalogued in any special manner; however, most railroads have found it expedient to make a geographical and alphabetical cross index for them. This is usually in ledger or bound book form. With such an index and knowing either the mile post, valuation section, or town location, it is an easy matter to find the proper drawing.

It is important that sufficient data be posted on the index cards to thoroughly identify the drawing and to make it unnecessary to pull out three or four from the files before finding the right one. Sometimes the descriptive matter is so vague as to cause inefficient office routine. The essential information required by all systems is:

1. Drawing number and filing reference
2. Title (Additional qualifying or descriptive information here will assist in recognizing the plan wanted.)
3. Scale, if any
4. Date
5. Type of drawing (cloth tracing, paper tracing, blueprint, etc.)

Supplementing the above information, some offices note additional data, such as:

6. Reasons for preparation, or purpose, such as:
   a. Proposed
   b. As built
   c. Retirement
7. Revision dates
8. Maker of plan
9. Office where made

Filing Equipment

Filing equipment is generally described in terms of the kind of storage that is provided, or as vertical, horizontal and roll.

The vertical type cabinet can be used for the storage of both large and small drawings. The drawings are grouped according to size and placed in folders of appropriate dimensions. The smaller folders are held upright in slot-partitioned drawers and the larger ones hung in box-like cases. Total storage capacity is quite large, with each folder holding about fifty tracings. This system is particularly convenient when it is desired to group together complete sets of plans for a large construction job. Right-of-way and track maps (valuation maps) are usually stored in this manner.

Horizontal drawer cabinets are more commonly used than any other type of filing equipment. The flat drawers, partitioned to suit different size drawings, are well suited for the filing of active, semi-active or inactive drawings. New sectional units can be added when necessary to increase storage capacity. The shallow drawers permit quick handling with but little wear and tear on the tracings.

In the Proceedings for 1938, Vol. 39, pages 659 and 660, is shown a partitioning arrangement of flat, horizontal drawers to suit different sizes of drawings. The partitions are made with thin wood strips fastened to the bottom and sides of the drawers. In practice, it has been found advisable to partition off only three or four drawers at a time. Then, as existing compartments become filled, new partitions can be installed to suit the sizes required.

While roll filing is especially adapted to long or odd sized drawings, this method can be used for all sizes and is done in drawer style cabinets as well as pigeonhole cabinets or shelves.

Some offices use only one type of filing equipment; others combine the use of the three. Approximately 50 percent of the railroads own vertical units. All of them own and use some kind of horizontal and roll filing equipment.

It is found impractical to classify filing cabinets according to sizes as each drafting organization has to provide for its own individual requirements.

Filing calls for other specialized equipment such as index card files, guides, etc. Filing equipment of all kinds is now obtainable in stock sizes that will suit almost any requirements. Units are now advertised that combine all three methods of filing in addition to having special box compartments for card indexes and shelves for the storage of field notebooks.

Conclusions

It cannot be said that one method is always better than another because that which is best suited to the individual needs of one office might not be so well adapted to another. Each system has its special features and advantages.

The portion of the report presented above is offered as information.

Supplemental Subjects

In addition to the assigned work, your committee has reviewed two subjects reported on previously, for possible Manual inclusions.

Welding Symbols

At the present time there are no welding symbols in the Manual.

The American Welding Society has recently developed a new code of welding symbols which is now being considered for adoption as an American standard. Recognizing the authority of the American Welding Society, it is believed desirable to have its symbols available for drafting room use. However, until such time as they have been adopted by the American Standards Association, these symbols will be subject to revisions. To avoid having material in the Manual which might soon be out of date, it is proposed to include only a reference. Your committee recommends that the following information be published in the Manual on page 11–98:

WELDING SYMBOLS

It is recommended that the symbols of the American Welding Society be used. These symbols together with instructions for their use are published in bulletin form and may be obtained from the American Welding Society.

Style To Be Used in the Preparation of Reports and Specifications

In the Proceedings for 1938, Vol. 39, there is a report entitled "Style To Be Used in the Preparation of Reports and Specifications". This report was originally presented as information but with the understanding that it would be reviewed and considered for inclusion in the Manual.

Your committee recommends that the material shown in Proceedings for 1938, Vol. 39, pages 661 to 669, inclusive, be published in the Manual as pages 11–121 to 11–129, inclusive.

Report on Assignment 4

Recommended Practice To Be Followed with Respect to Maintenance of Way Accounts and Statistical Requirements

H. L. Restall (chairman, subcommittee), Anton Anderson, E. V. Braden, W. F. Cummings, C. D. Johnson, W. M. Ludolph, W. S. McFetridge, A. T. Powell, D. C. Teal.

The committee has had under study this year a system of recording the physical characteristics and location of certain types of electrical equipment, and now has under consideration the enlarging of the assignment to embrace other kinds of physical property to be covered by a uniform system of recording.

Report on Assignment 6 (a)

Resumé of Developments of the Current Year in Connection With Regulatory Bodies and the Courts

S. H. Barnhart (chairman, subcommittee), F. B. Baldwin, H. D. Barnes, B. A. Bertenshaw, W. C. Bolin, V. H. Doyle, D. E. Field, C. C. Haire, H. N. Halper; R. J. Herring, A. T. Hopkins, W. R. Kettenring, E. M. Killough, C. A. Knowles, P. R. Leete, D. O. Lyle, W. S. MacCulloch, W. S. McFetridge, H. L. Restall, H. J. Stroebel, V. P. Turnburke, H. C. Wertenberger, Louis Wolf.

The Transportation Act of 1940, approved September 18, 1940, which amended in many particulars the existing Interstate Commerce Act, carried forward without change the entire Valuation Act. The ICC appropriation for the fiscal year beginning July 1, 1940, includes $640,000 for its Bureau of Valuation, the same amount as for the previous two years. On October 1, 1940, the total force of the bureau numbered 188 employees.

By its order of January 1, 1940, the ICC increased from $100 to $500 the minimum amount to be charged to the Investment in Road and Equipment Account for property changes, which will result in reducing the number of minor items which must be handled in valuation reporting where carriers exercise the option permitted under the order.

During the year 1939 Class I carriers charged to Account 459, Valuation Expenses, an amount of $425,589, contrasted with $623,463 for the year 1938.

Carriers have been engaged in filing with the Bureau of Valuation reports required by Valuation Order No. 3, consisting of returns on B. V. Form 588, which contain the details of property changes necessary to bringing previous engineering inventories forward to new valuation dates. These returns are likewise utilized by the Land and Accounting Sections to revise their land reports and estimates of original cost, respectively. As of October 1, 1940, all Class I carriers had filed these returns through the year 1935; 98 percent, through 1936; 87 percent, through the year 1937; 69 percent, through the year 1938; and 26 percent, through the year 1939, or were approximately 93 percent* current. In order to have the information necessary to bring their underlying valuation figures to current dates, the director of valuation requested Class I carriers to file returns on B. V. Form 589, Summary of Annual Charges and Credits to Investment in Road and Equipment Account, for those years where report on Form B. V. 588 was not rendered.

The Engineering Section of the Bureau of Valuation, having completed revised inventories for all Class I carriers through 1927, is engaged in bringing these inventories forward to later dates and as of October 1 had completed 64 percent of the mileage through 1932; 41 percent through 1934; 13 percent through 1936; and 2 percent through 1938, or approximately 59 percent* current. The work of the Accounting Section in preparing summaries of original costs and that of the Land Section in revising land valuations have advanced to about 56 percent* and 58 percent*, respectively.

No tentative valuations as of current dates were completed and served on railroad companies, but at the request of the commission, the bureau brought to date the underlying valuation estimates of carriers involved in reorganization proceedings. In some instances, reports were prepared showing a property breakdown by mortgage districts. In a number of cases, carriers checked these estimates of original cost, cost of reproduction new, less depreciation, and land values.

At the direction of the commission, the bureau also spent considerable time in working up estimates for use in a number of rate cases involving switching rates and also in the Barge Line case involving line haul rates, likewise in a number of cases involving competitive truck and rail rates. Estimates were also prepared for a number of individual roads relating to the amount of deferred maintenance, if any, for use in pending cases.

During the year the Bureau of Valuation completed and issued its final valuations on pipe line carriers inventoried as of December 31, 1934, which was the original valuation date. A summary showing the more important findings in these valuations, has been prepared by the bureau. Copies of the summary may be procured from Mr. E. H. Bunnell, vice-president, Finance, Accounting, Taxation and Valuation Department, AAR, Washington, D. C. The bureau also started the initial work of inventorying the property of those pipe line companies added to its program since 1934 and served a few tentative valuations, and issued some final reports, prepared as of varying dates from 1937 through 1939.

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* Based on 5,750,000 mile-years from basic valuation through 1939.

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"Exhibit 1"

RECORD OF BALLAST CHANGES

(Name of Road)

Line No.	LOCATION		AFE	Date				Total Cu. Yds.	CUBIC YARDS								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)

SPECIFICATIONS FOR FORM—

Form as shown 11 inches by 17 inches. All lines and printing black. Form may be printed as perforated sheet for binding or as record card.

INSTRUCTIONS FOR USE OF FORM—

This form may be used for recording ballast changes or as a continuing record of ballast inventory.

The spaces in the top of the form (above the column ruling) may be used for recording the key information, or index general location or other designations as to the unit or units reported on the sheet

Recording Separately Each Mile of a Group of Miles on One Sheet of Form.

Use columns 2 and 3 for location and description of project.

Columns 4 and 5 are for recording AFE number and date.

Columns 6, 7 and 8 may be used for such data as kind of ballast source of ballast, average haul, etc

Show in the upper caption space of column 9 (reading downward), Mile, Length feet; From station; Plus feet, To station; Plus feet. The corresponding upper caption spaces of columns 10 to 18, inclusive, are for recording for each mile the Mile number; Length, Station; Plus; Station, and Plus.

Line 1 should be used to designate (in any selected descriptive column) and to record in each of the columns 10 to 18, inclusive, the cubic yards of ballast for each mile (length in feet) recorded on the sheet, computed in accordance with adopted standard. Column 9 should record the total yardage shown in columns 10 to 18 inclusive.

Show on line 2 (or as many of following lines as may be required) and in appropriate columns the "Basic Inventory" of ballast.

Enter in successive order on line 3 (or line next following "Basic Inventory") and following lines changes as they occur.

Additions and retirement quantities may be entered in same column by indicating retirements in red.

Totals may be made of ballast in track at any desired date.

An appropriate continuation sheet may be used.

The same usage as outlined may be made of the form when used as a continuing record of ballast inventory or when used for recording ballast changes only except that when used for recording ballast changes only the "Basic Inventory" of ballast and the quantities computed in accordance with the adopted standard section may not be needed.

Recording as a Whole a Substantial Stretch of Track on One Sheet of Form

Use columns 2 and 3 for designating changed portion.

Columns 4 and 5 are for recording AFE number and date.

Columns 6, 7 and 8 may be used for such data as description of project, source of ballast, average haul of ballast, etc

Show the kinds of ballast in the upper caption spaces of columns 10 to 18, inclusive. Column 9 should record the total yardage shown in columns 10 to 18, inclusive.

Line 1 should be used to designate (in any selected descriptive column) and to record in column 9 the total cubic yards of ballast in the stretch of track recorded on a sheet computed in accordance with adopted standard section.

Show on line 2 and in appropriate columns the "Basic Inventory" of ballast

Enter in successive order on line 3 and following lines, changes as they occur.

Additions and retirement quantities may be entered in same column by indicating retirements in red.

Totals may be made of ballast in track at any desired date.

The same usage as outlined may be made of the form when used as a continuing record of ballast inventory or when used for recording ballast changes only except that when used for recording ballast changes only the "Basic Inventory" of ballast and the quantities computed in accordance with the adopted standard section may not be needed.

Various joint cost data committees composed of the commission's valuation engineers and railroad representatives continued their study of the more important items entering into railroad construction in an endeavor to keep informed as to the current trends, and their reports and conclusions were circularized among the carriers. The Joint Equipment committee completed and issued its report entitled, "Costs of Railroad Equipment and Machinery," which contains the cost data summaries for all types of equipment for which cost data have been published and, likewise, all tables of average relationships of costs appearing in its previous reports, thereby giving complete coverage for the years 1920–1939. The 1939 edition of "Railroad Construction Indices" was prepared and released by the Bureau of Valuation. Copies of these reports may be obtained from Mr. E. H. Bunnell, vice-president, Finance, Accounting, Taxation and Valuation Department, AAR, Washington, D. C.

Court Decisions

There were no noteworthy decisions by the U. S. Supreme Court involving valuation issues since the last report was written.

A number of utility cases involving rates were litigated in state courts, but no new issues were presented. Many states are adopting the continuous inventory system, similar to that adopted by the ICC for railroads, which has proved effective in reducing the time and effort required in making revaluations of utility properties for regulatory purposes.

Report on Assignment 6 (b)

ICC Valuation Orders, Reports and Records

(Subcommittee personnel same as for Assignment 6 (a))

Further study has been made of the subject, Forms for a Record of Ballast Changes. With the aid of suggestions and forms submitted by members of the committee a general form has been developed. Modifications of this form are now in use and are satisfactory. This form, designated as Record of Ballast Changes, is submitted as Exhibit 1, and it is recommended that it be adopted as recommended practice and published in the Manual as Form No. 1114–A, page 11–23.1.

The committee has given continued study and consideration during the year to the subject, Study of Valuation Order No. 3 Reports and Records to Determine if Further Simplifications Are Possible. While several suggestions as to simplifications have been considered, there is nothing of major importance to be included in this report.

The subject, Form of Order No. 3 Reports in Connection with Joint Projects, Federal-Railroad has been given continued consideration, but due to difficulties with respect to the classification of such property, it has not been possible to develop a conclusion.

Report on Assignment 7

Report Upon Changes In, Revisions and Interpretations of, ICC Accounting Classifications

H. D. Barnes (chairman, subcommittee), F. B. Baldwin, S. H. Barnhart, W. C. Bolin, C. C. Haire, J. H. Hande, R. J. Herring, W. R. Kettenring, Henry Lehn, W. M. Ludolph, O. M. Miles, H. L. Restall, C. P. Richardson, V. P. Turnburke.

Your committee has continued the review of proposed accounting rulings or orders submitted by the ICC Bureau of Accounts in subject form as outlined in the Proceedings for 1939, Vol. 40, page 746. Summaries of the opinions of the members of the entire committee have been furnished by Mr. E. H. Bunnell, vice-president, AAR, for the following:

ICC Bureau of Accounts Subject No.	*Subject*
197 Revised	Proposed order modifying Investment in Road and Equipment Account 41, Cost of Road Purchased, cancellation of Account 42, Reconstruction of Road Purchased, and creation of new Account 42, Difference between the Investment and the Money Outlay for Construction and Improvement of Property Acquired. This proposal has since been revised and is now before this committee for further consideration.
220 Revised	Proposed order modifying the last two paragraphs of Section 2 of General Instructions in Classification of Investment in Road and Equipment defining "cost"; modifying text of Road and Equipment Account 2½ and Note A to Account 39 and addition of note to Account 754.
225 Revised	Proposed order amending paragraph 1 of General Instructions in Classification of Investment in Road and Equipment; modifying text of Account 701 and adding Note C thereunder.
241	Proposed order modifying the title and text of General Balance Sheet, Account 702, Improvements on Leased Railway Property.
243	Proposed "A" case prescribing the accounting for the cost of excavation through existing embankments to install bridges or culverts.
245	Proposed order cancelling fourth paragraph of Road and Equipment Account 76, Interest During Construction, change in Note B, and addition of new Note E thereunder, cancelling Case 177 of Accounting Bulletin No. 15.
257	Proposed order modifying paragraph (c) of Section 4 of General Instructions in Classification of Investment in Road and Equipment relating to "cost of work train service", by eliminating rent for carrier's own equipment used in construction service.
261	Proposed order modifying texts of Account 21, Grain Elevators, 22, Storage Warehouses of the Classification of Investment in Road and Equipment with appropriate changes in the Classification of Operating Revenues and Expenses and in the text of Account 705, Miscellaneous Physical Property.

In addition to the above mentioned subjects the following were in the hands of the committee for review at the time this report was prepared:

ICC Bureau of Accounts Subject No.	*Subject*
247 Revised	Proposed order modifying Sections 7 and 8 of the General Instructions in the Classification of Investment in Road and Equipment, to provide that all retirements of road property, except important sections of the main line, or a branch line, shall be charged to operating expenses.
253 Revised	Proposed order modifying the Classification of Investment in Road and Equipment, and Operating Revenues and Operating Expenses to provide that the total cost of all additions and betterments to existing tracks, except the installation of ballast in tracks not previously ballasted, shall be charged to operating expenses.
258	Proposed order modifying the Classification of Investment in Road and Equipment, and Operating Revenues and Operating Expenses to substitute the "Group Method" for the "Unit Method" of depreciation accounting as an optional provision.
263	Proposed order modifying the instructions under General Account II, Equipment in the Classification of Investment in Road and Equipment to define "rebuilt equipment".

Since this committee's last report (Proceedings for 1940, Vol. 41, pages 472 to 474), ICC has issued the following orders modifying the accounting classifications:

Order dated December 6, 1939, concelling Account 25, Gas Producing Plants, 245, Gas Producing Plants and 246 Gas Producing Plants—Depreciation; making numerous changes in certain Income and General Balance Sheet Accounts; and modifying Cases 196 and 221 of Accounting Bulletin No. 15.

Order dated January 17, 1940, modifying the text of Account 101, Freight of the Classification of Operating Revenues and Operating Expenses by the addition of Note G prescribing sub-accounts for payments for pick up and delivery services and switching services when performed in connection with line haul transportation of freight.

Order dated January 17, 1940, modifying the answer to Section (b) of the answer to Case 186, Accounting Bulletin No. 15 to read, "To Account 2, Land for Transportation Purposes".

Order dated January 31, 1940, effective January 1, 1940 revising the minimum rule in the Classification of Investment in Road and Equipment from $100 to $500. A carrier may adopt a minimum less than $500 if it first files with the commission the amount which it proposes to adopt.

Order dated March 12, 1940, modifying the text of Income Accounts 503 and 536.

Order dated September 30, 1940, effective January 1, 1941, modifying the title and text of Account 702, Improvements on Leased Railway Property; modification of item included in Account 3, Grading, the text of Account 102, Passenger, the title and text of Account 103, Excess Baggage, the text of Account 108, Other Passenger-Train, the text of Account 775, Accrued Depreciation-Road; cancellation of Accounts 713, Traffic and Car-service Balances Receivable; 759, Traffic and Car-service Balances Payable, and 771, Tax Liability; and the addition of new Accounts 713, Traffic and Car-service Balances-Dr., 759, Traffic and Car-service Balances-Cr., and 767, Accrued Tax Liability. The numbers of Accounts 766 and 767 are changed to 764 and 766, respectively; Cases 144 and 246 of Accounting Bulletin No. 15 are cancelled and the answer to Case 80, same document, is modified; and Section 23 of Special Instructions for Operating Expenses is cancelled.

Order dated October 17, 1940, effective January 1, 1941, amending Section 1 of General Instructions in Classification of Investment in Road and Equipment and modifying text of Account 701, Investment in Road and Equipment, and adding Note C thereto; cancellation of Accounts 709 and 710 and modification of Accounts 708, 712 and new Account 709, Temporary Cash Investments prescribed.

In addition to these orders the Bureau of Accounts has released the following new and revised accounting rulings:

Issued January 1, 1940

Case A-4—Revised. Accounting for amounts received from pipe line companies and others for rights to construct and maintain pipe lines on a carrier's right-of-way.

Case A-6—Revised. Accounting for exchange of land both when there is and when there is not a cash transaction.

Case A-16—Revised. Accounting for a carrier's liability for an award under the Workmen's Compensation Act.

Case A-34—Revised. Accounting for taxes on jointly used and jointly owned property.

Case A-75—Revised. Accounting for loss due to depreciation of rail and other track material returned to stock after having been leased.

Case A-132—Revised. Accounting for income taxes on interest on tax free bonds assumed by the accounting company and income taxes withheld in payment of interest to non-resident aliens.

Case A-153. Accounting for payroll taxes assessed under the provisions of the Social Security Act (or Railroad Unemployment Insurance Act) and the Carrier's Taxing Act of 1937 based on the payroll of a carrier's employees and added to the cost of labor performed for others in connection with joint facility arrangement and otherwise.

Issued March 1, 1940

Case A-154. Accounting for additional fill and new ballast applied in raising the grade of track and for existing ballast material retained in the embankment.

Case A-155. Accounting for compensation received by a carrier for performance of services in connection with the administration of the Railroad Unemployment Insurance Act.

Case A-156. Accounting for purchase of equipment under conditional sale contract which provides for the transfer of title upon performance of all obligations thereunder.

Case A-157. Accounting for the cost of excavation through existing embankments to install bridges or culverts.

Issued May 1, 1940

Case A–95. Cancelled. This case was in connection with the accounting for the maturity of receiver's certificates.

Case A–158. Interpretation of Section 7 of Special Instructions to Balance Sheet Accounts.

Issued July 1, 1940

Case A–29. Cancelled. This case covered the accounting for funds deposited with insurance companies to insure performance of contracts.

Case A–128. Cancelled. This case pertained to the accounting for services performed by one carrier for another in lieu of the continuation of operation of trackage rights by the latter.

Case A–159. Accounting for the sale of second hand passenger coaches requiring repairs to place them in serviceable condition.

The Bureau of Accounts by Accounting Series Circular dated March 20, 1940, requires all steam carriers to inventory their materials and supplies for the year 1940 and annually thereafter unless otherwise directed.

The effective date of the proposed order of the ICC covering the accounting for ballast (ICC Bureau of Accounts Subject No. 232) has been withheld and the vice-president of the Finance, Accounting, Taxation and Valuation Department of the AAR is handling the negotiations between individual carriers and the ICC Bureau of Valuation.

During the year the F.A.T.&V. Department of the AAR has prepared in convenient loose leaf form a reprint of Accounting Bulletin No. 15 corrected to date, together with the "A" cases and appropriate indices.

This report is submitted as information with the recommendation that the subject be continued.

Report on Assignment 8

Methods of Avoiding Duplication of Reports and for Simplifying and Coordinating Work Under the Requirements of the ICC and Other Public Authorities

F. B. Baldwin (chairman, subcommittee), H. D. Barnes, S. H. Barnhart, H. N. Halper, C. A. Knowles, P. R. Leete, D. O. Lyle, W. S. MacCulloch, Louis Wolf.

During the year your committee has maintained contact with those departments or committees of the AAR and other railroad committees charged with the responsibility of dealing with those bureaus and departments of the government requiring reports from railroads. These committees have presented the railroad viewpoint in contemplated changes or expansion of requirements and have endeavored to keep the requirements within reasonable limits, and where possible have secured some simplification or elimination of those that are onerous.

On the other hand, the information required by the Railroad Retirement and Unemployment Insurance acts has added to the number of reports demanded of railroads; also the activities of the Bureau of Statistics on the subject of cost finding have added to the work of the railroads in supplying data.

In at least two states, the requirements of the state commissions are being met in part by furnishing copies of reports to the ICC required under Valuation Order No. 3, in lieu of separate reports prepared on forms prescribed by the state commission.

The Corporation Commission of Oklahoma, for many years, has required a quarterly filing of copies of roadway completion reports with sketches or prints showing work completed; also, an accounting statement, by primary accounts, of the net expenditures for the state as a whole. For the past several years the commission has been accepting a blue print copy of the report on B. V. Form No. 588–R for the state as filed with the ICC, in lieu of the completion reports and summaries thereof. The saving of the expense of preparing and filing copies of large numbers of completion reports is substantial.

The Minnesota Railroad and Warehouse Commission in 1939, agreed to accept a copy of the carriers' reports to the ICC showing equipment changes on B. V. Form No. 588–R and Subschedule "B", amended to give the total salvage recovered from equipment retired, by primary accounts, in lieu of a detailed annual report of the additions and retirements of the units of equipment on special forms furnished by the state commission for that purpose. The substitution of the report required by the ICC under Valuation Order No. 3 for the special state report and the records necessary for its preparation has resulted in a substantial saving to the carriers.

As a matter of information the text of the ICC order dated November 15, 1940, relative to its organization schedule and assignment of work and functions under amended Section 17 of the Interstate Commerce Act is presented as Exhibit 2.

This report is submitted as information.

Exhibit 2

Order

At a General Session of the Interstate Commerce Commission, held at its office in Washington, D. C., on November 15, 1940

Section 17 of the Interstate Commerce Act, as amended (U.S.C. title 49, sec. 17), and other provisions of law being under consideration, the following order was duly adopted:

ORDERED: Effective December 2, 1940, except as may be otherwise provided herein, the following organization schedule and assignment of work and functions shall be in force:

DIVISIONS OF THE COMMISSION

That there continue to be, as at present, five divisions of the commission, known, respectively, as divisions 1, 2, 3, 4 and 5, consisting of three members each.

As provided by section 17 of the Interstate Commerce Act, as amended, each division shall have authority to hear and determine, order, certify, report or otherwise act as to any work, business, or functions assigned or referred to it under the provisions of that section, and with respect thereto shall have all the jurisdiction and powers conferred by law upon the commission, and be subject to the same duties and obligations.

Each division with regard to any case or matter assigned to it, or any question brought to it under this delegation of duty and authority, may call upon the whole commission for advice and counsel, or for consideration of any case or question by an additional commissioner or commissioners assigned thereto; and the commission may recall and bring before it as such any case, matter or question so allotted or assigned and may either dispose of such case, matter, or question itself, or may assign or refer the matter to the same or another division.

Each division may determine the time and place for its conferences and determine its order of business.

Assignment of Duties to Divisions

That work, business, and functions of the commission be assigned and referred to the respective divisions for action thereon, as follows:

Division 1

General conduct of administrative matters not otherwise assigned or reserved, including among other things, work formerly assigned to the following committees but reassigned to Division 1 by the order of May 8, 1939: Salaries and Personnel, Finance, Cooperation with State Commissions, Organization, Building and Assignment of Space, Admissions to Practice, Reporting, and Annual Report.

Section 20 (1) to (10), inclusive, relating to the reports, records, and accounts of carriers, lessors, and other persons under Part I.

Section 204 (a) (1), (2), and (4); section 220; and section 222 (b), (d), and (g), so far as those sections relate to reports, records, and accounts of carriers, brokers, and other persons under Part II.

Section 313, relating to accounts, records, and reports of carriers and lessors under Part III.

Sections 1 (21), 5 (3), 6 (10) 10, 15 (11) and (12), 16 (8) to (12), inclusive; 20a (11) and (12), 25 (h), of Part I; section 222 of Part II; sections 316 (b) and 317 of Part III, and the Elkins Act, as amended, so far as relating to discovery and enforcement of penalties for violations of provisions of law.

Section 13 (3) of Part I, so far as relating to the institution of investigations specified in that paragraph, on the petition of the carrier or carriers concerned.

Section 304 (c), relating to classifications of groups of water carriers subject to Part III and rules, regulations, and requirements relating thereto.

Section 204 (c) and section 304 (e), so far as relating to the investigation of complaints of alleged non-compliance with provisions of Parts II and III hereinbefore assigned to Division 1 or requirements established pursuant thereto.

Matters coming from the Bureau of Personnel Supervision and Management under Executive Order No. 7916, of June 24, 1938, and amendatory and supplementary Executive Orders and matters assigned to Division 1 by the order of the Commission of July 24, 1939, amending an order of October 12, 1935.

Matters coming from the Bureau of Inquiry under Parts I and III, the Elkins Act, and acts supplemental thereto, and the Clayton Antitrust Act, as amended, and from the Section of Law and Enforcement of the Bureau of Motor Carriers, so far as relating to the discovery of derelictions and enforcement of penal provisions of Part II.

Admission, disbarment, and suspension of practitioners before the commission, under Rule I–B of the Rules of Practice.

Division 2

Section 4, relating to long-and-short-haul and aggregate-of-intermediate rates, and relief therefrom.

Section 6, except paragraphs (11) and (12), relating to schedules of carriers under Part I, sections 217 and 218, relating to tariffs of common carriers and schedules of contract carriers under Part II, and section 306, relating to tariffs of common carriers and schedules of contract carriers under Part III, including, among other matters, applications thereunder, forms and specifications, and questions turning upon the construction or application thereof.

Section 15 (7) of Part I, sections 216 (g) and 218 (c) of Part II, and section 307 (g) and (i) of Part III, relating to the disposition of applications for suspension of schedules or parts thereof, including authority to institute investigations into rates, fares, practices, and charges of carriers under Parts I, II, and III, as ancillary to a proceeding of investigation and suspension.

Sections 6 (11) (b) and 6 (12) of the Interstate Commerce Act and section 11 (d) of the Panama Canal Act, U. S. Code, t. 49, sec. 51, relating to the establishment, under the additional authority conferred upon the commission by the Panama Canal Act of proportional rates to or from ports, and through rail and water arrangements in foreign commerce.

Section 19a, relating to the valuation of the property of carriers.

Section 20 (11) of Part I and section 219 of Part II, so far as relating to the authorization of released rates and ratings.

Sections 3(2), 223, and 318, so far as relating to the prescription of rules governing the delivery of freight and the settlement of rates and charges, and to prevent unjust discrimination, under Parts I, II, and III.

Section 22 so far as relating to reduced rates in case of calamitous visitation or disaster.

Section 304 (d) of Part III, relating to relief from the provisions of that part because of competition from carriers engaged in foreign commerce.

Section 204 (c) and section 304 (e), so far as relating to the investigation of complaints of alleged non-compliance with provisions of Parts II and III hereinbefore assigned to Division 2 or requirements established pursuant thereto.

Standard Time Act of March 19, 1918, as amended, U. S. Code, t. 15, secs. 261–265, inclusive.

Matters coming from the Board of Reference, relating to instructions concerning the informal consideration of unusual matters and cases for which there is no governing precedent.

Matters coming from the Bureau of Informal Cases.

Division 3

Civil Aeronautics Act of 1938, approved June 23, 1938, U. S. Code, t. 49, sec. 643, so far as relates to action as members of a joint board, as may be directed by the chairman of the commission.

Section 1 (9) to (17), inclusive, relating to switch connections, car-service and emergency directions with respect thereto, and contracts of common carriers by railroad or express companies for the furnishing of protective service against heat or cold.

Section 5 (1), relating to the pooling of traffic, service, or gross or net earnings of common carriers subject to the act.

Section 3 (5), relating to requirement of common use of terminals and compensation therefor.

Section 6 (11) (a) of the Interstate Commerce Act, and section 11 (d) of the Panama Canal Act, relating to the additional jurisdiction over rail and water traffic conferred upon the commission by the Panama Canal Act, U. S. Code, t. 49, sec. 51, with respect to physical connections between rail lines and docks;—and section 201 (c), Transportation Act, 1920, as amended, U. S. Code, t. 49, sec. 141 (c).

Section 15 (10), relating to the direction of the routing of unrouted traffic.

Sections 15 (13), 225, and 314, relating to fixation of reasonable allowances to the owner of property transported for transportation services rendered, and Ex Parte No. 11, The Tap Line Case.

Section 25 (a) to (g), inclusive, as amended, relating to the installment and maintenance of safety devices by carriers by railroad, other than enforcement of penalties.

Section 1 (21) (other than enforcement of penalties), so far as relating to the compulsory construction of new roads or procurements of additional facilities.

Section 204 (a) (1), (2), (3), and (5) of Part II so far as relating to the establishment of reasonable requirements for the safe transportation of explosives and other dangerous articles, including inflammable liquids, inflammable solids, oxidizing materials, corrosive liquids, compressed gases, and poisonous substances.

Section 204 (c) so far as relating to the investigation of complaints of alleged non-compliance with provisions of Part II hereinbefore assigned to Division 3 or requirements established pursuant thereto.

Matters arising under the Transportation of Explosives and Dangerous Articles Act, Accident Reports Act, Safety Appliance Act, Hours of Service Act, Locomotive Inspection Act, Medals of Honor Act, Ash Pan Act, Railroad Retirement Act of 1937, Carriers Taxing Act of 1937, Railroad Unemployment Insurance Act, the Railway Labor Act, as respectively amended; the Block Signal Resolution of June 30, 1906, and Sundry Civil Appropriation Act of May 27, 1908; Postal Service Acts, U. S. Code, t. 39, c. 6, 12, 13, 14 and 15, so far as those acts relate to duties of the Commission.

Divisions 2 and 3 alternately, in monthly rotation:

All cases not otherwise herein assigned or referred to another division or reserved to the commission, arising under Part I, and all cases involving rates, fares, or charges arising under Parts II and III, which cases (a) have involved the taking of testimony at public hearings, and are set to be argued orally before one of such divisions, or (b) are submitted without oral argument, but which have involved the taking of testimony at public hearings.

Division 4

Section 1 (18) to (20), inclusive, and sections 303 (1), 309, 310, 311, and 312, relating to certificates of convenience and necessity under Parts I and III and permits under Part III.

Section 5 (2) to (13), inclusive, (other than enforcement of penalties), and 210a (b) of Part II, relating to the consolidation, merger, purchase, lease, operating contracts, and acquisition of control of carriers, and to non-carrier control.

Section 5 (14) to (16), inclusive, relating to common control of railroads and common carriers by water.

Section 302 (e) and section 303 (b), (c), (d), (e), (f), (g), and (h), relating to exemptions of water carriers from the provisions of Part III. Sections 20a and 214 (other than the enforcement of penalties), relating to the issuance and approval of securities of carriers under Parts I and II, and to the holding of inter-locking positions as director or officer.

Section 204 (c) and section 304 (e), so far as relating to the investigation of complaints of alleged non-compliance with provisions of Parts II and III hereinbefore assigned to Division 4 or requirements established pursuant thereto.

The Uniform Bankruptcy Act, as amended, U. S. Code, t. 11, relating to the reorganization of corporations subject to the exercise of the regulatory powers of the commission.

Matters arising under the Reconstruction Finance Corporation Act, as amended, and under Section 20 of Title II of the Emergency Relief and Construction Act of 1932, as amended.

Matters arising under the Clayton Antitrust Act, as amended (other than enforcement of penalties).

Matters arising under Section 22 (b) (9) of the Internal Revenue Code (relating to exclusions from gross income) as amended by the Act approved June 29, 1939, 53 stat. c. 247, Sec. 215 (a) p. 875.

Division 5

Section 203 (b), relating to partial exemption from the provisions of Part II, including determinations as to the necessity for application of Part II to transportation within a municipality, between contiguous municipalities, or within an adjacent zone, and the determination of the limits of such zones, referred to in section 203 (b) (8) and to casual transportation operations by motor vehicle, referred to in section 203 (b) (9).

Section 204 (a) (1) to (3), so far as relates to reasonable requirements with respect to continuous and adequate service and transportation of baggage and express by common carriers, and to qualifications and maximum hours of service of employees and safety of operation and equipment for common, contract, and private carriers, but not including requirements for the safe transportation of explosives and other dangerous articles.

Section 204 (a) (4) and section 211 (a) to (c), relating to the regulation of brokers (other than their accounts, records, and reports).

Section 204 (4a), relating to certificates of exemption to motor carriers operating solely within a single State.

Section 204 (7), so far as relates to inquiries into the management of the business of motor carriers and brokers and persons controlling, controlled by, or under common control with motor carriers and requests for information deemed necessary to carry out the provisions of Part II.

Section 204 (b), relating to the establishment of classifications of brokers or of groups of carriers and just and reasonable rules, regulations and requirements therefor.

Section 204 (c), so far as relating to investigation of complaints of alleged non-compliance with the provisions of Part II assigned to Division 5 or requirements established pursuant thereto.

Sections 206, 207, and 208, relating to certificates of public convenience and necessity.

Section 209, relating to permits.

Section 210, relating to dual operations.

Section 210a (a), relating to grants of temporary operating authority.

Section 212, relating to suspension, change, revocation, and transfer of certificates, permits, and licenses.

Section 215, relating to security for the protection of the public.

Section 224, relating to identification of motor carriers.

Section 226, relating to investigation of motor vehicle sizes, weights, etc.

Any other matters arising under Part II not hereinbefore specially assigned or referred to other divisions.

In connection with the foregoing assignments Division 5 is authorized to institute, conduct and determine investigations into motor-carrier practices pertaining to matters covered by such assignments.

From such assignment of work there shall be reserved for consideration and disposition by the commission (1) all investigations on the commission's own motion heretofore entered upon and hereafter instituted, except as hereinbefore otherwise provided, and (2) all applications for rehearing, reargument or other reconsideration and all cases before the commission for reconsideration, except as hereinafter otherwise provided; and there shall also be excepted from this assignment of work all cases submitted prior to November 1, 1940, either to the commission or to a division thereof, or submitted to the commission and specially referred to a division, the various cases enumerated in any previous order of the commission as reserved for consideration and disposition by the commission, and all cases otherwise specially assigned.

Unless otherwise ordered by the commission, any commissioner who is transferred from a division shall continue as a member of such division for the disposition of cases orally argued and submitted prior thereto, and those in which drafts of final reports are under consideration, in lieu of the commissioner designated to serve as a regular member of the division.

Assignment of Duties to Individual Commissioners

That the following portions of the work, business, and functions of the commission, be assigned and referred to individual commissioners as herein designated.

To the Individual Members of Divisions 2 and 3

In rotation, in each month, to the members of the particular division which, according to the assignment heretofore made, is designated to receive submissions of rate, etc., cases in that month: (a) shortened procedure cases under Rule of Practice X–A, submitted without oral argument during the month; and (b) shortened procedure cases assigned for oral argument during the month.

To Individual Members of the Commission

The commissioner to whom the Bureau of Traffic reports: (a) special permissions or other permissible waivers of rules regarding schedules of rates, etc., under sections 6, 217, 218, and 306; (b) released rates applications under section 20 (11); (c) Ex Parte No. 13, with respect to modifications under section 6 (3) of posting requirements of section 6 (1); and (d) reduced rates authorizations in cases of calamitous visitation under section 22.

The commissioner to whom the Bureau of Accounts reports: distribution of carrier accounts and spreading of items over periods of time; and prescription of depreciation rates and modification thereof as to individual carriers under sections 20 (4), 220 (c), and 313 (d).

The commissioner to whom the Bureau of Service reports: uncontested matters relating to the transportation of explosives and other dangerous articles.

The commissioner to whom the Bureau of Locomotive Inspection reports: uncontested matters arising under the Boiler Inspection Act, as amended.

The commissioner to whom the Bureau of Safety reports: uncontested matters under section 25, the Safety Appliance Acts, as amended, and the Hours of Service Act, as amended.

The commissioner to whom the Bureau of Finance reports: applications under section 20a (12) for authority to hold the position of officer or director of more than one corporation, when all the corporations are part of the same system.

The commissioner to whom the Bureau of Statistics reports: requests of carriers for extension of time for filing annual reports.

The commissioner to whom the Bureau of Informal Cases reports: applications and complaints on the special docket.

The commissioner to whom the Bureau of Inquiry reports: the reference of cases involving supposed violations of law under Parts I, II and III of the Interstate Commerce Act, the Elkins Act, or related acts, to the Department of Justice for investigation and possible prosecution.

The chairman of the respective divisions: merely procedural matters in any formal case or pending matter, and extensions of time for compliance with orders (except in investigations on the commission's own motion), in any such case or matter, when the subject matter or particular proceeding has been or is assigned or referred to the divisions; *Provided,* that if the proceeding has been assigned to a commissioner for administrative handling or preparation of report, such commissioner shall act on such procedural matters (including extensions of time for compliance with orders); and if the subject matter or particular proceeding has not been assigned or referred to a division or to a commissioner, the chairman of Division 1 may act on such matters.

In each of the foregoing delegations and assignments to an individual commissioner, it is contemplated that in event of his absence or disability the senior member of the division which has jurisdiction of the subject matter or proceeding who is present shall act instead of the commissioner above designated. In event of the absence or disability of a commissioner to whom a proceeding not referred to a division has been assigned for administrative handling or preparation of report, procedural matters in connection with such proceeding may be acted upon by the chairman of the commission.

In respect of all such matters, petitions for reconsideration or for rehearing of any order or decision of an individual commissioner as herein authorized shall be initially passed upon by the division to which the general subject is referred, and if the general subject has not been referred to a division, then by the commission.

All such petitions shall be governed by the general rules of practice of the commission.

Bureaus of the Commission

That the bureaus of the commission shall report as follows: (a) with respect to administrative matters, including personnel and salaries matters, to Division 1, through the commissioner to whom the bureau reports; (b) with respect to matters of policy and functioning, through the division or commissioner to whom the bureau reports, to the division or to the commission, as set forth below:

Bureaus of the Commission	*Reports Through*	*To*
Accounts	Commissioner in charge	Division 1
Administration	Chairman, ex officio	Division 1
Finance	Commissioner in charge	Division 4
Formal Cases: generally	Commissioner in charge	Commission
matters pending before divisions	Chairman of division	Division
Informal Cases	Commissioner in charge	Division 2
Inquiry	Commissioner in charge	Division 1
Law	Commissioner in charge	Commission
Locomotive Inspection	Commissioner in charge	Division 3
Motor Carriers	Commissioner in charge	Division 5
Tariff matters	Commissioner in charge	Division 2
Finance matters	Commissioner in charge	Division 4
Personnel Supervision and Management	Chairman, ex officio	Division 1
Safety	Commissioner in charge	Division 3
Service	Commissioner in charge	Division 3
Statistics	Commissioner in charge	Commission, except as to matters assigned to Division 1
Traffic	Commissioner in charge	Division 2
Valuation	Commissioner in charge	Division 2
Water Carriers	Division 1	Commission

Standing Committees of the Commission

That there continue to be, as at present, two standing committees of the commission, namely the Committee on Rules and Reports and the Legislative committee, consisting of three members each, appointed by the commission, which shall designate the chairman thereof. The chairman of the commission may designate a commissioner to fill a vacancy on any committee until the commission otherwise orders.

Rehearings and Further Proceedings

For the proper and more convenient dispatch of business, and to the ends of justice, the following regulations of the conduct of proceedings are adopted (in addition to those governing the parties, as set out in the Rules of Practice), in respect of rehearings, reconsiderations, further hearings, and supplementary proceedings, when upon the application of any party to the decision, order, or requirement of a division of the commission.

The application (and any supporting or opposing documents) when submitted shall be considered by the division: if the division grants the same, the application will stand as granted by the division and denied by the commission, and further proceedings will be before the division and under its direction. Any further decision, order, or requirement of the division shall be subject to application for rehearing as provided in the act. If the division does not grant the application, the application (and supporting or opposing documents) will be considered by the commission, which in its discretion will determine if sufficient reason for granting a rehearing or taking any other action has been made to appear.

By the Commission.

(Seal) W. P. Bartel,
Secretary.

Report of Special Committee on Impact

J. B. Hunley, *Chairman,*
O. F. Dalstrom
S. F. Grear
M. Hirschthal
C. S. Johnson
A. N. Laird
B. R. Leffler
C. T. G. Looney
J. A. Newlin
G. E. Robinson
C. P. Schantz
C. E. Sloan
F. E. Turneaure
W. M. Wilson
Committee

To the American Railway Engineering Association:

The assignments to your committee are as follows:

1. Tests of short steel spans with open floor, together with effect of track inequalities and worn wheels on such spans.

2. Tests of steel spans with ballasted deck, including spans with pre-cast concrete decks and poured-in-place concrete decks; also tests on ballasted decks with timber floor; particular attention to be given to the damping due to the type of deck and the track ballast.

3. Tests of dynamic shear in steel girder and truss spans.

4. Tests of impact in columns and hangers of steel spans.

5. Tests of rigid frame structures of steel and concrete.

As an initial step in the study of the above assignments, your committee asked for the approval of a request for an appropriation of $4,000 to be expended during 1940 in the analysis of valuable test data at that time available to the committee. This budget request was endorsed by the Board of Direction and authorized by the Association of American Railroads.

Accordingly, work was started on the analysis of stress and deflection measurements made by the Pennsylvania Railroad on two spans on the main line at Chester, Pa. These measurements were considered especially valuable because they afforded a comparison of impact effects produced by steam locomotives and electric locomotives without unbalanced counterweights in the drivers; because tests were conducted at speeds as high as 105 miles per hour with the electric and 90 miles per hour with the steam locomotives; and because actual stresses were measured with new type electric gages not available in earlier tests. In addition to the information acquired, the analysis of these tests has been of very great value in clarifying the future test procedure that should be followed by the committee.

Other test data remain to be analyzed during 1941. It is also proposed to carry out a program of field tests during 1941 with instruments and funds made available to the committee by the Association of American Railroads.

The committee's report on the analysis of the Pennsylvania impact tests follows:

The Special Committee on Impact,
J. B. Hunley, *Chairman.*

Bulletin 422, January, 1941.

Description and Analysis of the Bridge Impact Tests Made by the Pennsylvania Railroad at Chester, Pa.

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LIST OF PLATES AND DIAGRAMS

Description and Analysis of the Bridge Impact Tests Made by the Pennsylvania Railroad at Chester, Pa.

1. Digest

This report embraces a description and analysis of tests made by the Pennsylvania Railroad on two plate girder spans at Chester, Pa., their length being 55 ft. 10 in. and 122 ft. respectively. The tests were made after the electrification of its four track line between New York and Washington in order to determine not only the comparative impact effects of the two types of electric locomotives which would be operated in this territory but also to compare the impact effects of these electric locomotives with steam locomotives which had been in operation for some time. These tests were conducted at considerable expense to the Pennsylvania Railroad and the Special Committee on Impact appreciates the opportunity afforded to analyze and present these data.

Stresses, vertical deflections, and lateral deflections were measured at the center of each span under the four different types of locomotives running at various speeds ranging from approximately 5 m.p.h., which may be considered as static loading, up to a maximum speed of 105 m.p.h. for the two types of electric locomotives, 80 m.p.h. for the freight type steam locomotive and 90 m.p.h. for the passenger type steam locomotive. Excellent electrical measuring equipment was developed for use in these tests and every care was taken in calibrating the instruments and conducting the tests; hence, it is believed the results can be accepted with full confidence.

The results of these tests are of particular interest to railway engineers generally for two reasons: First, because the highest speeds, which were considerably higher than in any previous tests, give information of value with respect to present day speed of operation, and second, because a comparison is afforded between the effects of locomotives with and without the so-called hammer blow resulting from the over-balance in the driving wheels of steam locomotives.

The total impact effects produced by each of these locomotives, in percent of the stresses measured at a speed of approximately 5 m.p.h. are shown in Figs. 44 to 51, inclusive. It will be noted that in general there was an increase, at the very high operating speeds, in impact effect with an increase in speed but that this increase was moderate, except for the electric Class P5–A on the 55-ft. 10-in. span. With respect to comparison of the impact effects with the electric and steam locomotives, the following tabulation is an average of five of the maximum impact effects found for each type of locomotive on each span:

Class	*Type*	*Average Speed*	*Average Impact Percent*
55-ft. 10-in. Span			
P5–A	Electric	80	49
GG–1	Electric	90	39
K4–S	Steam (passenger)	72	59
M1–A	Steam (freight)	57	35
122 ft. 0-in. Span			
P5–A	Electric	87	26
GG–1	Electric	98	18
K4–S	Steam (passenger)	86	29
M1–A	Steam (freight)	70	28

It will be noted from the above tabulation and Figures 44 to 51, that there was no marked reduction in impact with the electric locomotives even though they had no unbalanced counterweight. However, it should be pointed out that these two types of steam locomotives were exceptionally well balanced and the hammer-blow effect was within reasonable limits at the speeds used. It can be seen from Figures 44 to 51 that the total impact effects, with the exception of the electric locomotives on the 55-ft. 10-in. span, are within the maximum allowance as provided for in the section on design in the present AREA Specifications for Steel Railway Bridges and AREA Rules for Rating Existing Iron and Steel Bridges. However, it should be kept in mind that these tests represent but two spans, and until such time as these data can be compared with data on other spans, no definite conclusions should be drawn.

In addition to these total dynamic effects, the data were also analyzed for the purpose of studying the magnitude of the individual impact effects which make up the total impact effect. These individual effects, expressed in percentage of the static stress, and as found from this study, are as follows:

1. A definite increase in stress due to speed and termed "speed effect", was found throughout the tests entirely distinct from the vibrations that were developed by the moving loads. A probable explanation of this speed effect is the centrifugal force developed by the locomotives in following the path of the deflected span. The results of this study are shown in the upper diagrams in Figs. 28 to 35 inclusive. The maximum speed effects generally range from 15 to 20 percent on the 55-ft. 10-in. span, and 10 to 13 percent on the 122-ft. span.

2. Measurements frequently showed an increase in stress in one girder with a corresponding decrease in stress in the other girder of the same span, which is termed "roll effect" and is presumably caused by the spring borne weight of the locomotive oscillating about a horizontal axis. These results are shown in the lower diagrams of Figures 28 to 35 inclusive. One outstanding characteristic of the roll effect is that there was a rather narrow range in speed for each locomotive on each span, through which range the roll reached a maximum, decreasing from this maximum at either lower or higher speeds. The roll effect on the 55-ft. 10-in. span had a maximum value of approximately 15 percent for all locomotives except the P5–A electric for which it was 27 percent. On the 122-ft. span, the maximum roll effect values were approximately 10 percent for all locomotives except the P5–A for which this value was 16 percent.

3. The test measurements showed that vibrations were induced in the test spans by the electric locomotives even though there was no periodic disturbing force set up by unbalanced counterweights. This impact effect has been termed "track effect" and is presumably due to irregularities in the track surface or wheel treads; to the periodic effect of wheel loads coming and going off the span, or to other conditions of track and locomotive that would tend to produce a vertical vibration in the spring borne weight of the locomotive or in the girders.

These are the first comprehensive tests with electric locomotives, making it possible to analyze this track effect separately from the out-of-balance counterweight effect. The results are shown in Figures 36 to 39 inclusive.

The outstanding characteristics of the results are the narrow range within which the test results were found to lie and the fact that the track effect seemed to increase rather rapidly up to a speed of 30 to 40 m.p.h., particularly on the 55-ft. 10-in. span, and at a much less rapid rate thereafter. Maximum track effects, as to be expected, were greater on the short span ranging from 10 to 15 percent, compared to approximately 5 percent on the 122-ft. span.

4. The combined track and hammer-blow effect for the steam locomotives is shown in Figures 40 to 43 inclusive, for which locomotives these two effects could not be separated. Generally these results follow reasonably well the theory of forced vibration

of a loaded bridge span subjected to the disturbing force of the unbalanced counterweights. On the long span the maximum impact due to combined track and hammer-blow effect ranged from 10 to 20 percent and on the short span from 25 to 30 percent. It seems possible that the bridge vibrations set up by unbalanced counterweights may have been broken up, to a certain extent, by the track effect disturbances, and in the range of critical speed, damped by locomotive spring action.

2. Foreword

With the electrification of the Pennsylvania Railroad, between New York and Washington, it became necessary to consider the comparative effect on bridges of electric locomotives operating at high speeds, with steam locomotives of approximately equal weight. Little was definitely known as to the dynamic forces imposed by such electric motors, and it was decided to make a series of tests with both the steam and electric locomotives to be used in this territory.

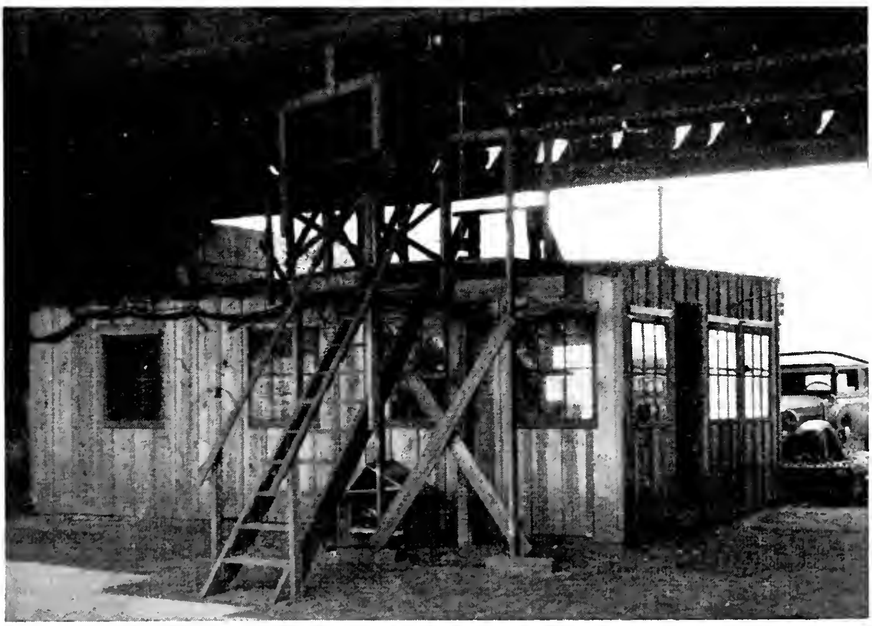
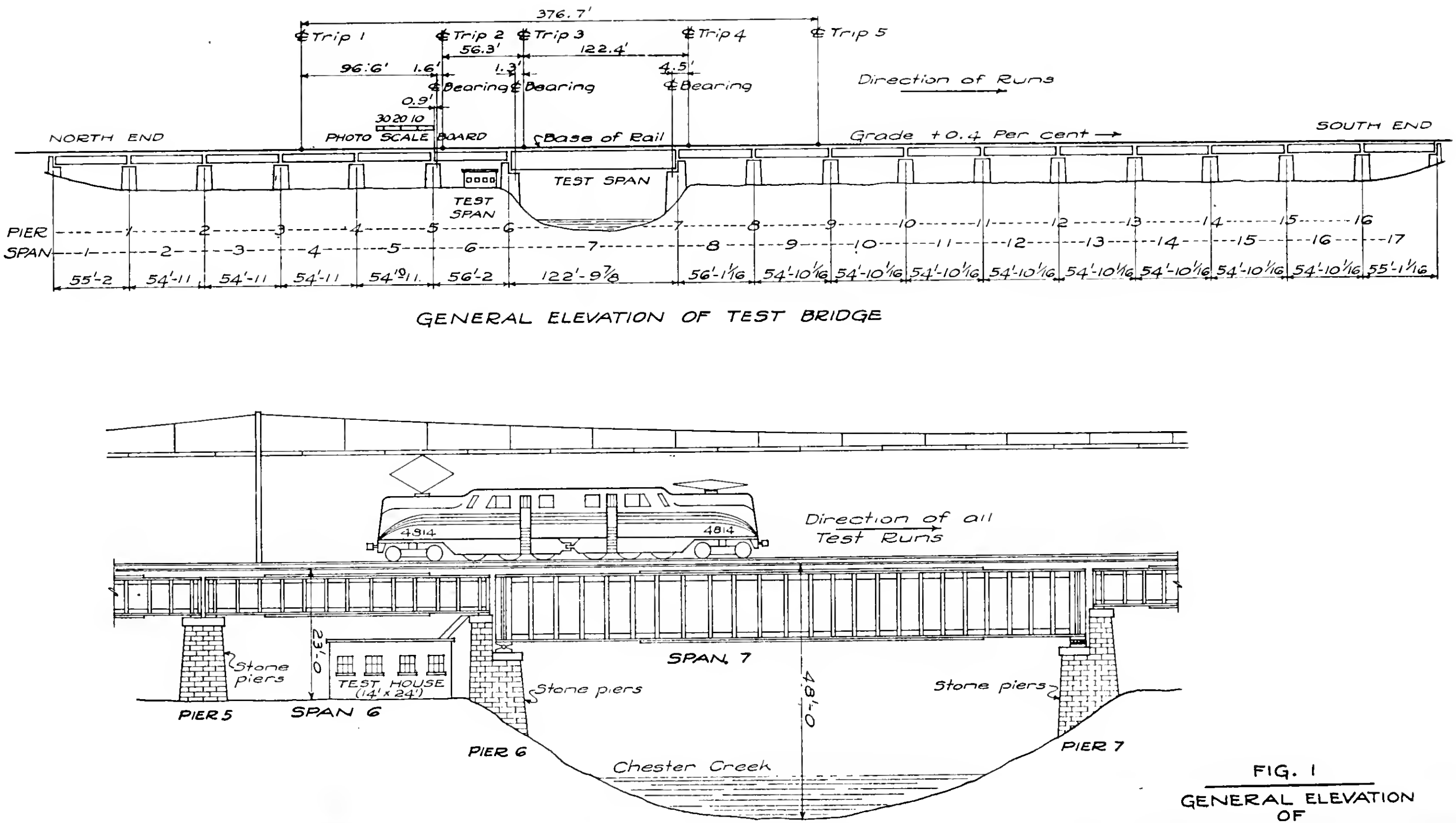


Fig. 2—General View of Test Building

The bridge selected for this test was located at Chester, Pa., and consisted of sixteen 55-ft. 10-in. and one 122-ft. four-track, deck girder spans, with open decks; see Fig. 1. By applying the necessary instruments to the long span and one adjacent short span, impact data could be obtained on a long girder, and one of average length with each test run.

It was felt that the desired information could best be had by the use of magnetic strain gages and recorded by means of oscillographs. A discussion with representatives of the General Electric Company resulted in an arrangement by which that company developed and furnished the necessary instruments for recording strains, vertical and lateral deflections.



GENERAL ELEVATION OF TEST BRIDGE

GENERAL ELEVATION OF TEST SPANS

FIG. 1

GENERAL ELEVATION OF TEST BRIDGE AND TEST SPANS

To house the equipment, a building 14 ft. by 24 ft. was erected under the short span adjacent to the pier between the two test spans; see Fig. 2. Suitable desks for the operators and recorders, and tables and shelving for the oscillographs, relays, meters, etc., were provided. It also contained a dark room in which the films could be developed immediately upon their removal from the oscillographs.

A 3-kw., 60-cycle electric power line was carried into the test building for light, heat, fans, battery charging transformer, motor-generator set, water cooler, radio and miscellaneous power.

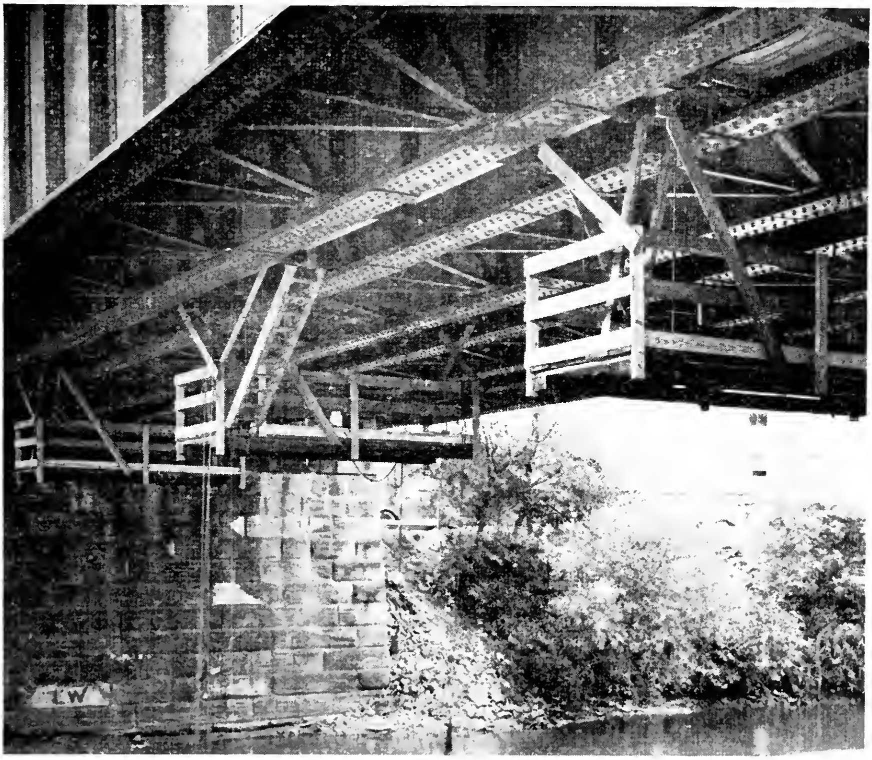


Fig. 3—View of Footwalk and Hanging Platforms

Telephone connection was made with the Pennsylvania Railroad Wilmington exchange; also with the interlocking tower at Baldwin, two miles north of the bridge, and with the Lamokin Street tower three quarters of a mile south. Telephone communication was also arranged between the test building, the upper deck of the bridge, and all gage positions on the two spans.

Hanging platforms were suspended beneath the long span at the center and quarter points. A footwalk running from Pier 6 to Pier 7 between the girders under tracks 3 and 4 and suitable stairways or ladders were constructed to afford access to the hanging platforms. See Fig. 3. The roof of the test building, as shown in Fig. 2, was used to provide access to the gages on the short span.

All electrical measuring and recording equipment was installed and operated by the General Electric Company. Railroad employees were in charge of the operation of the test locomotives and other work on the track. Watchmen were continuously on duty during test runs, acting as whistle men and giving warning of the approach of trains by means of push button signals located at various points on the bridge.

3. Instruments

The instruments used in these tests were of the electrical type and consisted of: 20 electro-magnetic strain gages by which a continuous record of the strains at various points could be obtained; two lateral deflectometers and two vertical deflectometers located at the center of the spans recording the lateral and vertical movements during each run; and one timer from which the speed of the locomotives was obtained. In addition to these electrical instruments, two mechanical deflectometers were used which also recorded directly the vertical movements at the center of the test spans.

Electro-Magnetic Strain Gages

The general principle, by which strains are measured by the electro-magnetic strain gage, is based on the fact that a magnetic circuit, in which the lines of magnetic force must travel through both a magnetic material and an air gap, has the major part of its reluctance in that part of its path which is through the air gap, even if the gap be very short. Therefore, a small change in the length of the air gap will have a relatively large effect on the total reluctance of the circuit and on the current carried in the winding of the magnets.

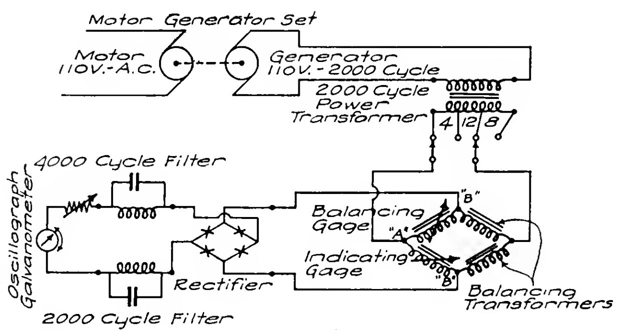


FIG. 4A
DIAGRAMMATIC CIRCUIT OF MAGNETIC STRAIN GAGES

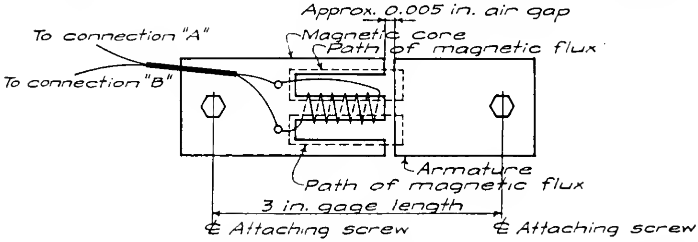


FIG. 4B
SCHEMATIC DRAWING OF ONE MAGNETIC STRAIN GAGE
(USED FOR EITHER BALANCING GAGE OR INDICATING GAGE)

The complete electrical circuit for one electro-magnetic strain gage, from generator to oscillograph, is shown diagrammatically in Fig. 4 A. It can be seen that the electrical circuit, in which the indicating gage operates, is a Wheatstone bridge through which the 2,000-cycle current passes. The indicating gage and one of the balancing transformers, connected in series, form one side of the bridge while the balancing gage and the other balancing transformer, connected in series, form the other side of the bridge. Since the two sides of the bridge are connected in parallel, the 2,000-cycle current passes through the two sides in an inverse proportion to the resistance offered by each side.

The electro-magnetic strain gage, which can be used for either the indicating gage or the balancing gage, consists essentially of an electro-magnet wound on a ꟷ shaped core with an armature across the legs of the core, see Fig. 4 B. The magnetic core is attached to one gage point while the armature is attached to the other gage point. The construction of the instrument is such that when it is placed in working position, a definite air gap is provided between the armature and the ends of the magnetic core. When a current is passed through the coil, a path of magnetic flux is set up through the core, and this passes from the core through the air gap into the armature, through the armature and then back across the air gap and again into the core. Since a very small change in the air gap greatly varies the resistance of the path of the magnetic flux, the amount of current flowing in the coil will be changed accordingly.

In operation, the indicating gage is attached to the member in which the strain is to be measured; see Fig. 5. It is fastened by special screws which are seated in two drilled and tapped holes, the center of these holes being exactly a gage length apart, in this case three inches, and in the line of stress. The balancing gage working in conjunction

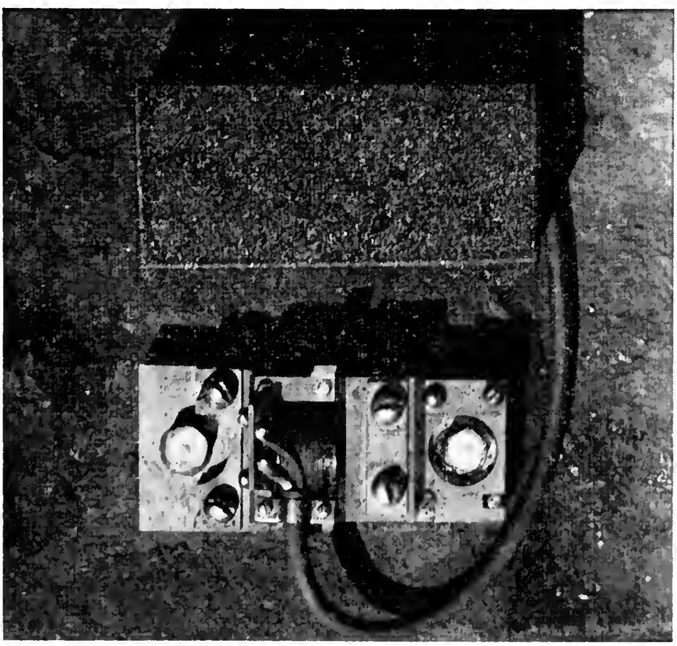


Fig. 5—View of Indicating Gage on Test Member

with the indicating gage is not attached to the member, but is located at some convenient point in the circuit.

Since the change in the length of the air gap of the indicating gage is directly proportional to the change in the distance between its two attaching screws, any strain in the member on which the indicating gage is mounted produces a change in the length of its air gap. As previously mentioned, any change in the length of the air gap greatly varies the resistance of the path of the magnetic flux and therefore of the electrical current flowing in the coil itself.

Any strain in the member, to which the indicating gage is attached, changes the amount of current flowing through its side of the Wheatstone bridge, but since the length of the air gap in the balancing gage remains constant, the amount of current flowing through this side of the Wheatstone bridge remains constant. This variation in resistance between the two sides results in a change of potential in the Wheatstone bridge, and by means of a galvanometer in the oscillograph, can be indicated on the record. This out-of-balance current from the Wheatstone bridge is rectified and filtered so as to produce a direct current before reaching the galvanometer.

The four oscillographs used in these tests were of the 6-element type, that is, each oscillograph had 6 galvanometers, each of which was connected with a gage or deflectometer, so that a simultaneous and continuous record of 24 strains or deflections could be had for each test run. On the electro-magnet of the galvanometer, there was mounted a tiny mirror intercepting a ray of light, and any change in potential in the Wheatstone bridge, caused by a variation of strain in the member with the consequent

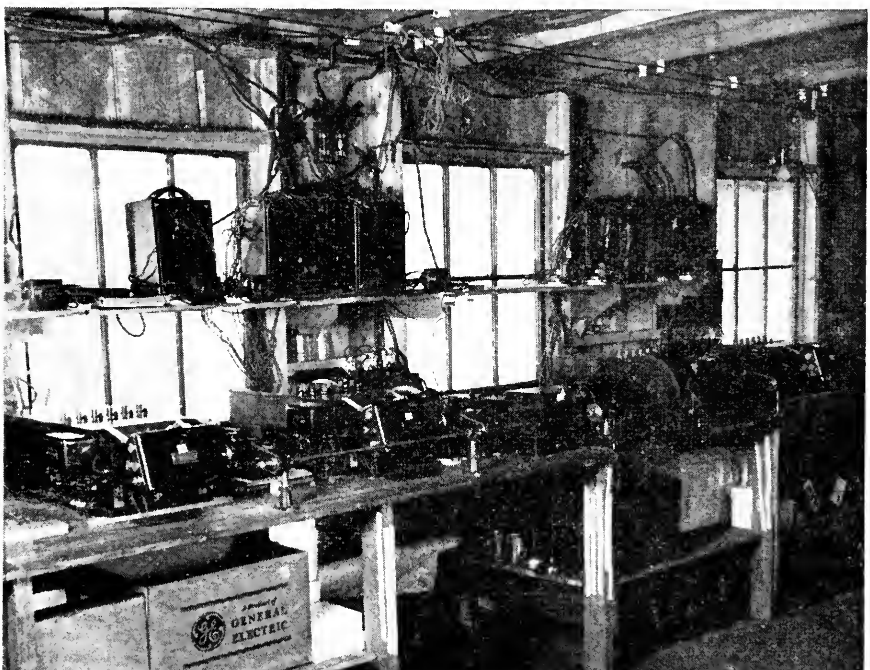


Fig. 6—View of Oscillographs in Test Building

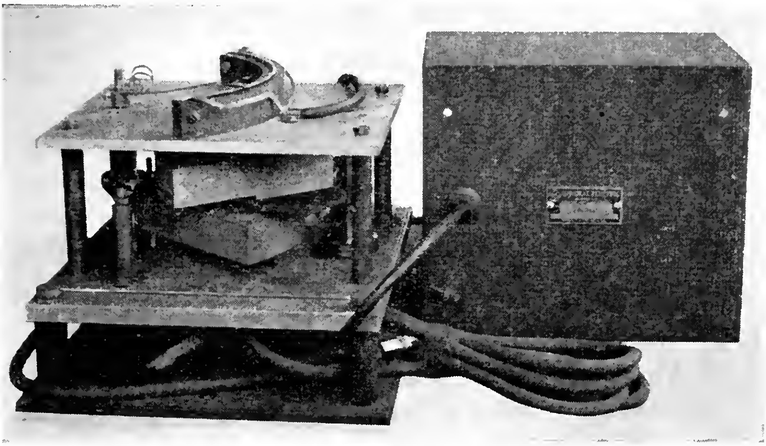


Fig. 7—View of Electrical Lateral Deflectometer

change in the air gap of the indicating gage, produced a deflection, proportional to the change in voltage, in the magnet and mirror. The light ray reflected from the mirror registered on a photographic film, and the strain gage circuits were so adjusted that 0.001 in. strain in the member produced a change in position, of the reflected ray on the film, of 1.0 in.

For stresses within the proportional limit, the unit stress "f" is equal to the unit deformation "$\triangle$", multiplied by the modulus of elasticity "E", divided by the length between gage points "l", or $f = \frac{\triangle E}{l}$. Assuming a value of 30,000,000 lb. per sq. in. for the modulus of elasticity of steel, a movement of 0.001 in. between the gage points, which are 3 in. apart, represents a stress of 10,000 lb. per sq. in.

Supersensitive galvanometers, having an average sensitivity of 0.15 milliampere per millimeter deflection of the light ray on the film, were used for all strain gage recorders. Galvanometers, having a sensitivity of 1.50 milliampere per millimeter deflection of the light ray on the film, were used for all vertical and lateral deflection recorders.

In addition to the strain and deflection records, timing waves from the 60-cycle power supply were recorded on the film by each oscillograph. The amplitude of this wave was temporarily increased as the locomotive passed over trips 2, 3 and 4 placed on the rail at various points on the bridge as shown on Fig. 1. All records were taken on film six inches wide and five feet long, an average of five runs being taken on each film.

An electric motor and a gear box were used to drive the oscillograph film holders through a jack shaft, the speed of the film being increased or decreased by shifting the gears. See Fig. 6. The oscillograph equipment was automatically started and stopped by other track contacts operating through a relay system.

Electrical Lateral Deflectometers

The electrical lateral deflectometers (see Fig. 7) operated on the principle of the seismograph, the weights in these instruments being so balanced as to be sensitive only to lateral motion or to lateral tilt. Any lateral movement of the girders, on which they were mounted produced a proportional change between the weights and the case, causing a contact arm to move along a rheostat which changed the voltage in the circuit. The change in voltage was recorded by the galvanometer in the oscillograph. The circuits of

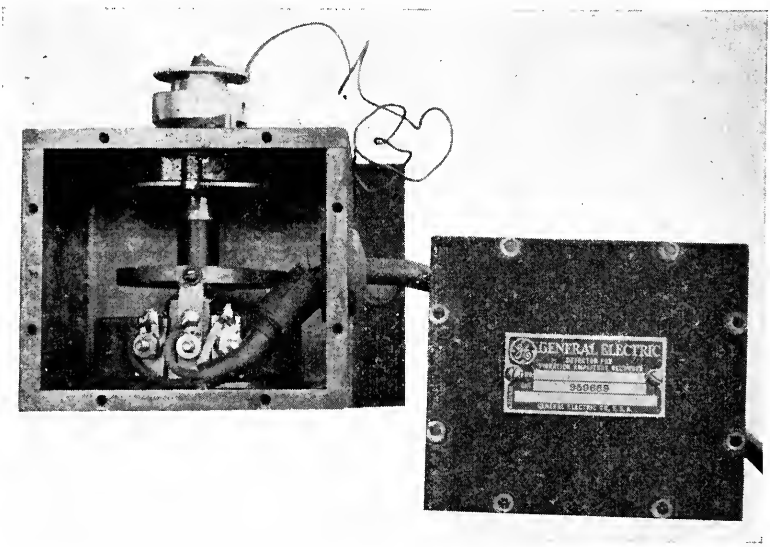


Fig. 8—View of Electrical Vertical Deflectometer

the lateral deflectometer were adjusted so that 1,000 in. lateral deflection in the girder produced a movement of the reflected light ray on the photographic film of 1.0 in. These instruments were normally level but small changes in level during the test run produced only a slow shifting of the zero line which did not interfere in any way with the observation of the lateral deflection.

Electrical Vertical Deflectometers

The electrical vertical deflectometers (see Fig. 8) consisted of a rheostat with a contact arm. They were mounted at the center of the spans, with a wire running from the contact arm to the ground, tension in the wire being maintained by a coil spring. Any vertical movement of the girder caused the contact to move along the rheostat, changing the voltage in the circuit, this change in voltage being translated through the galvanometer, into a corresponding movement of the light ray on the film. The electrical vertical deflectometer circuits were adjusted so that 1.000 in. vertical movement of the girder produced a movement of the ray on the film of 2.0 in.

Mechanical Vertical Deflectometer

The two mechanical vertical deflectometers (see Fig. 9) were furnished by the Cleveland, Cincinnati, Chicago & St. Louis Railway, each being attached to one girder of both spans. Their construction and method of operation are fully described in AREA Proceedings for 1936, Vol. 37, page 754. As the records, being directly inscribed on paper, were immediately available after each run, they were used throughout the tests for the purpose of quickly selecting the speed of subsequent runs, and ascertaining the maximum oscillation and critical speed of the particular locomotive used.

Speed Recorder

A synchronous timer was used to record the time, to the nearest hundredth of a second, required for the locomotive to pass between trips 1 and 5 located as shown in Fig. 1, the distance between them being 376.7 ft.

Location of Instruments

Five electro-magnetic strain gages, one electrical lateral deflectometer, one electrical vertical deflectometer and one mechanical vertical deflectometer were used on the 55-ft. 10-in. test span. The location of these instruments is shown in Fig. 10. One of the gages was placed diagonally on the outside of the web at the south end of the west girder, for the purpose of measuring the shearing stress, but due to high frequency lateral vibrations in the web, bending stresses as well as shearing stresses were recorded. These bending stresses were magnified due to the fact that the air gap on the instrument was at a distance of 7/8 in. from the face of the plate, and since it was impossible to determine how much of the total stress was due to bending, and how much to shear, these records have been disregarded.

It should be pointed out that both the electrical and mechanical vertical deflectometers were placed on the east girder of the 55-ft. 10-in. span, so that no record of

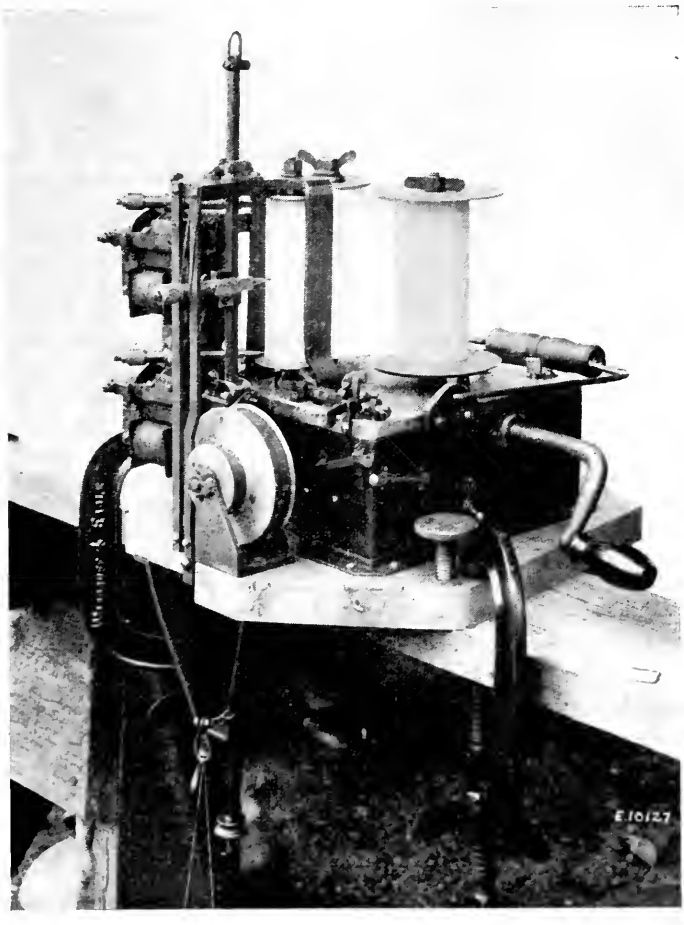


Fig. 9—View of Mechanical Vertical Deflectometer

deflections in the west girder was obtained. These instruments were not used on the west girder of this span as the test building, which was directly under the girder, interfered with running the wire from the instrument to the ground.

Fifteen electro-magnetic strain gages, one electrical lateral deflectometer, one electrical vertical deflectometer and one mechanical vertical deflectometer were used on the 122-ft. test span. The location of these instruments is shown in Fig. 12. One of the strain gages was placed on the outside of the web at the south end of the west girder, but, as in the case of the 55-ft. 10-in. span, no reliable results as to shearing stresses were obtained. Eight of the strain gages were placed on the top and bottom cover plates of both girders at the quarter points, and two were placed at the center of the span on the outstanding leg of the top and bottom flange angles of the west girder. Since the results, obtained from a preliminary study of all the test records, indicated that the strains recorded by these ten strain gages were comparable with the strains recorded by the four strain gages, located at the center of the span on the cover plates, the stresses recorded by these ten gages have been omitted in this report.

4. Spans Tested

Span No. 6: 55-ft. 10-in. Deck Girder Span

This span consisted of two girders 55 ft. 10 in. long overall, and 54 ft. center to center of bearings, as shown in Fig. 10. It was fabricated in 1903 and was designed for a live load equivalent to Cooper's E–40, using lower stresses than present day allowances. The capacity of this span, using the present AREA design stresses and impact, would be E–50. The center line of track did not coincide with the center line of span, the track being off center to the west, one inch at the north end and two inches at the south end. With an average eccentricity of 1½ in., the west girder would carry 52.5 percent of the total load and the east girder 47.5 percent.

The deck was of the "open type"; that is, the timber ties supporting the rail rested directly on the girder flanges. The rail was P.S. 130-lb. section and the location of the track joints is shown in Fig. 11. The rail was not uniformly supported by ties, and the distance between the base of rail and top of tie plate or tie, at each tie, is shown in Fig. 11.

Since the gage length was three inches, it was felt that the total strain between the gage points would not be greatly affected by the local strains at rivet holes and that a better comparison of measured and calculated stress could be obtained if the theoretical stresses were computed from the gross moment of inertia of the girder section. Deflection is not materially affected by local strains at net sections, but depends largely upon the strains throughout the span length, so that the theoretical stresses and deflections in the various tables have been computed from the gross section at the center of the span.

Span No. 7: 122-ft. Deck Girder Span

This span consists of two girders 122 ft. long overall and 119 ft. 3 in. center to center of bearings, as shown in Fig. 12. It was fabricated in 1903 and designed for a live load equivalent to Cooper's E–40. The capacity of this span, using present AREA design stresses and impacts, would be E–64.

The center line of track, at both ends was ¾ in. west of the center line of span and this eccentricity would cause a distribution of live load between the west and east girders of 50.8 percent and 49.2 percent, respectively.

As with span No. 6, the deck was of the open type, with uneven bearing of the rail on the ties. The play between the base of rail and top of tie plate or tie, and the location of the rail joints, are shown in Fig. 13. *(Text continued on page 413)*

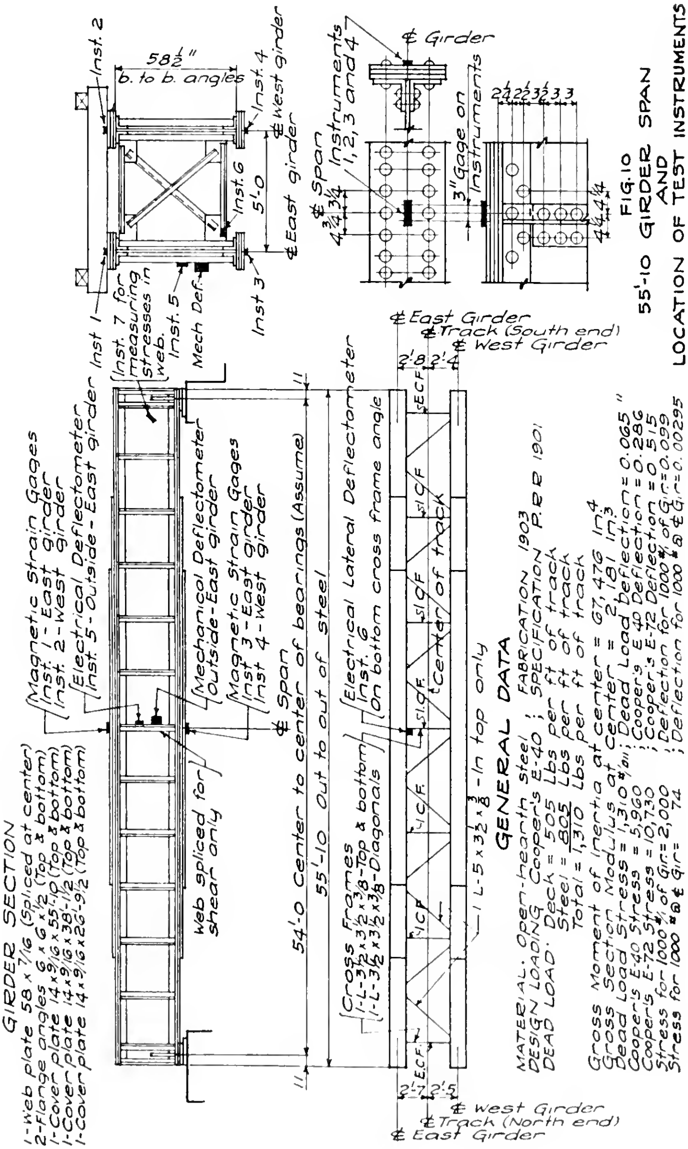


FIG. 10
55'-10 GIRDER SPAN
AND
LOCATION OF TEST INSTRUMENTS

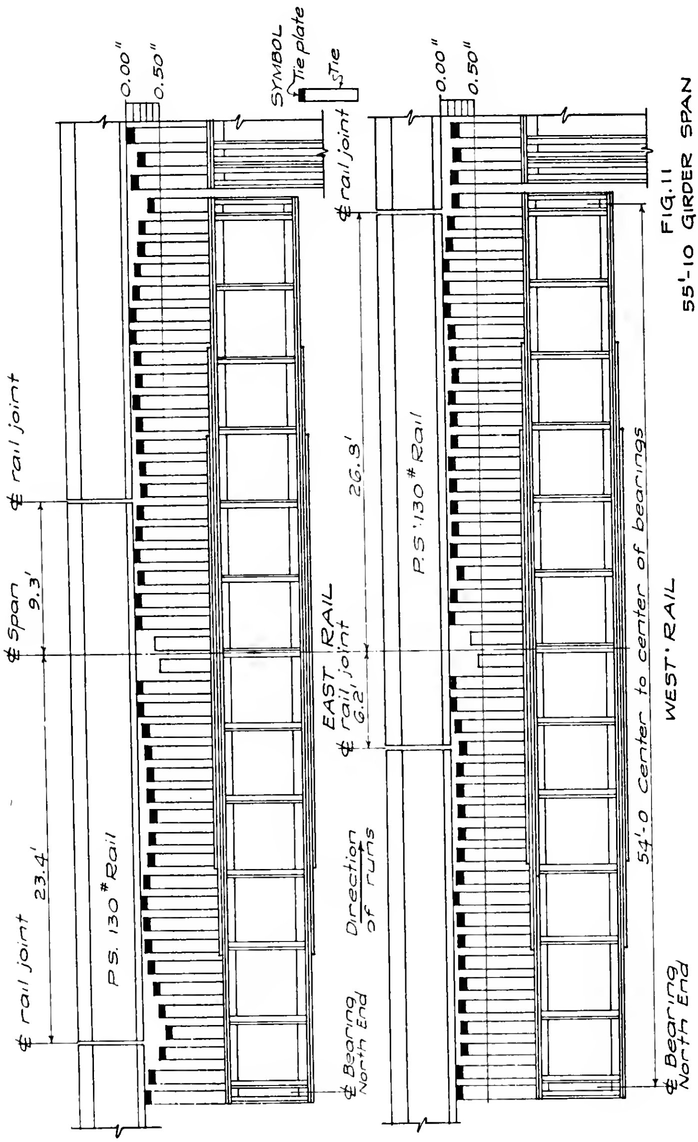


FIG. 11
55'-10 GIRDER SPAN
RELATION OF RAIL TO RAIL SUPPORT

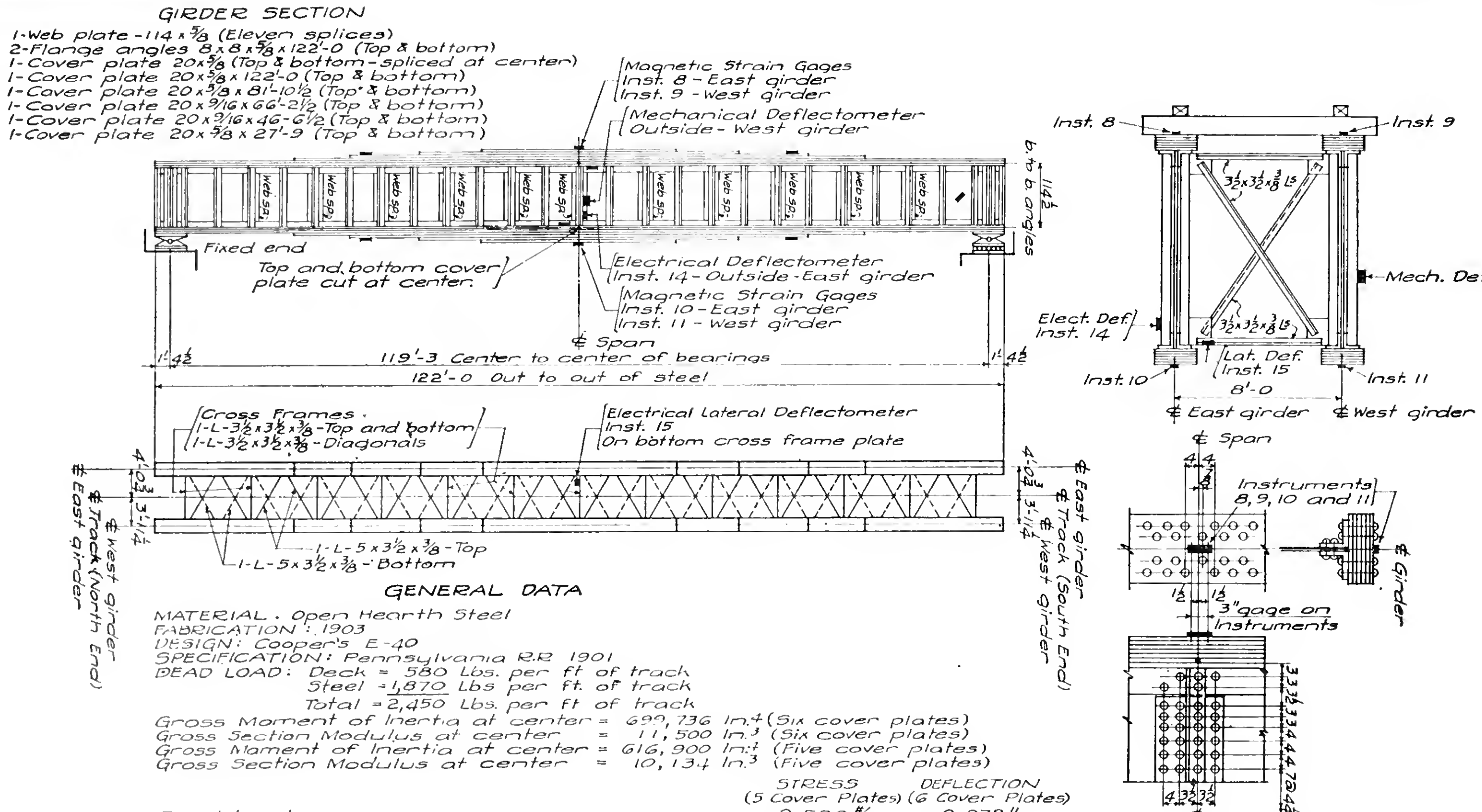


FIG. 12
122'-0 GIRDER SPAN
AND
LOCATION OF TEST INSTRUMENTS

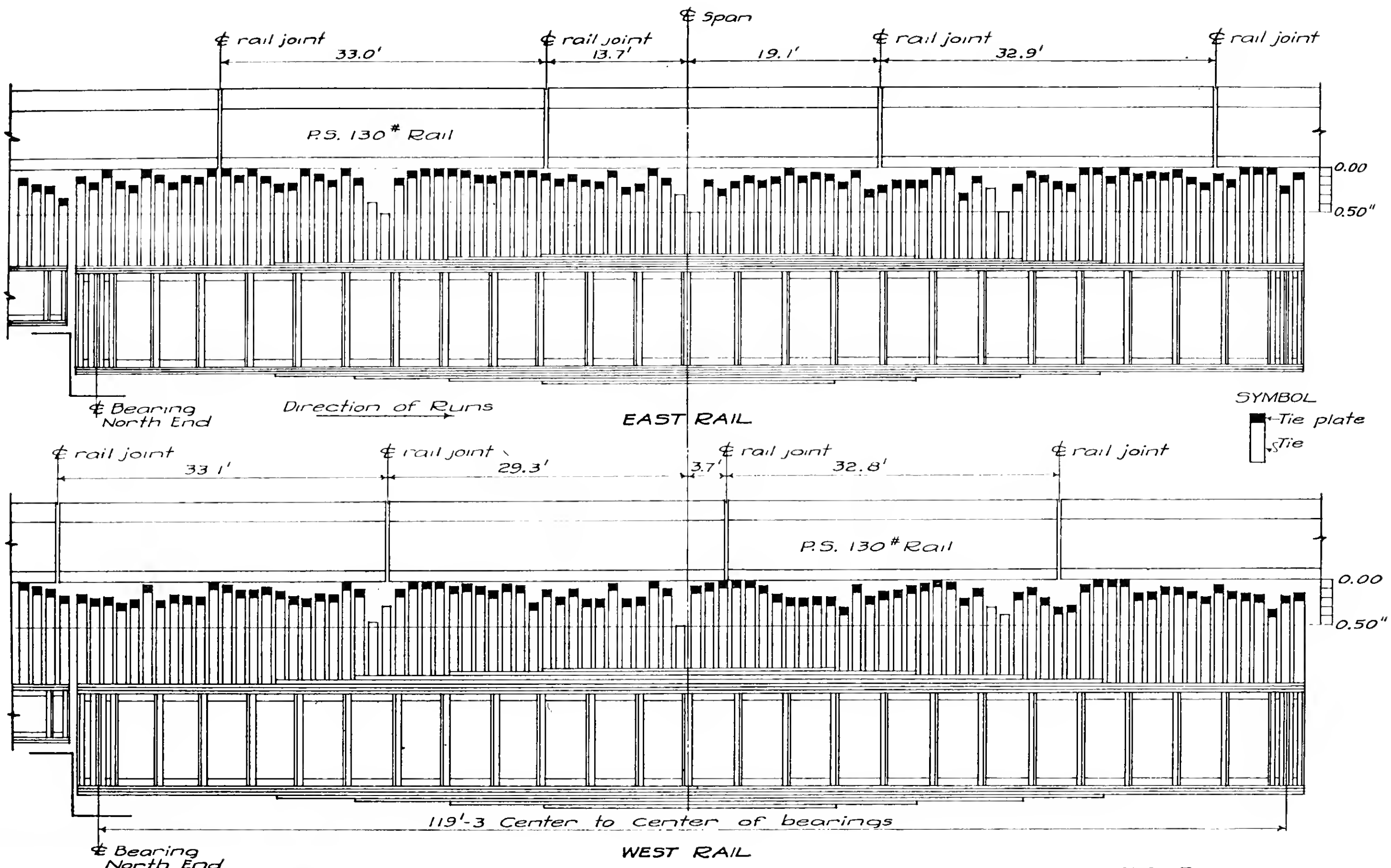


FIG. 13
122'-0 GIRDER SPAN
RELATION OF RAIL TO RAIL SUPPORT

It will be noted that in this span the first cover plate on both the top and bottom flanges is cut at the center, the outer plates serving as a splice, so that, in computing the theoretical stresses, the gross moment of inertia, including only the five outer cover plates was used, but for computing deflections, all six plates were considered as part of the gross section.

5. Locomotives Used in Tests

Four locomotives were used in the tests, two high speed electric (Classes P5–A and GG–1), one steam passenger (Class K4–S) and one steam freight (Class M1–A). The two steam locomotives were of the two-cylinder type, the left pin leading the right by 90 deg. and with the eccentric cranks trailing. All runs were made without any additional equipment, except for the tenders on the steam locomotives.

The following is a brief description of these four locomotives used:

Electric Locomotive Class P5–A—No. 4779

The rating of this locomotive, in terms of Cooper's loading, on the 55-ft. 10-in. span is E51.3 for center stress and E52.6 for center deflection. The rating on the 122-ft. span is E40.2 for center stress and E38.6 for center deflection. The total weight of the locomotive in working order with tanks filled with oil and water is 394,950 lb., and from individual scale weights of the wheels it was found that the left side carried 201,760 lb. or 51.1 percent, and the right side 193,190 lb. or 48.9 percent of the total.

This locomotive is of the 2–C–2 type with six traction motor armatures. The armature shaft is geared to a quill which drives the wheels through spring cups. Axles 1, 2 and 6 are equipped with SKF roller bearings while axles 3, 4, 5 and 7 are equipped with Timken roller bearings. The lateral clearance of the center plate on the front truck was $\frac{3}{32}$ in. and on the rear truck $\frac{1}{16}$ in. All general data regarding this locomotive such as axle spacing, wheel weights, actual wheel diameters, wheel clearance, equalizing system, spring arrangement and spring frequencies are shown in Fig. 14.

Electric Locomotive Class GG–1—No. 4814

The rating of this locomotive, in terms of Cooper's loading, on the 55-ft. 10-in. span is E43.8 for center stress and E45.9 for center deflection. The rating on the 122-ft. span is E41.7 for both center stress and center deflection. The total weight of the locomotive in working order with tanks filled with oil and water is 463,840 lb. the left side weighing 232,040 lb. or 50.0 percent and the right side weighing 231,800 lb. or 50.0 percent.

This locomotive is of the 2–C + C–2 type with twelve motor armatures. The armature shaft is geared to a quill which drives the wheels through spring cups. All boxes are equipped with Timken roller bearings. Both front and rear unit engine truck center plates have a lateral clearance of $\frac{1}{16}$ in. All general data regarding this locomotive such as axle spacing, wheel weights, actual wheel diameters, wheel clearance, equalizing system, spring arrangement and spring frequencies are shown in Fig. 15.

Steam Locomotive Class K4–S.—No. 3843 With Tender No. 3511

This locomotive is of the 4–6–2 type and is used in high speed passenger service. The tender, which has 2-axle trucks, has a capacity of 12,150 gal. of water and 18 tons of coal. The rating of this locomotive with fully loaded tender, in terms of Cooper's loading, on the 55-ft. 10-in. span is E53.0 for center stress and E52.9 for center deflection. The rating on the 122-ft. span is E44.7 for center stress and E43.7 for center deflection. The total weight of the locomotive, without tender, is 314,120 lb., the left side weighing 157,600 lb. or 50.2 percent and the right side weighing 156,520 lb. or 49.8 percent. The total weight of the tender in working order, with full water tank and coal bunker, is 195,950 lb., the left side weighing 95,530 lb. or 48.8 percent and the right side weighing 100,620 lb. or 51.2 percent. All data regarding this locomotive as to its axle spacing, wheel weights, actual wheel diameters, wheel clearances, equalizing system, spring arrangement and spring frequencies are shown in Fig. 16.

Steam Locomotive Class M1-A.—No. 6718 With Tender No. 6711

This locomotive is of the 4-8-2 type and is used in high speed freight service. The tender, which has 3-axle trucks, has a capacity of 22,100 gal. of water and 31.5 tons of coal. The rating of this locomotive with fully loaded tender, in terms of Cooper's loading, on the 55-ft. 10-in. span is E60.4 for center stress and E60.9 for center deflection. The rating on the 122-ft. span is E55.9 for center stress and E57.6 for center deflection. The total weight of the locomotive, without tender, is 387,580 lb. the left side weighing 198,010 lb. or 51.1 percent and the right side weighing 189,570 lb. or 48.9 percent. The total weight of the tender in working order, with full water tank and coal bunker, is 385,070 lb., the left side weighing 194,420 lb. or 50.5 percent, and the right side weighing 190,650 lb. or 49.5 percent. All data regarding this locomotive as to its axle spacing, wheel weights, actual wheel diameters, wheel clearances, equalizing system, spring arrangement and spring frequencies are shown in Fig. 17.

6. Locomotive Characteristics Affecting Dynamic Stresses

The dynamic effect of any locomotive on a structure depends upon the following:

(a) The static weight and spacing of the various axles
(b) The friction of its springs and their frequency of vibration
(c) The period of its roll or rotation about a horizontal axis
(d) The period of its nosing or rotation about a vertical axis
(e) The condition of its wheels
(f) The counter-balancing

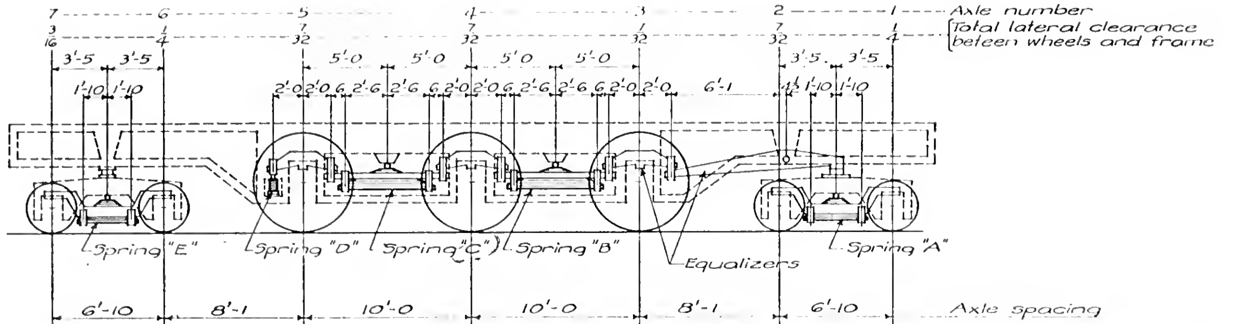
(a) While the spacing and weights on the individual axles of a locomotive primarily affect the static live load stresses, they do have some bearing on the dynamic stresses. The frequency of the natural vibrations of any span will be lower under a heavy load than under a light load, so that the synchronous speed of a locomotive, operating over any particular span, depends upon its weight. This is particularly important with two-cylinder steam locomotive, or any engine having unbalanced rotating weights.

The static weight of a locomotive, insofar as it fixes the static deflection, would seem from these tests, as will be shown later, to have some bearing on the dynamic effect. This action is apparently due to the centrifugal force exerted as the locomotive follows the path of the deflected span.

(b) The period of vibration of the locomotive springs was not measured in these tests, but the theoretical frequency has been computed from the known spring deflection constants. The friction of the springs and the frequency of their vibration have a marked effect on the damping of the bridge vibrations, and it was found that such damping occurred during many of the test runs.

For the purpose of estimating the frequency of vibration of the sprung weight of the locomotives used in these tests, the coefficient of spring deflection (required load in pounds to produce one inch deflection or compression) was obtained from the mechanical department of the Pennsylvania Railroad and the static deflection under the spring borne weight on the axles and the corresponding frequency of vibration for each spring or axle

(Text continued on page 419)



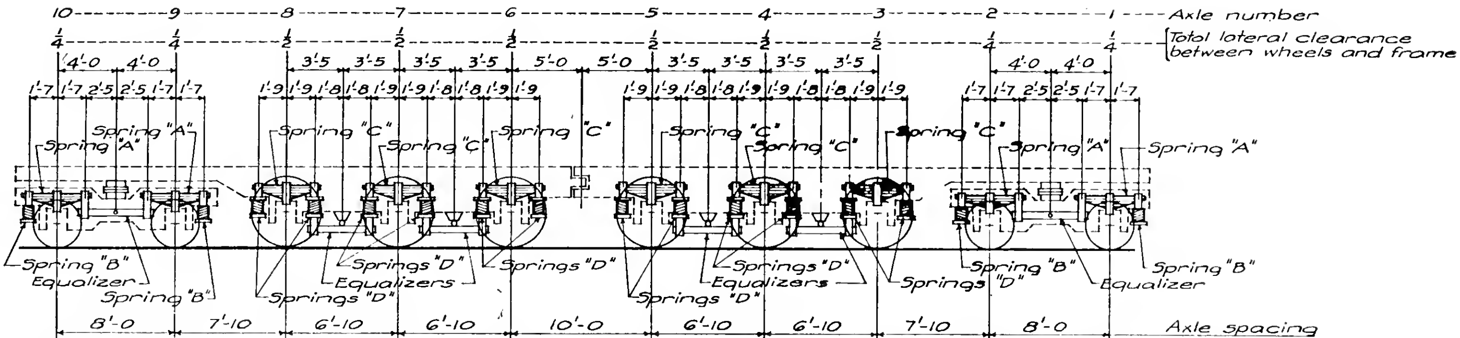
Axle number	7	6	5	4	3	2	1
Actual wheel diameter	35.98	35.98	72.00	72.00	72.00	35.79	35.48
Sprung weight per axle	40,530	40,520	59,600	60,530	60,040	34,350	34,380
Unsprung weight per axle	4,250	4,250	16,000	16,000	16,000	4,250	4,250
Total wheel weights-Left side	25,050	25,100	36,070	36,300	34,220	22,650	22,370
Total wheel weights-Right side	19,730	19,670	39,530	40,230	41,820	15,950	16,260
Sprung weight per axle / Total weight per axle	0.905	0.905	0.788	0.790	0.790	0.890	0.890

LOCOMOTIVE SPRING DATA

SPRING NUMBER	AXLE NUMBER	NUMBER OF SPRINGS	LOAD REQUIRED TO PRODUCE ONE INCH DEFLECTION	SPRUNG WEIGHT POUNDS	STATIC DEFLECTION INCHES	TIME OF VIBRATION SECONDS	FREQUENCY VIBRATIONS PER SECOND
A	1 and 2	2	22,250	68,730	1.55	0.396	2.52
B	3 and 4	2	12,450	60,230	2.42	0.497	2.01
C	4 and 5	2	12,450	60,010	2.41	0.495	2.02
D	5	2	9,460	29,800	1.57	0.400	2.50
E	6 and 7	2	22,250	81,050	1.82	0.431	2.32

TOTAL FOR LOCOMOTIVE: Load required to produce one inch deflection = 157,720 Lbs.
Sprung weight = 329,860 Lbs.
Static deflection = 2.09 In.
Time of vibration = 0.463 Sec.
Frequency = 2.16 Vib. per sec.
$\frac{\text{Sprung weight}}{\text{Total weight}} = 0.834$

FIG. 14
LOCOMOTIVE CLASS P5-A,
SPRING ARRANGEMENT AND EQUALIZING SYSTEM



Axle number	10	9	8	7	6	5	4	3	2	1
Total lateral clearance between wheels and frame	1/4	1/4	1/2	1/2	1/2	1/2	1/2	1/2	1/4	1/4
Actual wheel diameter	35.98	35.98	56.99	56.99	56.99	56.99	56.99	56.99	35.98	35.98
Sprung weight per axle	33,760	39,010	41,460	41,450	40,160	37,800	43,140	46,200	36,530	34,170
Unsprung weight per axle	4,790	4,790	8,500	8,500	8,500	8,500	8,500	8,500	4,790	4,790
Total wheel weight-Left side	18,260	20,510	28,000	26,520	25,500	21,700	24,180	26,250	19,870	21,250
Total wheel weight-Right side	20,290	23,290	21,960	23,430	23,160	24,600	27,460	28,450	21,450	17,710
Sprung weight per axle / Total weight per axle	0.885	0.890	0.829	0.829	0.824	0.816	0.835	0.844	0.885	0.877

Axle spacing: 8'-0, 7'-10, 6'-10, 6'-10, 10'-0, 6'-10, 6'-10, 7'-10, 8'-0

LOCOMOTIVE SPRING DATA

AXLE NUMBER	SPRING NUMBER	NUMBER OF SPRINGS	LOAD REQUIRED TO PRODUCE ONE INCH DEFLECTION: EACH SPRING	LOAD REQUIRED TO PRODUCE ONE INCH DEFLECTION: TOTAL FOR AXLE	SPRUNG WEIGHT POUNDS	STATIC DEFLECTION INCHES	TIME OF VIBRATION SECONDS	FREQUENCY VIBRATIONS PER SECOND
1	A B	2 2	14,250 10,750	21,400	34,170	1.60	0.403	2.48
2	A B	2 2	14,250 10,750	21,400	36,530	1.70	0.416	2.40
3	C D	2 8	12,750 7,220	17,700	46,200	2.61	0.515	1.94
4	C D	2 8	12,750 7,220	17,700	43,140	2.44	0.500	2.00
5	C D	2 8	12,750 7,220	17,700	37,800	2.14	0.467	2.14
6	C D	2 8	12,750 7,220	17,700	40,160	2.26	0.480	2.08
7	C D	2 8	12,750 7,220	17,700	41,450	2.34	0.490	2.04
8	C D	2 8	12,750 7,220	17,700	41,460	2.34	0.490	2.04
9	A B	2 2	14,250 10,750	21,400	39,010	1.82	0.431	2.32
10	A B	2 2	14,250 10,750	21,400	33,760	1.58	0.401	2.49

TOTAL FOR FRONT UNIT:

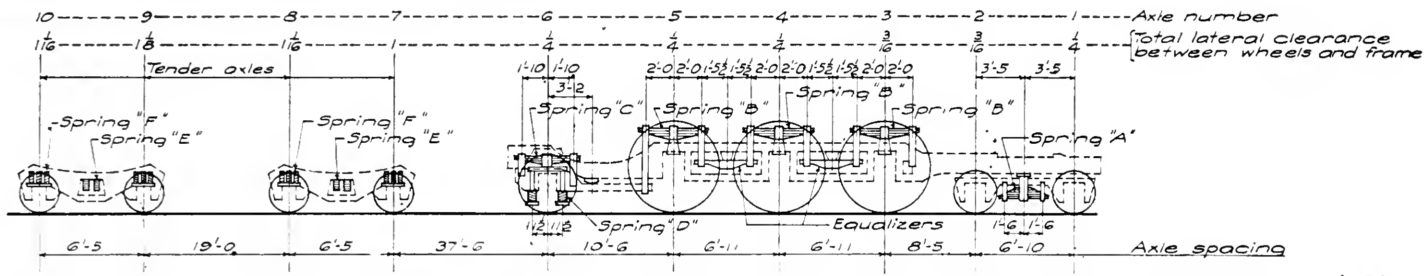
Load required to produce 1 in. deflection = 95,900 Lbs.
Sprung weight = 197,840 Lbs.
Static deflection = 2.07 In.
Time of vibration = 0.458 Sec.
Frequency = 2.18 Vib/sec.
$\frac{\text{Sprung weight}}{\text{Total weight}} = 0.848$

TOTAL FOR REAR UNIT:

Load required to produce 1 in. deflection = 95,900 Lbs.
Sprung weight = 195,840 Lbs.
Static deflection = 2.04 In.
Time of vibration = 0.456 Sec.
Frequency = 2.19 Vib/sec.
$\frac{\text{Sprung weight}}{\text{Total weight}} = 0.847$

FIG. 15
LOCOMOTIVE CLASS GG-1

SPRING ARRANGEMENT AND EQUALIZING SYSTEM



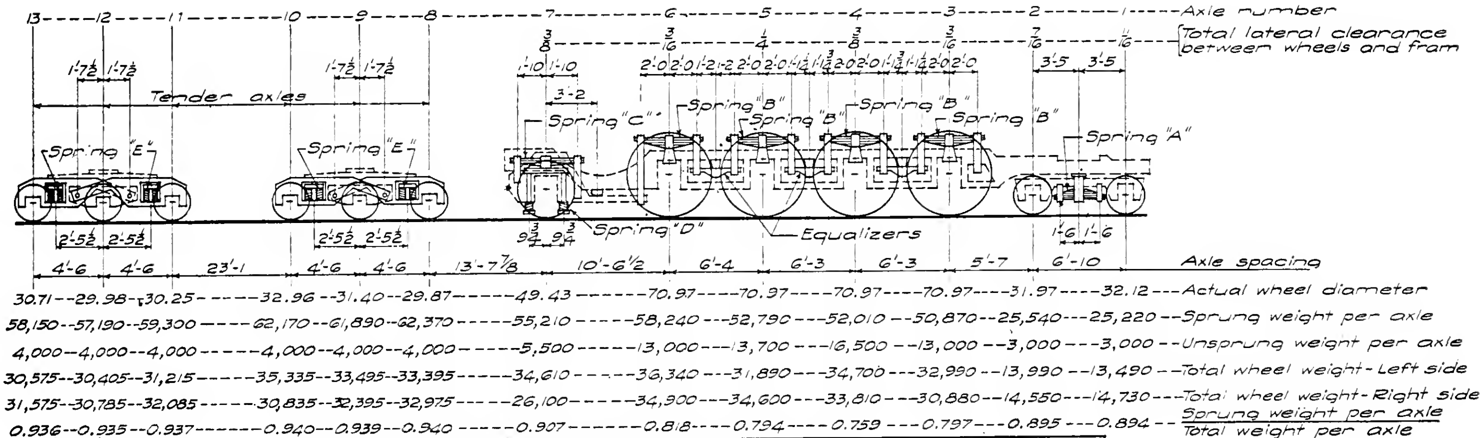
Axle number	10	9	8	7	6	5	4	3	2	1
Actual wheel diameter	35.06	33.27	33.81	33.69	49.69	78.95	78.95	73.95	34 84	34.84
Sprung weight per axle	40,460	39,120	53,130	51,240	48,990	55,220	51,080	57,790	23,720	24,220
Unsprung weight per axle	3,000	3,000	3,000	3,000	5,500	13,000	15,600	13,000	3,000	3,000
Total wheel weights-Left side	19,595	20,475	27,545	27,715	28,250	33,870	33,530	34,680	12,970	14,300
Total wheel weights-Right side	23,865	21,645	28,585	26,525	26,240	34,350	33,150	36,110	13,750	12,920
Sprung weight per axle / Total weight per axle	0.930	0.929	0.946	0.944	0.899	0.809	0.766	0.816	0.888	0.889

LOCOMOTIVE AND TENDER SPRING DATA								
AXLE NUMBER	SPRING NUMBER	NUMBER OF SPRINGS	LOAD REQUIRED TO PRODUCE ONE INCH DEFLECTION — EACH SPRING	LOAD REQUIRED TO PRODUCE ONE INCH DEFLECTION — TOTAL FOR AXLE	SPRUNG WEIGHT — POUNDS	STATIC DEFLECTION — INCHES	TIME OF VIBRATION — SECONDS	FREQUENCY — VIBRATIONS PER SECOND
1 And 2	A	2	24,700	49,400	47,940	0.97	0.314	3.18
3	B	2	21,700	43,400	57,790	1.33	0.369	2.71
4	B	2	21,700	43,400	51,080	1.18	0.347	2.88
5	B	2	21,700	43,400	55,220	1.14	0.341	2.93
6	C	2	11,000	31,100	48,990	1.58	0.401	2.49
	D	4	2,275					
7 And 8	E	4	67,800	46,000	104,370	2.27	0.480	2.08
	F	12	4,620					
9 And 10	E	4	67,800	46,000	79,580	1.73	0.420	2.38
	F	12	4,620					

TOTAL FOR LOCOMOTIVE

Load required to produce one inch deflection = 210,700 Lbs
Sprung weight = 261,030 Lbs
Static deflection = 1.24 In.
Time of vibration = 0.355 Sec
Frequency = 2.81 Vib. per sec
$\frac{\text{Sprung weight}}{\text{Total weight}} = 0.83.$

FIG. 16
LOCOMOTIVE CLASS K4-5
SPRING ARRANGEMENT AND EQUALIZING SYSTEM



LOCOMOTIVE AND TENDER SPRING DATA

AXLE NUMBER	SPRING NUMBER	NUMBER OF SPRINGS	LOAD REQUIRED TO PRODUCE ONE INCH DEFLECTION EACH SPRING	LOAD REQUIRED TO PRODUCE ONE INCH DEFLECTION TOTAL FOR AXLE	SPRUNG WEIGHT POUNDS	STATIC DEFLECTION INCHES	TIME OF VIBRATION SECONDS	FREQUENCY VIBRATIONS PER SECOND
1 and 2	A	2	24,700	49,400	50,760	1.03	0.325	3.08
3	B	2	21,700	43,400	50,870	1.17	0.346	2.89
4	B	2	21,700	43,400	52,010	1.20	0.350	2.86
5	B	2	21,700	43,400	52,790	1.22	0.352	2.84
6	B	2	21,700	43,400	58,240	1.34	0.369	2.71
7	C	2	11,000	31,100	55,210	1 78	0.425	2.35
	D	4	2,275					
8,9 and 10	E	20	9,867	97,340	186,430	0.94	0.308	3.24
11,12 and 13	E	20	9,867	197,340	174,640	0.88	0.299	3.34

TOTAL FOR LOCOMOTIVE: Load required to produce one inch deflection = 254,100 Lbs
Sprung weight = 319,880 Lbs.
Static deflection = 1.26 In.
Time of vibration = 0.359 Sec
Frequency = 2.78 Vib. per sec
$\frac{\text{Sprung weight}}{\text{Total weight}} = 0.825$

FIG. 17
LOCOMOTIVE CLASS MI-A
SPRING ARRANGEMENT AND EQUALIZING SYSTEM

was then computed. The static deflection of the total sprung weight of the locomotive and the corresponding frequency of the spring group was then computed by using the sum of the coefficients for each spring or axle. This method assumes that the equalizing system will adjust the axle loads so that there will be a uniform static deflection of the locomotive.

The theoretical frequencies of the locomotive springs are given in Figs. 14 to 17, inclusive.

(c) While the magnitude of the roll of the locomotive, or the transfer of weight from one rail to the other, could be obtained from the stress readings in the two girders of one span, no instruments were available for measuring the period of this roll. It is hoped that this information can be obtained in future tests as it may help to establish some relation between speed and the amount of roll, and it is one of the factors affecting the nosing force.

(d) What is said as to the rolling of the locomotive, applies equally to the nosing or weaving from side to side. This movement is probably periodic and may produce lateral stresses of such magnitude that they can not be disregarded. That this force was quite large, in these tests at least, is apparent from the measured lateral deflection of the spans.

(e) Irregularities in the wheel treads or their eccentric mounting produce vertical forces when the locomotive is in motion and the same effect may be caused by inequalities in the surface of the rail. These forces have a relatively greater effect on short spans than on long spans.

(f) An important dynamic effect from a locomotive is due to the centrifugal forces set up by the unbalanced weights on its drivers. In these tests such forces occurred only with the steam engines, as there were no unbalanced rotating weights on the wheels of the electric locomotives.

This unbalanced condition of the steam locomotives is frequently referred to as overbalance and consists of weight added to the wheels to partially counteract the effect of the reciprocating parts, which consist of the piston, cross-head, union link and a part of the main rod. The necessary information required for the analysis of the counterbalancing of these locomotives was furnished by the mechanical department of the Pennsylvania Railroad and is given in Tables 1 and 2.

In calculating the centrifugal force or "hammer blow" produced by the two steam locomotives, it was thought desirable to compute the overbalance by two methods which are usually referred to as the "static method" and the "dynamic method". In the static method of analysis the static weights of the main rod, side rods, eccentric crank, eccentric rod, crank pin and counterweights are considered but the transverse moments caused by these weights rotating in different planes are neglected. In the dynamic method of analysis not only the weights of the main rod, side rods, eccentric crank, eccentric rod, crank pin and counterweight but also the transverse moments due to their different planes of rotation are considered.

In the dynamic method of analysis certain refinements are also made in the determination of the effective revolving weight of the main rod, eccentric crank and eccentric rod. The motion of the main rod, relative to the locomotive, is of course rotational at one end and reciprocating at the other. The equivalent revolving weight of the crank pin end of the main rod may be determined by the equations for plane motion of a rigid body. Investigations of a number of main rods have shown that the equivalent revolving weight is approximately seven-eighths of the scale weight of the crank pin end, and this value was accordingly used in these analyses.

TABLE 1

GENERAL LOCOMOTIVE DATA
LOCOMOTIVE CLASS K4-S (STEAM)

Crank Pin Radius	14 in.
Stroke	28 in.
Cylinder Centers	89 in.
Driver Circumference (Actual)	20.67 ft.
Speed at One Revolution per Second:	
(a) Feet per Second	20.67
(b) Miles per Hour	14.093
Total Weight of Engine	314,120 lbs.
Total Weight of Full Tender	195,960 lbs.

FRONT DRIVER (Wheel #3)

Weight of Side Rod	164 lbs.
Weight of Side Rod Fit	40 lbs.
Counter-weight	439 lbs.
Side Rod Centers	76.00 in.
Counter-weight centers	60.50 in.

MAIN DRIVER (Wheel #4)

Weight of Side Rod	652 lbs.
Weight of Side Rod Fit	86 lbs.
Weight of Back End of Main Rod (Actual)	586 lbs.
Weight of Back End of Main Rod (Corrected)	514 lbs.
Weight of Main Rod Fit	75 lbs.
Weight of Eccentric Crank	130 lbs.
Weight of Eccentric Crank Fit	15 lbs.
Weight of Back End of Eccentric Rod (Actual)	30 lbs.
Weight of Back End of Eccentric Rod (Corrected)	26 lbs.
Counter Weight	1740 lbs.
Side Rod Centers	76.00 in.
Main Rod Centers	89.00 in.
Eccentric Crank Centers	98.75 in.
Counter-weight Centers	63.00 in.
Eccentric Crank Length	15.88 in.
Eccentric Throw	15.00 in.
Distance Center of Gravity of Eccentric Crank from Center of Rotation	10.00 in.

REAR DRIVER (Wheel #5)

Weight of Side Rod	190 lbs.
Weight of Side Rod Fit	40 lbs.
Counter-weight	465 lbs.
Side Rod Centers	89.00 in.
Counter-weight Centers	60.50 in.

RECIPROCATING WEIGHTS (One Side)

Piston and Piston Rod	467 lbs.
Cross-Head Shoe and Pin	604 lbs.
Union Link	11 lbs.
Main Rod Front End	474 lbs.
Total	1556 lbs.

RECIPROCATING WEIGHTS BALANCED

	Dynamic Method of Analysis		Static Method of Analysis	
	Right Side	Left Side	Right Side	Left Side
Front Driver	209	209	235	235
Main Driver	92	66	235	235
Rear Driver	215	215	235	235
Total	516	490	705	705
Per Cent.	33.2	31.5	45.4	45.4

$$\frac{\text{Weight of Engine}}{\text{Reciprocating Weights}} = \frac{314{,}120}{1{,}556} = 202$$

The weight of the eccentric crank for both steam locomotives is 130 lb. with its center of gravity 10 in. from the center of rotation of the main driver. A radial line through the center of gravity of the eccentric crank makes an angle of approximately 15 deg. with a radial line through the crank pin and lags the pin in rotation in both main drivers when the motion of the locomotive is forward. For purposes of analysis it was convenient to divide the weight of the eccentric crank into two components, one being parallel to a radial line through the crank pin and the other at an angle of 90 deg. thereto. The equivalent revolving weight of the back end of the eccentric rod was added to the 90-deg. component while the part of the crank pin encircled by the eccentric crank was added to the component parallel to a radial line through the crank pin.

TABLE 2

GENERAL LOCOMOTIVE DATA
LOCOMOTIVE CLASS M1-A (STEAM)

Crank Pin Radius	15 in.
Stroke	30 in.
Cylinder Centers	91.5 in.
Driver Circumference (Actual)	18.58 ft.
Speed at One Revolution per Second:	
(a) Feet per Second	18.58
(b) Miles per Hour	12.668
Total Weight of Engine	387,580 lbs.
Total Weight of Full Tender	385,070 lbs.
FRONT DRIVER (Wheel #3)	
Weight of Side Rod	136 lbs.
Weight of Side Rod Fit	36 lbs.
Counter-weight	366 lbs.
Side Rod Centers	76.625 in.
Counter-weight Centers	60.875 in.
MAIN DRIVER (Wheel #4)	
Weight of Side Rod	625 lbs.
Weight of Side Rod Fit	108 lbs.
Weight of Back End of Main Rod (Actual)	606 lbs.
Weight of Back End of Main Rod (Corrected)	531 lbs.
Weight of Main Rod Fit	109 lbs.
Weight of Eccentric Crank	130 lbs.
Weight of Eccentric Crank Fit	20 lbs.
Weight of Back End of Eccentric Rod (Actual)	30 lbs.
Weight of Back End of Eccentric Rod (Corrected)	26 lbs.
Counter-weight	1766 lbs.
Side Rod Centers	76.625 in.
Main Rod Centers	91.500 in.
Eccentric Crank Centers	103.00 in.
Counter-weight Centers	63.25 in.
Eccentric Crank Length	16.77 in.
Eccentric Throw	15.00 in.
Distance Center of Gravity of Eccentric Crank from Center of Rotation	10.00 in.
INTERMEDIATE DRIVER (Wheel #5)	
Weight of Side Rod	463 lbs.
Weight of Side Rod Fit	36 lbs.
Counter-weight	713 lbs.
Side Rod Centers	76.625 in.
Counter-weight Centers	61.000 in.
REAR DRIVER (Wheel #6)	
Weight of Side Rod	144 lbs.
Weight of Side Rod Fit	36 lbs.
Counter-weight	394 lbs.
Side Rod Centers	76.625 in.
Counter-weight Centers	60.875 in.
RECIPROCATING WEIGHTS (One Side)	
Piston and Piston Rod	609 lbs.
Cross Head Shoe and Pin	737 lbs.
Union Link	21 lbs.
Main Rod Front End	515 lbs.
Total	1882 lbs.

RECIPROCATING WEIGHTS BALANCED

	Dynamic Method of Analysis		Static Method of Analysis	
	Right Side	Left Side	Right Side	Left Side
Front Driver	189	189	214	214
Main Driver	45	22	214	214
Intermediate Driver	149	149	214	214
Rear Driver	189	189	214	214
Total	572	549	856	856
Per Cent.	30.4	29.2	45.5	45.5

$$\frac{\text{Weight of Engine}}{\text{Reciprocating Weights}} = \frac{387,580}{1,882} = 206$$

The revolving weights may be considered to be proportional to the rotational or centrifugal forces which act radially, for any given speed of the locomotive, and for convenience they may be considered as forces with horizontal and vertical components. Using the values of these forces with the crank pin on the right side in an up position, moments of (1) the vertical forces and (2) the horizontal forces acting on a pair of driving wheels, are taken about a vertical plane through the center of the counterweight of the left wheel of the pair. Corresponding moments are then taken about the vertical plane through the center of the counterweight of the right driver. From these moments the resultant unbalanced weights (horizontal and vertical components and their resultant) in the plane of the counterweight are determined.

It should be understood that these calculated values of resultant unbalanced weights do not in any way show lack of proper attention to the counterbalancing of the locomotives. It is common practice to place more counterweight in the driving wheels of a locomotive than is required to balance the rotating parts in order that the inertia effects of the reciprocating parts may be reduced, with a resulting reduction in the shaking forces on the locomotive frame and in the reduction of its nosing tendency. It is necessary, however, to know the amount and position of the resultant unbalanced weights in each driving wheel resulting from this practice in order that proper interpretation may be placed on the measured oscillations.

The general formula for calculating the hammer blow produced by the unbalanced rotating parts is the formula for centrifugal force

$$H.B. = \frac{W}{g} r\omega^2$$

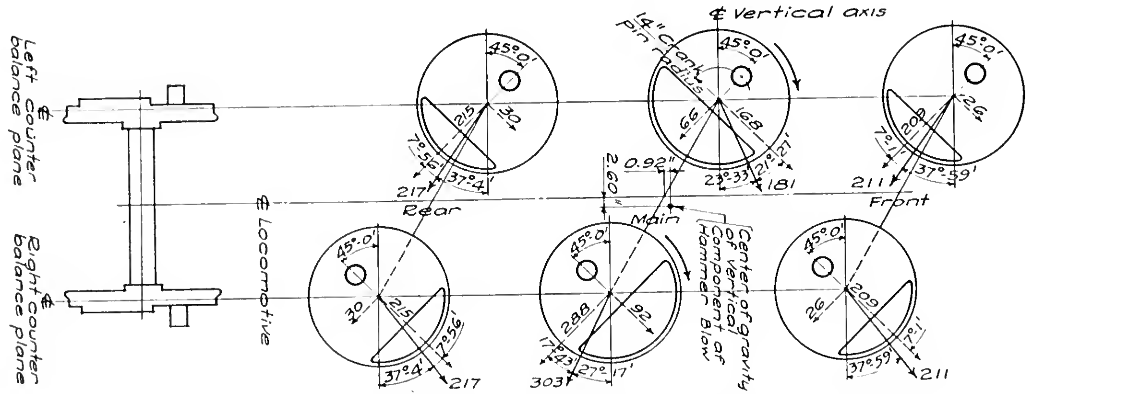
in which

$H.B.$ = Hammer blow or centrifugal force in pounds
W = The unbalanced weight at crank-pin radius which produces the hammer blow in pounds
g = The acceleration due to gravity in feet per second per second
r = The crank pin radius in feet
ω = The angular velocity in radians (1 revolution = 2π radians)

Upon examining the oscillograph records, of which those shown in Figures 24 to 27, inclusive, are typical, it can be seen that both girders are acting in unison, that is, the oscillations in both the east and west girders are in phase. The resultant axle hammer blow was therefore considered as producing the oscillations instead of the resultant hammer blow for each side of the locomotive. It should be understood that in short spans, in which there are no cross bracing, the two stringers or girders may act independently. For such spans the resultant hammer blow for each side of the locomotive should be used. The maximum resultant axle hammer blow, for the locomotives used, occurs when the crank pins on the left side are 45 deg. past, and the crank pins on the right side are within 45 deg. of the vertical.

The resultant unbalanced weights as computed by the dynamic method of analysis, for each driver of the two steam locomotives with the maximum hammer blow at one revolution per second and the vertical component of the hammer blow when the pins are 45 deg. from the vertical (pin position for maximum effect on the bridge) are shown in Figures 18 and 19. These results, as mentioned previously, are based upon an analysis considering the out-of-plane effect of the revolving parts and certain refinements in the determination of the effective revolving weights of the main rod, eccentric crank and eccentric rod.

The results obtained from a counterbalance analysis of these locomotives by the static method of analysis, in which the effective revolving weight of the main rod on the crank pin is considered as the actual scale weight, and neglecting the 90-deg. component of the eccentric crank and eccentric rod and the out-of-plane effects of all the revolving parts, are shown in Figures 20 and 21. *(Text continued on page 427)*



COMPONENTS AND RESULTANT UNBALANCED WEIGHTS IN POUNDS
(Pin position for maximum effect on bridge)

MAXIMUM HAMMER BLOW AT ONE REVOLUTION PER SECOND

	RIGHT SIDE	LEFT SIDE
Front driver	302	302
Main driver	434	259
Rear driver	311	311

VERTICAL COMPONENT OF HAMMER BLOW AT ONE REVOLUTION PER SECOND
(Crank pins at 45°-0')

	RIGHT SIDE	LEFT SIDE	BOTH SIDES
Front driver	238	238	476
Main driver	385	237	622
Rear driver	238	238	476
Total	861	713	1574

OVERBALANCE OPPOSITE PINS
(Reciprocating balance)

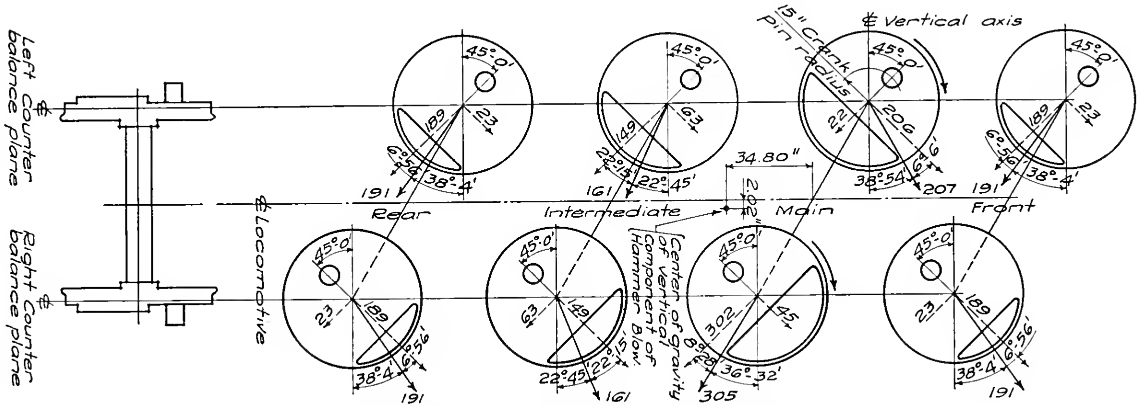
	RIGHT SIDE	LEFT SIDE	BOTH SIDES
Front driver	209	209	418
Main driver	92	66	158
Rear driver	215	215	430
Total	516	490	1006

$$H.B \ @ \ 1 \ r.p.s. = \frac{W}{g} \cdot r \cdot \omega^2$$

$$= \frac{W}{32.2} \cdot \frac{14}{12} \cdot (2 \times 3.1416)^2 = 1.43 W$$

FIG. 18
LOCOMOTIVE CLASS K4-S

UNBALANCED WEIGHTS
BY
DYNAMIC METHOD OF ANALYSIS



COMPONENTS AND RESULTANT UNBALANCED WEIGHTS IN POUNDS
(Pin position for maximum effect on bridge)

MAXIMUM HAMMER BLOW AT ONE REVOLUTION PER SECOND

	RIGHT SIDE	LEFT SIDE
Front driver	292	292
Main driver	466	317
Inter. driver	247	247
Rear driver	292	292

VERTICAL COMPONENT OF HAMMER BLOW AT ONE REVOLUTION PER SECOND (Crank pins at 45°-0')

	RIGHT SIDE	LEFT SIDE	BOTH SIDES
Front driver	231	231	462
Main driver	375	246	621
Inter. driver	231	231	462
Rear driver	231	231	462
Total	1068	939	2007

OVERBALANCE OPPOSITE PINS (Reciprocating balance)

	RIGHT SIDE	LEFT SIDE	BOTH SIDES
Front driver	189	189	378
Main driver	45	22	67
Inter. driver	149	149	298
Rear driver	189	189	378
Total	572	549	1121

$$H\,B. \text{ @ } 1\,r.p.s. = \frac{W}{g} \cdot r\,\omega^2$$

$$= \frac{W}{32.2} \cdot \frac{15}{12} \cdot (2 \times 3.1416)^2 = 1\ 53\,W$$

FIG. 19
LOCOMOTIVE CLASS M1-A
UNBALANCED WEIGHTS BY DYNAMIC METHOD OF ANALYSIS

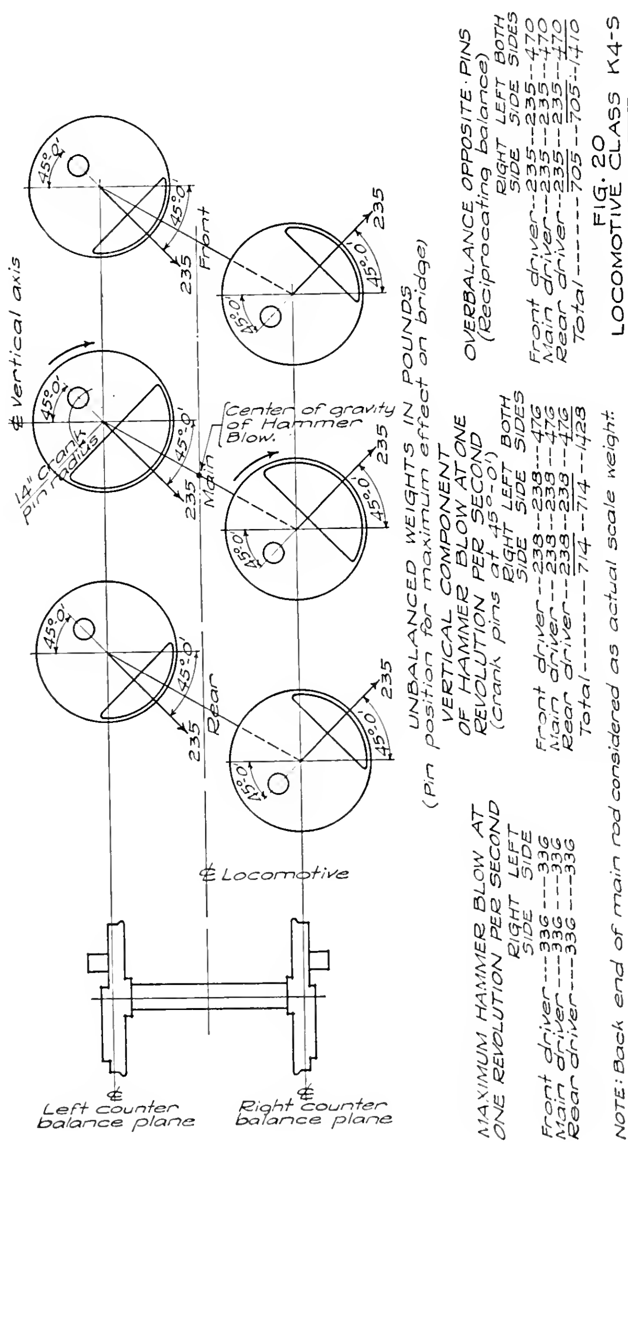
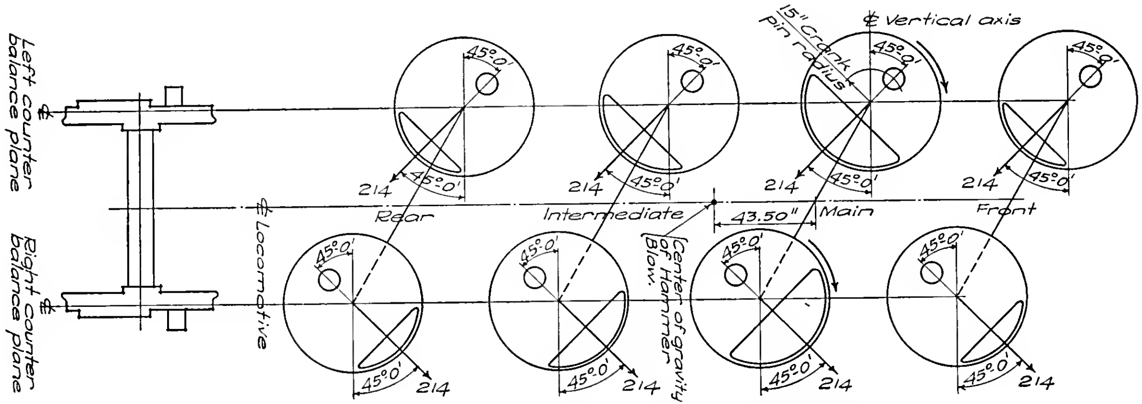


FIG. 20
LOCOMOTIVE CLASS K4-S
UNBALANCED WEIGHTS BY STATIC METHOD OF ANALYSIS



UNBALANCED WEIGHTS IN POUNDS
(Pin position for maximum effect on bridge)

MAXIMUM HAMMER BLOW AT ONE REVOLUTION PER SECOND

	RIGHT SIDE	LEFT SIDE
Front driver	327	327
Main driver	327	327
Inter. driver	327	327
Rear driver	327	327

VERTICAL COMPONENT OF HAMMER BLOW AT ONE REVOLUTION PER SECOND (Crank pins at 45°-0')

	RIGHT SIDE	LEFT SIDE	BOTH SIDES
Front driver	231	231	462
Main driver	231	231	462
Inter. driver	231	231	462
Rear driver	231	231	462
Total	924	924	1848

OVERBALANCE OPPOSITE PINS (Reciprocating balance)

	RIGHT SIDE	LEFT SIDE	BOTH SIDES
Front driver	214	214	428
Main driver	214	214	428
Inter. driver	214	214	428
Rear driver	214	214	428
Total	856	856	1712

NOTE: Back end of main rod considered as actual scale weight.

FIG. 21
LOCOMOTIVE CLASS M1-A
UNBALANCED WEIGHTS BY STATIC METHOD OF ANALYSIS

7. General Test Procedure

After the test building, platforms, foot-walk, stairs, etc., had been erected, the necessary holes in the girders of the test spans were drilled and tapped to provide for the attachment of the instruments. The electrical circuits for the gages and deflectometers were then connected, but the instruments were not placed until they had been calibrated.

In calibrating the electro-magnetic strain gages, the air gap in the balancing gage was first set to have a clearance of approximately 0.005 in. Each indicating gage was then placed on the calibrating stand and adjusted by changing its air gap until the galvanometer indicated that the amounts of current flowing through the two sides of the Wheatstone bridge were balanced. The air gap of the indicating gage was then changed by known increments and the corresponding deflection was recorded by the oscillograph. The change in the air gap was measured by means of the "Last Word" dial on the calibrating stand, which was graduated to record movements of 1/10,000 in. See Fig. 22. The desired amount of galvanometer deflection per increment of air gap change was secured by varying the resistance connected in series with the galvanometer.

After the gages had been calibrated they were placed on the test spans and a loaded car of known weight was spotted on the span in position for maximum moment and readings were taken with 10-in. Berry strain gages, held along side the magnetic strain gages. The result of this comparative test for both spans is given below:

	Berry Strain Gages *Stress* *lb. per sq. in.*	*Magnetic Strain Gages* *Stress* *lb. per sq. in.*
55-Ft. 10-In. Span		
Top—east girder—compression	7,200	6,800
Bottom—east girder—tension	7,100	7,600
Average—top and bottom	7,150	7,200
Percent variation—top or bottom stress from average	0.70	5.56
Top—west girder—compression	7,300	6,800
Bottom—west girder—tension	7,200	7,600
Average—top and bottom	7,250	7,200
Percent variation—top or bottom stress from average	0.69	5.56
122-Ft. Span		
Top—east girder—compression	4,500	4,900
Bottom—east girder—tension	4,600	4,800
Average—top and bottom	4,550	4,850
Percent variation—top or bottom from average.	1.10	1.03
Top—west girder—compression	4,400	4,600
Bottom—west girder—tension	4,800	5,100
Average—top and bottom	4,600	4,850
Percent variation—top or bottom from average.	4.35	5.15

Test runs were made at approximate speed variations of five m.p.h. up to the maximum speed permissible with the particular type of locomotive used. Runs at intermediate speeds were then made with a view to carefully checking the existence of any relation between the recorded dynamic values and the theoretical values which had previously been determined.

Photographs were taken of the steam locomotives on all runs when the speed exceeded 50 m.p.h. These photographs, of which Fig. 23 is typical, included a marker showing the run number and a scale board graduated in feet and attached to the rail. This scale board, together with arrow head painted on the driving wheels of the locomotive made it possible to determine the location of the crank pins with respect to the center of the spans.

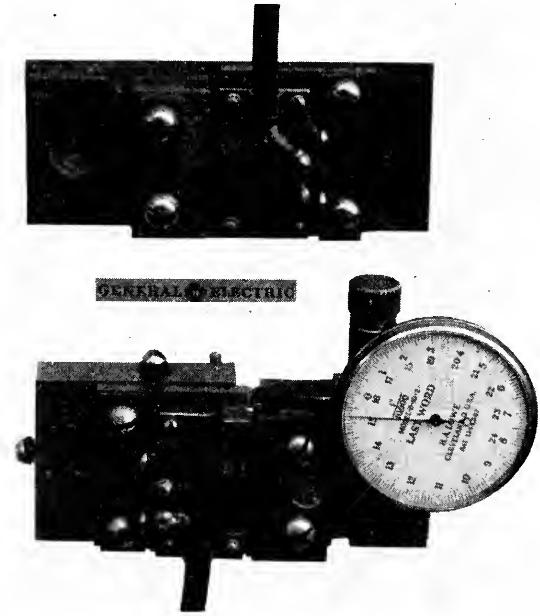


Fig. 22—View of Last Word Dial Calibrating Stand

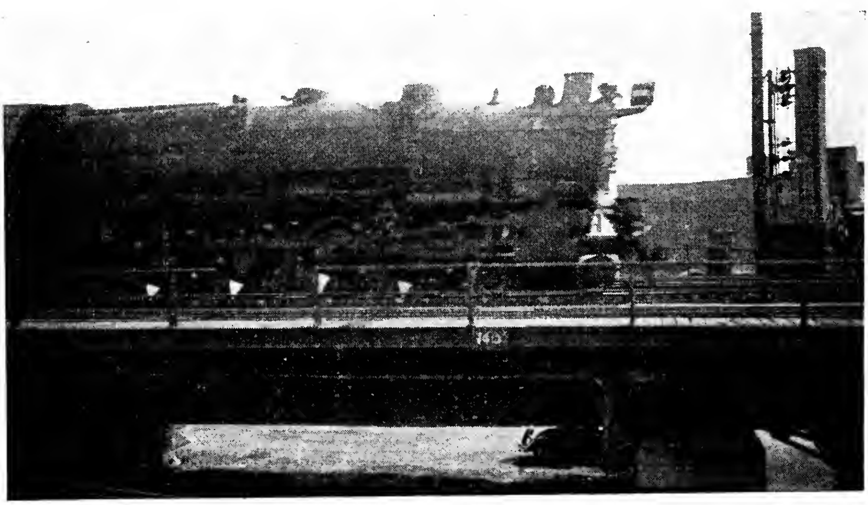


Fig. 23—View of Steam Locomotive on Test Span

All photographic and oscillograph films were developed in the dark room in the test building immediately after the exposures had been made. As soon as the films were dry, they were properly labeled to designate the date, run number, class and speed of locomotive and instrument numbers.

8. Analysis of Field Records

Test Records

Black-line prints of all the test records were made from the oscillograph photographic film and these prints were then bound together in three volumes and in consecutive order, according to speed, for each locomotive. Volume I contains all the records for span number 6, while Volumes II and III contain the records for span number 7.

Since it would make this report too voluminous to include all of the test records, only typical records are included as shown in Figures 24 to 27, inclusive. These volumes of test records, as well as the Big Four mechanical deflectometer records, are now on file in the engineering division offices, Association of American Railroads.

Reading of Records

For an analysis of the records it was first necessary to draw base lines representing zero stress and deflection. Since the reflected light ray was quite wide in some cases, resulting in a thick stress or deflection line, it was decided to measure all stresses and deflections from one side of the line, as shown in the typical examples, Figures 24 to 27. Light dotted lines, called upper and lower envelope curves, were then drawn through the peaks of the oscillations. A solid line, called the mean stress or mean deflection curve, was then drawn midway between the upper and lower envelope curves. It should be pointed out that, at very slow speeds, the mean stress or deflection curve represents the static stress or deflection, at the center of the span, for the different positions of the locomotive as it passed over the span. As the speed of the locomotive increases, the mean stress curve is affected by the speed of application of the load and by the roll of the locomotive, as will be shown later.

As pointed out in AREA Proceedings for 1936, Vol. 37, page 760, the oscillations in any span keep building up until they reach a maximum and then become smaller. In the 55-ft. 10-in. span, the maximum oscillation at all speeds occurred at the time of maximum mean stress or deflection. In long spans this condition may not obtain, as the oscillations usually reached their maximum value before the time of maximum mean stress or deflection when the speed exceeded the synchronous, and after that time when the speed was lower than synchronous. But in the 122-ft. span this variation was negligible, and, as with the short span, the values of the oscillations were scaled at the point of maximum mean stress or deflection.

Stress and Deflection Corrections

To the values of stresses and deflections, as first scaled from the records, it was necessary to make the following corrections:

(1) *Strain Instrument Correction.*—The center of gravity of the "air gap" on the magnetic strain gages being ⅞ in. from the base, the strains were recorded on a plane which was ⅞ in. farther from the neutral axis than the extreme part of the steel. Assuming that the stress is proportional to the distance from the neutral axis, this correction factor amounted to 0.972 for the 55-ft. 10-in. span and 0.985 for the 122-ft. span.

(2) *Mechanical Deflectometer Wire Tension Correction.*—As the span deflected from its initial position, there was a corresponding change in the spring tension, causing a change of stress in the wire leading to the ground weight. This variation in stress was

(Text continued on page 434)

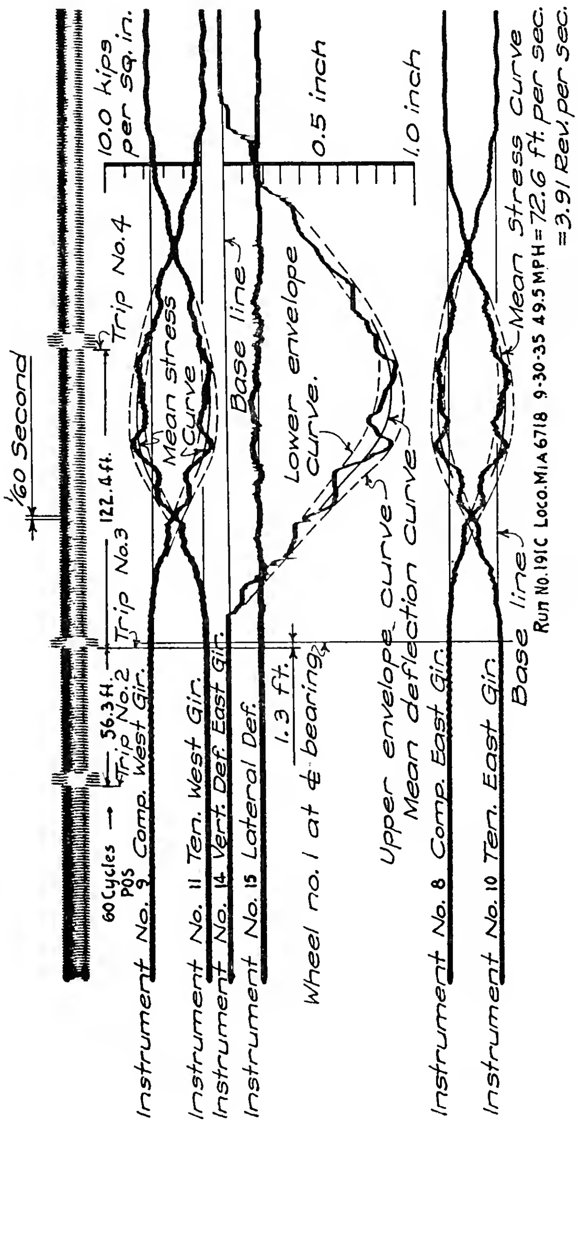


FIG. 24
TYPICAL STRAIN AND DEFLECTION RECORD
122'-0" GIRDER SPAN
LOCOMOTIVE CLASS MI-A (STEAM)

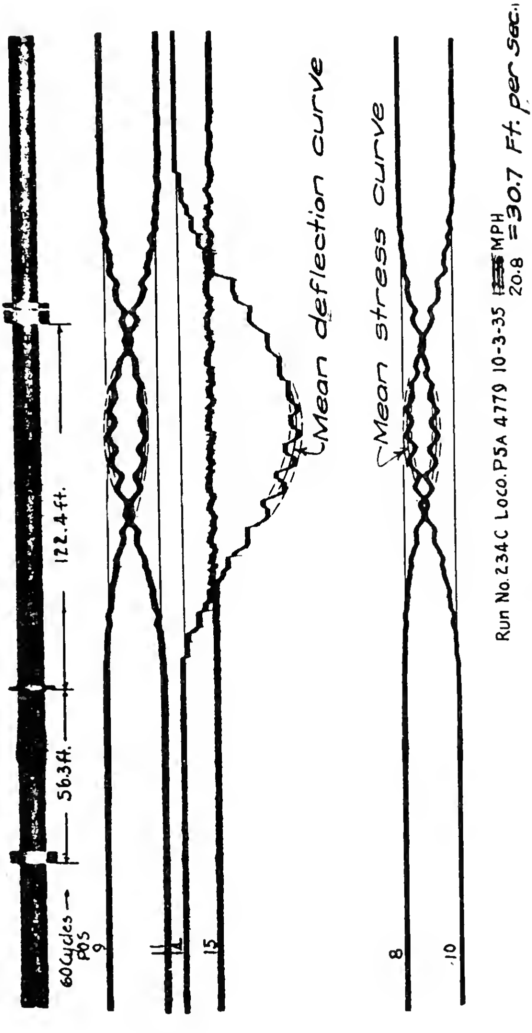


FIG. 25
TYPICAL STRAIN AND DEFLECTION RECORD
122'-0" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)

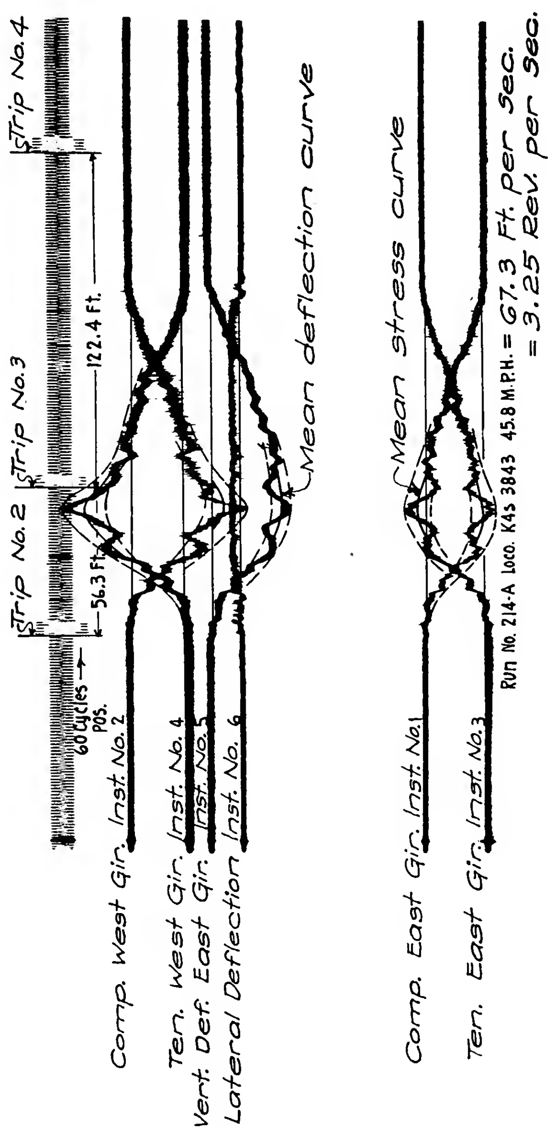


FIG. 26
TYPICAL STRAIN AND DEFLECTION RECORD
55'-10" GIRDER SPAN
LOCOMOTIVE CLASS K4-5 (STEAM)

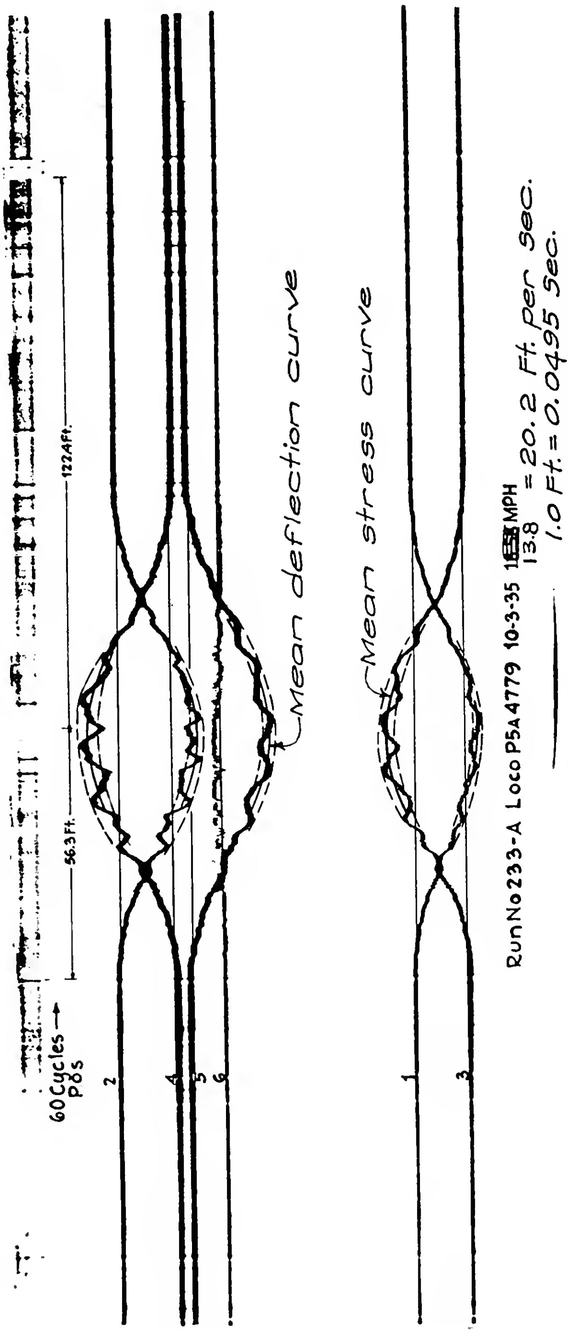


FIG. 27
TYPICAL STRAIN AND DEFLECTION RECORD
55'-10" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)

accompanied by a proportional variation in length, and for the wire used with these instruments, which was of 0.080 in. in diameter actuated by a spring having a constant of 2.2 lb., this correction amounted to 0.00279 in. additional deflection for each inch deflection of the 55-ft. 10-in. span and 0.00664 in. additional deflection for each inch deflection of the 122-ft. span.

(3) *Coal and Water Deduction Correction.*—The amount of coal and water in the tenders of the steam locomotives was measured and recorded before each test run. The variation in the stresses and deflections due to the difference in tender weights was computed and the scaled values for each run were corrected so that all of the values shown in the tables are on the basis of full tenders. Since the tender was not on the 55 ft. 10 in. span at the time of maximum stress and deflection, it was not necessary to correct these values. The correction factors for the 122-ft. span were as follows:

Locomotive Class K4–5

Stress in kips per sq. in. = 0.0465 P
Deflection in inches = 0.00734P

Locomotive Class M1–A

Stress in kips per sq. in. = 0.0755 P
Deflection in inches = 0.0107 P

in which "P" is the reduction in tender wheel loads, in kips.

The maximum correction for locomotive Class K4–S was for run 206 at a speed of 88.3 m.p.h., when sufficient water and coal had been used to reduce the tender wheel loads by 9.05 kips, so that it was necessary to add 0.42 kips per sq. in. to the mean and maximum stresses and 0.066 in. to the mean and maximum deflections. The maximum correction for locomotive Class M1–A was for run 154 at a speed of 46.2 m.p.h. The reduction in tender wheel loads for this run amounted to 9.08 kips so that it was necessary to add 0.69 kips per sq. in. to the mean and maximum stresses and 0.095 in. to the mean and maximum deflections.

The vertical stresses and deflections, as corrected, are shown for the four classes of locomotives, in Tables 3, 4, 5 and 6 for the 55-ft. 10-in. span and in Tables 7, 8, 9 and 10 for the 122-ft. span. In these tables, the "maximum stress" or "maximum deflection" is the sum of the "mean stress" or "mean deflection" and the "semi-amplitude stress" or "semi-amplitude deflection"; this stress or deflection includes all of the dynamic effects of the moving load except the roll effect.

It should be kept in mind that the measured stresses represent the average strain over the gage length of three inches and it is probable that they are lower in intensity than if they had been measured on a shorter gage length at a section through the rivet holes. These measured stresses therefore should not be considered as the maximum stress concentration which may occur, but they do indicate the variation in unit stress under different conditions of loading.

It will be noted that for most of the runs, the unit stress in the top flange is lower than that in the bottom flange. This may be due, in part, as pointed out above, to the fact that on the tension flange, the gages were affected more by the net section than the gages on the compression flange. By referring to the comparative tests made with the 10-in. Berry gages and the electro-magnetic gages under a stationary car of known weight, as given on page 427 it can be seen that the average of the top and bottom electro-magnetic gage reading agrees closely with the average of the Berry gage readings. For this reason it was felt that more reliable impact percentages would be secured if the average of the top and bottom stresses were used. Another factor contributing to this

(Text continued on page 447)

TABLE 3

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)

		STRAIN INSTRUMENTS																		DEFLECTION INSTRUMENTS					
		MEAN STRESSES Instrument Number						SEMI-AMPLITUDES Instrument Number						MAXIMUM STRESSES Instrument Number						Electrical Deflectometer East Girder			Mechanical Deflectometer East Girder		
		East Girder			West Girder			East Girder			West Girder			East Girder			West Girder								
Run No.	Speed M.P.H.	1 Comp.	3 Ten.	Ave.	2 Comp.	4 Ten.	Ave.	1 Comp.	3 Ten.	Ave.	2 Comp.	4 Ten.	Ave.	1 Comp.	3 Ten.	Ave.	2 Comp.	4 Ten.	Ave.	Mean	Semi-Amp.	Max.	Mean	Semi-Amp.	Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
100	4.3	6.90	7.58	7.24	6.70	8.34	7.52	0.29	0.29	0.29	0.39	0.19	0.29	7.18	7.86	7.52	7.08	8.54	7.81	0.480	0.010	0.490	0.500	0	0.500
229	4.6	6.50	8.26	7.38	7.96	8.94	8.45	0.19	0.29	0.24	0.68	0.29	0.53	6.70	8.54	7.62	8.64	9.22	8.93	0.420	0.010	0.430	0.470	0	0.470
101	4.9	6.80	7.68	7.24	6.89	8.35	7.62	0.29	0.29	0.29	0.39	0.39	0.39	7.09	7.97	7.53	7.28	8.74	8.01	0.480	0.010	0.490	0.495	0	0.495
102	5.6	7.00	7.86	7.43	7.09	8.35	7.72	0.39	0.39	0.39	0.39	0.39	0.39	7.38	8.26	7.82	7.48	8.74	8.11	0.480	0.020	0.500	0.505	0	0.505
230	7.5	6.50	8.26	7.38	8.16	8.54	8.35	0.19	0.39	0.29	0.59	0.39	0.49	6.70	8.64	7.67	8.74	8.94	8.84	0.420	0.010	0.430	0.480	0.015	0.495
232	10.2	6.41	8.15	7.28	8.25	9.03	8.64	0.10	0.49	0.25	0.78	0.48	0.63	6.51	8.65	7.58	9.03	9.61	9.32	0.415	0.015	0.430	0.470	0.020	0.490
231	13.4	6.51	7.95	7.23	7.86	8.64	8.25	0.49	1.07	0.78	0.87	1.17	1.02	7.00	9.04	8.02	8.74	9.84	9.29	0.410	0.050	0.460	0.460	0.070	0.530
233	13.8	6.32	7.96	7.14	8.06	8.66	8.36	0.49	0.78	0.63	0.68	0.98	0.83	6.81	8.75	7.78	8.75	9.61	9.18	0.420	0.030	0.450	0.455	0.045	0.500
253	14.2	6.32	7.86	7.09	7.78	8.06	7.92	0.49	0.78	0.63	0.68	0.98	0.83	6.81	8.65	7.73	8.46	9.04	8.75	0.410	0.030	0.440	0.485	0.045	0.530
234	20.8	6.42	8.06	7.24	7.97	8.55	8.26	0.58	0.68	0.63	0.68	0.58	0.63	7.00	8.76	7.88	8.65	9.13	8.89	0.425	0.025	0.450	0.460	0.040	0.500
235	26.1	6.42	8.26	7.34	8.26	8.76	8.51	0.49	0.49	0.49	1.36	0.78	1.07	6.90	8.76	7.83	9.62	9.52	9.57	0.430	0.020	0.450	0.475	0.025	0.500
236	28.7	6.42	8.26	7.34	8.36	8.46	8.41	0.58	0.49	0.53	1.17	0.68	0.92	7.00	8.76	7.88	9.52	9.14	9.33	0.430	0.020	0.450	0.480	0.030	0.510
237	29.3	6.42	8.26	7.34	8.15	8.65	8.40	0.68	0.58	0.63	1.17	0.58	0.87	7.09	8.83	7.96	9.32	9.22	9.27	0.420	0.030	0.450	0.480	0.040	0.520
104	32.3	7.67	8.25	7.96	7.09	8.05	7.57	1.07	0.87	0.97	0.49	0.58	0.53	8.74	9.12	8.93	7.57	8.65	8.11	0.480	0.050	0.530	0.490	0.060	0.550
252	34.9	6.70	8.26	7.48	8.45	8.35	8.40	0.87	0.77	0.82	0.97	0.58	0.77	7.58	9.02	8.30	9.42	8.94	9.18	0.455	0.035	0.490	0.510	0.045	0.555
251	41.3	6.60	8.16	7.38	7.96	8.26	8.11	1.07	0.77	0.92	1.07	0.87	0.97	7.67	8.93	8.30	9.03	9.13	9.08	0.440	0.030	0.470	0.510	0.050	0.560
105	42.3	7.48	8.06	7.77	6.99	8.05	7.52	1.17	0.77	0.97	0.87	0.87	0.87	8.65	8.85	8.75	7.86	8.94	8.40	0.490	0.055	0.545	0.485	0.065	0.550
238	46.5	7.09	8.45	7.77	8.35	7.97	8.16	0.78	0.78	0.78	1.07	1.07	1.07	7.86	9.22	8.54	9.42	9.04	9.23	0.450	0.030	0.480	0.500	0.040	0.540
107	49.5	7.58	8.16	7.87	6.99	7.87	7.43	0.97	0.77	0.87	0.77	0.87	0.82	8.55	8.93	8.74	7.76	8.74	8.25	0.490	0.050	0.540	0.500	0.035	0.535
106	51.1	7.67	7.87	7.77	6.99	7.77	7.38	0.97	0.97	0.97	0.97	0.97	0.97	8.65	8.85	8.75	7.96	8.74	8.35	0.500	0.040	0.540	0.500	0.030	0.530
108	59.5	7.38	8.16	7.77	7.38	7.86	7.62	0.68	0.48	0.58	0.97	0.87	0.92	8.06	8.64	8.35	8.35	8.75	8.55	0.490	0.030	0.520	0.485	0.025	0.510
239	61.5	7.09	8.25	7.67	8.16	8.26	8.21	0.78	0.39	0.58	1.36	0.97	1.16	7.86	8.64	8.25	10.20	9.88	10.04	0.435	0.015	0.450	0.480	0.020	0.500
246	67.6	6.51	5.93	6.22	10.40	10.50	10.45	0.97	0.97	0.97	1.17	1.17	1.17	7.58	7.88	7.73	11.58	11.68	11.63	0.370	0.030	0.440	0.355	0.055	0.430
109	70.4	6.42	6.32	6.37	8.85	9.43	9.14	1.27	0.97	1.12	0.87	0.97	0.92	7.68	7.28	7.48	10.00	10.90	10.45	0.360	0.060	0.420	0.360	0.060	0.420
240	71.0	6.42	6.52	6.47	9.42	10.20	9.81	1.17	0.97	1.07	0.88	0.78	0.83	7.58	7.48	7.53	10.30	10.90	10.60	0.340	0.040	0.380	0.350	0.050	0.400
241	72.4	6.61	6.51	6.56	9.72	10.60	10.16	1.17	1.07	1.12	0.97	0.97	0.97	7.78	7.58	7.68	10.70	11.58	11.14	0.340	0.040	0.380	0.360	0.050	0.410
243	76.5	6.70	6.60	6.65	10.00	10.70	10.35	1.17	0.97	1.07	1.17	1.17	1.17	7.78	7.58	7.68	11.08	11.78	11.43	0.345	0.035	0.380	0.360	0.030	0.390
249	76.5	6.32	6.22	6.27	9.88	10.50	10.19	0.97	0.97	0.97	0.87	0.97	0.92	7.28	7.18	7.23	10.80	11.48	11.14	0.350	0.040	0.390	0.365	0.045	0.410
242	78.8	6.70	6.32	6.51	9.84	10.60	10.22	1.07	0.87	0.97	1.07	1.07	1.07	7.58	7.58	7.58	10.88	11.66	11.27	0.340	0.030	0.385	0.360	0.045	0.410
244	85.4	6.90	6.42	6.66	11.08	11.38	11.23	0.87	0.97	0.92	0.87	1.07	0.97	8.35	8.05	8.20	11.95	12.43	12.19	0.360	0.030	0.420	0.365	0.045	0.440
245	87.8	7.18	7.86	7.52	10.60	9.91	10.26	1.36	0.88	1.12	1.36	0.97	1.16	8.54	8.74	8.64	11.95	11.95	11.95	0.425	0.035	0.460	0.440	0.045	0.485
111	91.8	6.12	6.61	6.36	8.94	9.42	9.18	0.68	0.49	0.58	0.97	1.17	1.07	8.06	8.64	8.35	9.88	10.60	10.24	0.395	0.035	0.515	0.380	0.040	0.490
248	99.5	7.86	9.52	8.69	9.84	9.04	9.44	0.87	0.97	0.92	1.36	1.16	1.26	8.74	10.50	9.62	11.18	10.20	10.69	0.490	0.040	0.530	0.605	0.025	0.630
112	99.7	7.86	9.04	8.45	8.16	9.14	8.65	1.17	1.17	1.17	1.17	0.87	1.02	9.04	10.20	9.62	9.32	9.72	9.52	0.495	0.045	0.540	0.530	0.040	0.570

NOTE: (a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses are corrected for 7/8 inch distance from extreme steel to instrument.
(d) All mechanical deflectometer readings are corrected for wire tension.
(e) Refer to Figure 10 for location of instruments.

TABLE 4

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC).

Run No.	Speed M.P.H.	STRAIN INSTRUMENTS: MEAN STRESSES, Instrument Number, East Girder 1 Comp.	East Girder 3 Ten.	Ave.	West Girder 2 Comp.	West Girder 4 Ten.	Ave.	SEMI-AMPLITUDES, Instrument Number, East Girder 1 Comp.	East Girder 3 Ten.	Ave.	West Girder 2 Comp.	West Girder 4 Ten.	Ave.	MAXIMUM STRESSES, Instrument Number, East Girder 1 Comp.	East Girder 3 Ten.	Ave.	West Girder 2 Comp.	West Girder 4 Ten.	Ave.	DEFLECTION INSTRUMENTS: Electrical Deflectometers East Girder Mean	Semi-Amp.	Max.	Mechanical Deflectometers East Girder Mean	Semi-Amp.	Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
155	4.4	5.44	6.51	5.98	5.73	7.58	6.66	0.19	0.19	0.19	0.10	0.19	0.14	5.64	6.71	6.18	5.83	7.78	6.80	0.370	0	0.370	0.410	0	0.410
156	9.8	5.73	6.61	6.17	6.22	8.16	7.19	0.10	0.19	0.14	0.19	0.19	0.19	5.83	6.80	6.32	6.22	8.16	7.19	0.370	0	0.370	0.400	0	0.400
228	10.3	5.63	6.52	6.08	6.90	7.58	7.24	0.10	0.19	0.14	0.29	0.10	0.20	5.73	6.71	6.22	7.19	7.68	7.44	0.370	0	0.370	0.400	0	0.400
157	12.7	5.35	6.71	6.03	5.93	7.87	6.90	0.29	0.19	0.24	0.19	0.29	0.24	5.64	6.90	6.27	6.12	8.16	7.14	0.370	0.010	0.380	0.400	0.020	0.420
158	15.6	5.44	6.61	6.02	5.73	7.68	6.70	0.29	0.19	0.24	0.19	0.29	0.24	5.73	6.80	6.26	5.93	7.97	6.95	0.370	0.010	0.380	0.400	0.010	0.410
159	18.5	5.44	6.51	5.98	6.03	7.78	6.90	0.39	0.29	0.34	0.29	0.39	0.34	5.83	6.80	6.32	6.32	8.16	7.24	0.370	0.010	0.380	0.380	0.020	0.400
160	25.0	6.61	6.61	6.61	6.83	7.97	7.00	0.29	0.29	0.29	0.49	0.58	0.54	6.90	6.90	6.90	6.52	8.55	7.54	0.390	0.010	0.400	0.410	0.010	0.420
161	28.7	6.71	6.71	6.71	5.83	7.68	6.76	0.49	0.39	0.44	0.49	0.68	0.58	7.20	7.10	7.15	6.32	8.36	7.34	0.380	0.020	0.400	0.410	0.020	0.430
165	35.2	5.83	6.80	6.32	6.12	7.97	7.04	0.49	0.49	0.49	0.78	0.58	0.68	6.32	7.29	6.80	6.90	8.55	7.72	0.380	0.020	0.400	-	-	-
162	35.7	6.12	6.61	6.36	5.93	7.87	6.90	0.49	0.49	0.49	0.49	0.58	0.54	6.61	7.10	6.86	6.42	8.45	7.44	0.390	0.010	0.400	-	-	-
227	39.7	5.54	6.61	6.08	7.48	7.48	7.48	0.39	0.39	0.39	0.49	0.39	0.44	5.93	7.00	6.46	7.97	7.87	7.92	0.380	0.010	0.390	0.410	0.020	0.430
163	39.8	5.93	6.51	6.22	6.12	7.87	7.00	0.49	0.39	0.44	0.49	0.39	0.44	6.42	6.90	6.66	6.61	8.26	7.44	0.390	0.010	0.400	0.410	0.020	0.430
164	44.7	6.22	7.00	6.61	6.22	8.07	7.14	0.49	0.58	0.54	0.58	0.58	0.58	6.71	7.58	7.14	6.80	8.65	7.72	0.390	0.020	0.410	0.420	0.030	0.450
166	50.1	5.93	6.61	6.27	6.42	7.97	7.20	0.58	0.68	0.63	0.78	0.78	0.78	6.51	7.29	6.90	7.20	8.75	7.98	0.390	0.020	0.410	0.410	0.020	0.430
226	51.1	5.83	7.10	6.46	7.19	7.58	7.38	0.29	0.39	0.34	0.87	0.87	0.87	6.12	7.49	6.80	8.06	8.45	8.26	0.380	0.020	0.400	0.420	0.020	0.440
178	54.8	6.22	6.80	6.51	6.42	7.97	7.20	0.49	0.49	0.49	0.68	0.87	0.78	6.71	7.29	7.00	7.10	8.84	7.97	0.390	0.020	0.410	0.400	0.020	0.420
225	57.0	5.64	6.61	6.12	7.78	7.87	7.82	0.39	0.49	0.44	0.97	0.87	0.92	6.03	7.10	6.56	8.75	8.74	8.74	0.380	0.020	0.400	0.400	0.030	0.430
177	59.8	5.73	6.32	6.02	6.61	8.26	7.44	0.49	0.49	0.49	0.78	0.87	0.82	6.22	6.81	6.52	7.39	9.13	8.26	0.370	0.020	0.390			
179	60.9	5.93	6.12	6.02	6.61	8.16	7.38	0.39	0.58	0.48	0.49	0.68	0.58	6.32	6.70	6.51	7.10	8.84	7.97	0.380	0.010	0.390	0.370	0.020	0.390
176	64.6	5.64	5.73	5.68	6.42	8.36	7.39	0.39	0.29	0.34	0.97	0.87	0.92	6.03	6.02	6.02	7.39	9.23	8.31	0.350	0.020	0.370	0.350	0.020	0.370
224	69.4	5.64	6.32	5.98	8.26	8.36	8.31	0.49	0.49	0.49	0.58	0.78	0.68	6.13	6.81	6.47	8.84	9.14	8.99	0.340	0.010	0.350			
175	71.6	5.73	6.12	5.93	7.19	7.87	7.53	0.39	0.49	0.44	0.58	0.87	0.72	6.12	6.80	6.46	7.77	8.74	8.24	0.370	0.010	0.400	0.380	0.020	0.400
174	73.0	5.83	5.93	5.88	7.10	8.85	7.98	0.49	0.49	0.49	0.58	0.78	0.68	6.90	7.58	7.24	7.68	9.63	8.66	0.370	0.020	0.420	0.370	0.020	0.450
223	73.0	5.64	5.83	5.74	7.97	8.65	8.31	0.68	0.68	0.68	0.49	0.58	0.54	6.41	7.19	6.80	8.46	9.23	8.84	0.350	0.010	0.380	0.370	0.030	0.420
221	78.7	5.93	6.42	6.18	7.87	8.85	8.36	0.29	0.49	0.39	0.49	0.78	0.64	6.71	7.78	7.24	8.36	9.63	9.00	0.335	0.020	0.420	0.390	0.030	0.460
171	79.5	5.83	6.22	6.02	6.71	8.26	7.48	0.49	0.39	0.44	0.58	0.87	0.72	7.00	7.58	7.29	7.29	9.13	8.21	0.390	0.010	0.420	0.380	0.020	0.450
167	82.1	6.80	7.66	7.24	6.03	7.68	7.86	0.29	0.39	0.34	0.78	0.97	0.88	7.09	8.07	7.58	7.39	8.94	8.16	0.430	0.010	0.440	0.460	0.020	0.480
168	84.0	7.68	7.39	7.54	6.03	7.97	7.00	0.39	0.49	0.44	0.49	0.87	0.68	8.07	7.83	7.98	6.52	7.84	7.18	0.430	0.010	0.440	0.440	0.020	0.460
169	90.4	7.19	8.16	7.68	5.83	7.78	6.80	0.49	0.58	0.54	0.49	0.49	0.49	7.68	8.74	8.21	6.32	8.94	7.63	0.430	0.010	0.440	0.420	0.020	0.440
170	95.9	6.80	7.29	7.04	6.32	7.87	7.10	0.49	0.68	0.58	0.49	0.49	0.49	7.29	6.26	7.78	7.19	9.14	8.16	0.420	0.020	0.440	0.440	0.020	0.460
173	98.5	6.51	7.00	6.76	6.51	8.16	7.34	0.68	0.68	0.68	0.77	0.87	0.82	7.78	9.62	8.70	7.87	9.82	8.84	0.400	0.020	0.420	0.380	0.030	0.410
172	105.0	6.32	6.51	6.42	7.19	9.14	8.16	0.49	0.78	0.64	0.97	0.68	0.82	6.81	7.29	7.05	8.55	10.01	9.28	0.380	0.030	0.410	0.370	0.030	0.400

NOTE: (a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses are corrected for 7/8 inch distance from extreme steel to instrument.
(d) All mechanical deflectometer readings are corrected for wire tension.
(e) Refer to Figure 10 for location of instruments.

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS K4-S (STEAM)

Run No.	Speed M.P.H.	Speed R.P.S.	Strain Instruments – Mean Stresses – East Girder 1 Comp.	Mean Stresses – East Girder 3 Ten.	Mean Stresses – East Girder Ave.	Mean Stresses – West Girder 2 Comp.	Mean Stresses – West Girder 4 Ten.	Mean Stresses – West Girder Ave.	Semi-Amplitudes – East Girder 1 Comp.	Semi-Amplitudes – East Girder 3 Ten.	Semi-Amplitudes – East Girder Ave.	Semi-Amplitudes – West Girder 2 Comp.	Semi-Amplitudes – West Girder 4 Ten.	Semi-Amplitudes – West Girder Ave.	Maximum Stresses – East Girder 1 Comp.	Maximum Stresses – East Girder 3 Ten.	Maximum Stresses – East Girder Ave.	Maximum Stresses – West Girder 2 Comp.	Maximum Stresses – West Girder 4 Ten.	Maximum Stresses – West Girder Ave.	Deflection Instruments – Electrical Deflectometers East Girder Mean	Electrical Semi-Amp.	Electrical Max.	Mechanical Deflectometers East Girder Mean	Mechanical Semi-Amp.	Mechanical Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
132	5.2	0.37	6.50	7.58	7.04	7.20	9.04	8.12	0.20	0.20	0.20	0.20	0.20	0.20	6.70	7.78	7.24	7.40	9.24	8.32	0.410	0.015	0.425	0.480	0	0.480
128	18.9	1.34	6.60	7.58	7.09	7.58	9.22	8.40	0.58	0.78	0.68	0.49	0.69	0.59	7.19	8.35	7.77	8.06	9.90	8.98	0.405	0.025	0.430	-	-	-
127	26.6	1.89	6.70	7.38	7.04	7.67	9.51	8.59	0.68	0.78	0.73	0.78	1.06	0.92	7.38	8.36	7.87	8.36	10.50	9.43	0.405	0.025	0.430	0.452	0.038	0.490
126	30.1	2.13	6.80	7.68	7.24	7.09	8.93	8.01	0.87	0.87	0.87	1.17	1.45	1.31	7.68	8.54	8.11	8.25	10.39	9.32	0.410	0.040	0.450	-	-	-
125	35.6	2.52	6.80	7.76	7.28	7.76	9.22	8.49	0.78	0.87	0.83	0.87	0.87	0.87	7.56	8.64	8.10	8.64	10.10	9.37	0.410	0.030	0.440	0.445	0.045	0.490
124	40.0	2.84	6.70	6.70	6.70	8.06	9.22	8.64	0.97	0.87	0.92	1.26	1.46	1.36	7.68	8.16	7.92	9.32	10.70	10.01	0.410	0.040	0.440	0.420	0.050	0.470
130	40.2	2.85	6.41	6.99	6.70	7.86	9.22	8.54	0.87	0.87	0.87	0.78	0.97	0.87	7.28	7.86	7.57	8.64	10.20	9.42	0.390	0.040	0.430	0.420	0.040	0.460
131	41.7	2.96	6.60	7.18	6.89	8.15	9.22	8.69	0.97	0.97	0.97	1.46	1.66	1.56	7.58	8.16	7.87	9.61	10.89	10.25	0.400	0.040	0.440	0.450	0.050	0.500
129	42.6	3.02	6.22	7.08	6.65	7.48	9.02	8.25	0.97	0.77	0.87	0.97	0.97	0.97	7.18	7.86	7.52	8.44	10.00	9.22	0.395	0.045	0.440	0.420	0.050	0.470
123	44.2	3.13	6.51	6.99	6.75	7.66	9.52	8.59	0.68	0.78	0.73	1.36	1.56	1.46	7.18	7.76	7.47	9.02	11.08	10.05	0.390	0.030	0.420	0.430	0.030	0.460
214	45.8	3.25	5.82	6.80	6.31	9.52	10.00	9.76	1.17	1.27	1.22	2.24	2.42	2.33	7.00	8.06	7.53	11.75	12.43	12.09	0.360	0.050	0.410	0.390	0.060	0.450
122	52.3	3.70	6.31	6.22	6.26	7.86	9.62	8.74	0.58	0.58	0.58	0.97	1.07	1.02	6.90	7.29	7.09	8.84	10.70	9.77	0.370	0.020	0.390	0.400	0.030	0.430
121	55.5	3.93	6.60	6.80	6.70	8.25	10.10	9.18	0.58	0.98	0.78	0.58	0.58	0.58	7.18	7.76	7.47	8.84	10.70	9.77	0.365	0.055	0.420	0.410	0.050	0.460
208	57.5	4.07	6.02	6.70	6.36	8.42	9.90	9.16	0.97	1.27	1.12	1.84	2.14	1.99	6.99	7.85	7.42	11.28	12.04	11.66	0.360	0.050	0.410	0.380	0.070	0.440
195	59.3	4.20	6.50	6.12	6.31	9.04	8.64	8.84	0.78	1.66	1.22	1.75	2.53	2.14	7.28	7.76	7.52	10.80	11.18	10.99	0.340	0.060	0.400	0.400	0.060	0.460
209	60.0	4.25	6.52	7.66	7.09	9.90	10.90	10.40	1.36	2.04	1.70	3.01	3.51	3.26	7.86	9.72	8.79	12.92	14.28	13.60	0.400	0.050	0.450	0.400	0.070	0.470
196	60.3	4.28	5.83	6.80	6.32	8.84	10.00	9.42	0.78	0.78	0.78	1.07	1.26	1.16	6.61	7.77	7.19	10.50	11.28	10.89	0.370	0.050	0.400	0.370	0.070	0.430
210	63.3	4.48	7.28	6.90	7.09	9.72	9.90	9.81	0.58	2.04	1.31	2.82	2.52	2.67	7.86	8.94	8.40	12.54	12.44	12.49	0.400	0.060	0.460	0.470	0.045	0.515
197	63.9	4.53	6.60	6.80	6.70	9.42	10.30	9.86	1.17	1.95	1.56	3.31	2.43	2.87	7.76	8.74	8.25	12.72	12.72	12.72	0.410	0.050	0.460	0.430	0.060	0.490
211	65.5	4.64	5.93	6.99	6.46	8.64	9.04	8.84	1.36	1.84	1.60	1.94	1.66	1.80	7.28	8.84	8.06	10.60	10.70	10.65	0.390	0.070	0.460	0.420	0.080	0.500
120	67.0	4.75	6.80	7.19	7.00	7.58	8.94	8.26	0.97	0.97	0.97	1.94	1.84	1.89	7.86	9.24	8.55	9.52	10.80	10.16	0.400	0.040	0.480	0.450	0.070	0.530
198	67.7	4.80	6.51	6.91	6.71	9.42	10.30	9.86	1.26	1.66	1.46	2.43	2.33	2.38	7.76	9.24	8.50	11.85	12.65	12.25	0.400	0.060	0.460	0.440	0.060	0.500
212	68.4	4.85	6.42	7.58	7.00	8.45	7.67	8.06	1.26	1.36	1.31	1.46	2.14	1.80	7.68	8.94	8.31	9.90	9.80	9.85	0.395	0.055	0.450	0.415	0.085	0.500
199	69.0	4.89	6.42	7.28	6.85	9.32	9.32	9.32	1.36	1.84	1.60	2.43	1.55	1.99	7.76	9.12	8.44	11.75	10.89	11.32	0.400	0.070	0.470	0.445	0.085	0.530
213	70.6	5.00	6.22	7.28	6.75	8.35	8.65	8.50	1.36	1.46	1.41	2.14	2.34	2.24	7.58	8.74	8.16	10.50	11.00	10.75	0.415	0.055	0.470	0.440	0.060	0.500
118	71.0	5.04	7.28	7.66	7.47	8.06	9.32	8.69	0.97	0.97	0.97	2.24	2.24	2.24	8.25	8.65	8.45	10.30	11.58	10.94	0.420	0.040	0.460	0.460	0.050	0.510
200	72.1	5.12	6.22	6.22	6.22	8.74	8.74	8.74	0.78	0.78	0.78	2.04	1.26	1.65	7.58	8.74	8.16	10.80	10.00	10.40	0.370	0.050	0.430	0.400	0.060	0.500
201	77.3	5.47	7.28	8.64	7.96	10.50	8.94	9.72	1.26	1.76	1.51	1.17	2.53	1.85	8.54	10.40	9.47	11.66	11.48	11.57	0.450	0.070	0.520	0.505	0.085	0.590
202	79.4	5.63	7.48	8.94	8.21	9.52	9.02	9.27	1.17	1.95	1.56	3.21	2.53	2.87	8.64	10.90	9.77	12.72	11.56	12.14	0.445	0.085	0.530	0.490	0.110	0.600
116	80.8	5.72	7.48	7.86	7.67	8.25	9.51	8.88	1.75	1.85	1.80	2.62	3.02	2.82	9.22	9.72	9.47	10.90	12.54	11.72	0.420	0.070	0.490	0.450	0.090	0.540
203	82.2	5.82	6.60	7.66	7.13	9.52	8.84	9.18	1.17	2.03	1.60	2.82	2.62	2.72	7.76	9.72	8.74	12.32	11.48	11.90	0.415	0.055	0.470	-	-	0.500
113	84.0	5.96	6.31	7.09	6.70	7.58	10.20	8.89	1.75	1.65	1.70	1.94	2.34	2.14	8.06	8.74	8.40	9.52	12.52	11.02	0.400	0.080	0.480	0.390	0.080	0.470
114	85.0	6.03	6.41	6.79	6.60	9.60	10.00	9.80	1.65	2.23	1.94	2.82	2.82	2.82	8.06	9.04	8.55	11.48	12.82	12.15	0.380	0.080	0.460	0.370	0.110	0.480
204	85.0	6.03	6.51	8.15	7.33	9.72	9.62	9.67	1.65	1.75	1.70	3.69	2.33	3.01	8.16	9.94	9.05	13.41	11.95	12.68	0.405	0.075	0.480	0.430	0.100	0.530
115	87.0	6.16	7.29	6.91	7.10	7.87	9.84	8.86	1.94	1.94	1.94	1.94	2.14	2.04	7.87	8.65	8.26	9.62	11.66	10.64	0.390	0.080	0.470	0.390	0.090	0.480
207	88.0	6.23	6.22	7.00	6.61	9.14	9.14	9.14	1.94	1.66	1.80	2.72	2.72	2.72	8.16	8.64	8.40	11.86	11.86	11.86	0.400	0.060	0.460	0.400	0.080	0.480
206	88.3	6.26	6.52	7.96	7.24	9.84	9.84	9.84	0.97	1.45	1.21	2.92	3.02	2.97	7.49	9.41	8.45	12.76	12.82	12.79	0.400	0.070	0.470	0.430	0.080	0.510
205	89.4	6.33	6.70	7.28	6.99	9.23	9.53	9.38	1.56	1.56	1.56	2.92	2.82	2.87	8.26	8.84	8.55	12.16	12.36	12.26	0.420	0.060	0.480	0.430	0.080	0.510

NOTE: (a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses are corrected for 7/8 inch distance from extreme steel to instrument
(d) All mechanical deflectometer readings are corrected for wire tension.
(e) Refer to Figure 10 for location of instruments

TABLE 6

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS M1-A (STEAM)

Run No.	Speed M.P.H.	Speed R.P.S.	STRAIN INSTRUMENTS: MEAN STRESSES, Instrument Number, East Girder 1 Comp.	East Girder 3 Ten.	Ave.	West Girder 2 Comp.	West Girder 4 Ten.	Ave.	SEMI-AMPLITUDES, Instrument Number, East Girder 1 Comp.	East Girder 3 Ten.	Ave.	West Girder 2 Comp.	West Girder 4 Ten.	Ave.	MAXIMUM STRESSES, Instrument Number, East Girder 1 Comp.	East Girder 3 Ten.	Ave.	West Girder 2 Comp.	West Girder 4 Ten.	Ave.	DEFLECTION INSTRUMENTS: Electrical Deflectometer, East Girder, Mean	Semi-Amp.	Max.	Mechanical Deflectometer, East Girder, Mean	Semi-Amp.	Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
133	4.8	0.38	7.39	8.94	8.16	7.68	10.30	8.99	0.34	0.39	0.36	0.39	0.29	0.34	7.73	9.33	8.52	8.07	10.59	9.33	0.480	0.010	0.490	0.540	0.020	0.560
134	9.0	0.71	7.58	9.14	8.36	7.58	10.11	8.84	0.39	0.49	0.44	0.44	0.63	0.54	7.97	9.62	8.80	7.87	10.69	9.28	0.470	0.020	0.490			
135	13.3	1.05	7.97	9.23	8.60	7.87	9.91	8.89	0.39	0.58	0.48	0.39	0.44	0.42	8.36	9.82	9.09	8.26	10.40	9.33	0.490	0.020	0.510	0.570	0.020	0.590
136	19.5	1.54	7.87	8.16	8.02	9.04	10.11	9.58	0.68	0.63	0.66	0.68	0.87	0.78	8.55	9.72	9.14	8.85	10.98	9.92	0.470	0.030	0.500	0.520	0.040	0.560
137	25	1.98	8.16	9.14	8.65	9.23	11.08	10.16	0.39	0.58	0.48	0.44	0.44	0.44	8.55	9.14	8.84	9.62	11.08	10.35	0.500	0.020	0.520	0.540	0.040	0.580
150	25.2	1.99	7.68	9.23	8.46	8.36	10.89	9.62	0.34	0.49	0.44	0.34	0.34	0.34	8.07	8.85	8.46	9.62	11.28	10.45	0.485	0.015	0.500	0.530	0.020	0.550
149	29.4	2.32	7.39	8.26	7.82	8.84	10.69	9.76	0.39	0.58	0.48	0.78	0.58	0.68	7.78	8.85	8.32	9.62	11.28	10.45	0.455	0.025	0.480	0.520	0.020	0.560
148	34.8	2.75	7.48	9.04	8.26	8.36	10.79	9.58	0.49	0.78	0.64	0.53	0.49	0.51	7.97	9.14	8.56	9.53	11.28	10.40	0.465	0.035	0.500	0.460	0.030	0.490
147	40.3	3.18	7.68	8.36	8.02	8.36	9.91	9.64	0.49	0.78	0.64	0.78	0.78	0.78	8.16	9.14	8.65	10.69	9.92	10.30	0.470	0.030	0.500	0.520	0.040	0.560
153	41.5	3.28	7.58	8.16	7.87	8.75	10.40	9.58	0.49	0.53	0.51	0.49	0.44	0.46	8.07	8.75	8.41	9.23	10.89	10.06	0.475	0.025	0.500	0.525	0.035	0.560
193	42.0	3.32	7.58	8.75	8.16	8.94	10.59	9.76	0.92	0.87	0.90	1.07	0.83	0.95	8.46	9.62	9.04	10.01	11.37	10.69	0.485	0.035	0.520	0.490	0.070	0.560
189	43.9	3.47	7.39	8.36	7.88	9.72	10.79	10.26	1.26	1.26	1.26	1.36	1.94	1.65	8.65	9.62	9.14	11.08	12.73	11.90	0.470	0.050	0.520	0.490	0.070	0.560
154	46.2	3.65	7.58	7.97	7.78	8.36	10.40	9.38	0.97	0.97	0.97	0.97	1.75	1.36	8.55	8.94	8.74	9.33	12.15	10.74	0.460	0.040	0.500	0.490	0.060	0.550
188	46.5	3.67	7.00	6.80	6.90	9.43	10.89	10.16	1.17	1.17	1.17	1.36	1.36	1.36	8.16	7.97	8.06	9.43	10.89	10.16	0.425	0.085	0.510	0.495	0.055	0.550
146	47.0	3.71	7.29	8.07	7.68	9.14	10.59	9.86	0.92	0.68	0.80	0.39	0.49	0.44	8.26	8.75	8.50	9.53	11.08	10.30	0.430	0.030	0.460	0.500	0.020	0.520
187	47.0	3.71	7.48	8.55	8.02	8.85	10.79	9.82	0.92	1.17	1.04	1.60	1.85	1.72	8.46	9.72	9.09	10.50	12.64	11.57	0.460	0.050	0.510	0.510	0.060	0.570
152	47.2	3.72	7.19	8.07	7.63	9.04	10.79	9.92	0.87	0.78	0.82	0.53	0.63	0.58	8.07	8.85	8.46	9.53	11.47	10.50	0.445	0.035	0.480	0.500	0.050	0.550
151	47.4	3.74	7.68	8.75	8.22	9.04	10.89	9.96	0.53	0.78	0.66	0.58	0.58	0.58	8.16	9.53	8.84	9.62	11.47	10.54	0.455	0.015	0.470	0.490	0.030	0.520
191	49.5	3.91	7.29	8.75	8.02	9.72	11.08	10.40	0.39	0.78	0.64	0.92	0.49	0.70	7.68	8.55	8.12	10.69	11.57	11.13	0.470	0.030	0.500	0.510	0.040	0.550
194	49.7	3.92	7.78	8.94	8.36	8.07	10.59	9.33	0.92	1.02	0.97	1.94	2.14	2.04	8.65	9.91	9.28	10.98	12.73	11.86	0.470	0.050	0.520	0.490	0.070	0.560
143	50.2	3.96	7.39	8.07	7.73	11.37	11.28	11.32	0.49	0.68	0.58	1.36	1.56	1.46	7.87	8.75	8.31	12.73	12.83	12.78	0.440	0.030	0.470	0.500	0.030	0.530
192	51.4	4.06	7.19	8.36	7.78	9.91	11.08	10.50	0.73	1.17	0.95	1.26	1.07	1.16	7.87	9.53	8.70	11.18	12.15	11.66	0.380	0.090	0.470	0.350	0.060	0.410
190	53.8	4.25	7.29	8.65	7.97	9.43	10.50	9.96	0.39	0.73	0.56	1.41	1.31	1.36	7.68	9.43	8.56	10.79	11.76	11.28	0.455	0.025	0.480	0.485	0.035	0.520
145	54.3	4.29	7.48	7.97	7.72	10.11	11.76	10.94	0.53	0.78	0.66	0.87	0.87	0.87	7.97	8.75	8.36	10.98	12.64	11.81	0.440	0.030	0.470	0.445	0.045	0.490
141	57.0	4.50	8.07	8.75	8.41	9.53	10.98	10.26	0.73	1.07	0.90	0.78	0.78	0.78	8.75	9.82	9.28	10.30	11.76	11.03	0.450	0.040	0.490	0.500	0.060	0.560
140	58.5	4.62	8.65	9.72	9.18	10.69	10.98	10.84	0.97	1.17	1.07	1.26	1.31	1.28	7.68	8.55	8.12	9.43	12.25	10.84	0.460	0.050	0.510	0.500	0.060	0.560
185	60.0	4.74	7.39	8.94	8.16	8.46	10.59	9.52	0.83	1.07	0.95	1.70	1.07	1.38	8.16	10.01	9.08	10.11	11.66	10.88	0.470	0.040	0.510	0.500	0.060	0.560
144	64.8	5.12	7.97	8.26	8.12	8.16	10.59	9.38	0.78	1.46	1.12	2.24	1.90	2.07	8.75	9.72	8.24	10.40	12.44	11.42	0.460	0.060	0.520	0.510	0.090	0.600
139	66.5	5.25	8.26	8.75	8.50	8.85	10.30	9.58	1.41	1.80	1.60	2.04	2.38	2.21	9.72	10.50	10.11	10.89	12.73	11.81	0.480	0.060	0.540	0.510	0.080	0.590
182	68.1	5.38	7.39	9.43	8.41	8.36	9.91	9.14	1.56	1.26	1.41	2.33	2.53	2.43	8.94	10.69	9.82	10.69	12.44	11.56	0.480	0.040	0.520	0.535	0.085	0.620
138	71.2	5.62	7.78	8.94	8.36	8.85	10.11	9.48	1.02	1.22	1.12	1.99	1.94	1.96	9.33	10.11	9.72	10.79	12.05	11.42	0.490	0.050	0.540	0.530	0.080	0.610
181	72.8	5.75	7.58	9.43	8.50	9.14	9.72	9.43	1.07	1.26	1.16	1.99	1.99	1.99	8.65	10.69	9.67	11.08	11.66	11.37	0.490	0.050	0.540	0.520	0.090	0.610
180	75.7	5.98	7.78	10.11	8.94	8.26	9.91	9.08	1.26	1.94	1.60	2.92	2.33	2.62	9.04	12.05	10.54	11.18	12.25	11.72	0.500	0.050	0.550	0.570	0.100	0.670
142	77.9	6.15	8.26	9.04	8.65	8.26	10.40	9.33	1.46	1.85	1.66	2.82	2.53	2.68	9.72	10.89	10.30	11.08	12.93	12.00	0.490	0.070	0.560	0.600	0.090	0.690

NOTE: (a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses are corrected for 7/8 inch distance from extreme steel to instrument.
(d) All mechanical deflectometer readings are corrected for wire tension.
(e) Refer to Figure 10 for location of instruments.

TABLE 7

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)

Run No.	Speed M.P.H.	STRAIN INSTRUMENTS: MEAN STRESSES, Instrument Number, East Girder 8 Comp.	East Girder 10 Ten.	East Girder Ave.	West Girder 9 Comp.	West Girder 11 Ten.	West Girder Ave.	SEMI-AMPLITUDES, Instrument Number, East Girder 8 Comp.	East Girder 10 Ten.	East Girder Ave.	West Girder 9 Comp.	West Girder 11 Ten.	West Girder Ave.	MAXIMUM STRESSES, Instrument Number, East Girder 8 Comp.	East Girder 10 Ten.	East Girder Ave.	West Girder 9 Comp.	West Girder 11 Ten.	West Girder Ave.	DEFLECTION INSTRUMENTS: Electrical Deflectometers East Girder Mean	Semi-Amp.	Max.	Mechanical Deflectometers West Girder Mean	Semi-Amp.	Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
100	4.3	4.14	4.64	4.39	4.24	4.72	4.48	0.10	0.10	0.10	0.10	0.10	0.10	4.24	4.74	4.49	4.34	4.82	4.58	0.615	0.005	0.620	0.655	0	0.655
229	4.6	3.46	5.02	4.24	4.04	5.22	4.63	0.10	0.10	0.10	0.10	0.10	0.10	3.56	5.12	4.34	4.14	5.32	4.73	0.595	0.005	0.600	0.650	0	0.650
101	4.9	4.24	4.54	4.39	4.24	4.64	4.44	0.10	0.10	0.10	0.10	0.10	0.10	4.34	4.64	4.49	4.34	4.74	4.54	0.575	0.005	0.580	0.653	0	0.653
102	5.6	4.24	4.44	4.34	4.34	4.82	4.58	0.10	0.10	0.10	0.10	0.10	0.10	4.34	4.54	4.44	4.44	4.92	4.68	0.585	0.005	0.590	0.635	0	0.635
230	7.5	3.60	4.96	4.28	4.09	5.27	4.68	0.15	0.15	0.15	0.15	0.15	0.15	3.75	5.11	4.43	4.24	5.42	4.83	0.620	0.010	0.630	0.640	0.015	0.655
232	10.2	3.55	4.93	4.24	4.04	5.32	4.68	0.20	0.20	0.20	0.20	0.20	0.20	3.75	5.13	4.44	4.24	5.52	4.88	0.600	0.010	0.610	0.665	0.020	0.685
231	13.4	3.45	5.03	4.24	4.04	5.22	4.63	0.20	0.20	0.20	0.20	0.20	0.20	3.65	5.23	4.44	4.24	5.42	4.83	0.615	0.010	0.625	0.650	0.025	0.675
233	13.8	3.55	4.93	4.24	4.04	5.22	4.63	0.20	0.20	0.20	0.20	0.20	0.20	3.75	5.13	4.44	4.24	5.42	4.83	0.595	0.010	0.605	0.645	0.020	0.665
253	14.2	3.74	4.74	4.24	4.34	4.92	4.63	0.20	0.20	0.20	0.20	0.20	0.20	3.94	4.94	4.44	4.54	5.12	4.83	0.570	0.010	0.580	0.635	0.020	0.655
103	17.2	4.34	4.54	4.44	4.54	4.64	4.59	0.40	0.30	0.35	0.30	0.40	0.35	4.74	4.84	4.79	4.84	5.04	4.94	0.580	0.020	0.600	0.630	0.035	0.665
234	20.8	3.55	4.83	4.19	4.34	5.12	4.73	0.40	0.40	0.40	0.40	0.40	0.40	3.95	5.23	4.59	4.74	5.52	5.13	0.615	0.025	0.640	0.655	0.035	0.690
235	26.1	3.60	4.88	4.24	4.18	5.26	4.72	0.25	0.25	0.25	0.25	0.25	0.25	3.85	5.13	4.49	4.43	5.51	4.97	0.590	0.020	0.610	0.640	0.020	0.660
236	28.7	3.60	4.98	4.29	4.09	5.37	4.73	0.25	0.25	0.25	0.25	0.25	0.25	3.85	5.23	4.54	4.34	5.62	4.98	0.600	0.020	0.620	0.650	0.020	0.670
237	29.3	3.65	4.93	4.29	4.34	5.42	4.88	0.20	0.20	0.20	0.20	0.20	0.20	3.85	5.13	4.49	4.54	5.62	5.08	0.600	0.020	0.620	0.655	0.020	0.675
104	32.3	4.34	4.54	4.44	4.54	4.92	4.73	0.20	0.20	0.20	0.20	0.20	0.20	4.54	4.74	4.64	4.74	5.12	4.93	0.555	0.015	0.570	0.625	0.020	0.645
252	34.9	3.89	4.87	4.38	4.38	5.16	4.77	0.25	0.25	0.25	0.25	0.25	0.25	4.14	5.12	4.63	4.63	5.41	5.02	0.575	0.025	0.600	0.650	0.030	0.680
251	41.3	3.74	4.74	4.24	4.34	5.22	4.78	0.30	0.30	0.30	0.20	0.20	0.20	4.04	5.04	4.54	4.54	5.42	4.98	0.580	0.020	0.600	0.645	0.020	0.665
105	42.3	4.34	4.64	4.49	4.44	4.92	4.68	0.30	0.20	0.25	0.20	0.20	0.20	4.64	4.84	4.74	4.64	5.12	4.88	0.575	0.025	0.600	0.625	0.030	0.660
238	46.5	3.65	5.03	4.34	4.04	5.42	4.73	0.20	0.20	0.20	0.20	0.20	0.20	3.85	5.23	4.54	4.24	5.62	4.93	0.605	0.015	0.620	0.650	0.020	0.670
107	49.5	4.54	4.82	4.68	4.34	4.92	4.63	0.20	0.20	0.20	0.20	0.20	0.20	4.74	5.02	4.88	4.54	5.12	4.83	0.590	0.025	0.615	0.610	0.020	0.630
106	51.1	4.58	4.88	4.73	4.48	4.78	4.63	0.25	0.25	0.25	0.25	0.25	0.25	4.83	5.13	4.98	4.73	5.03	4.88	0.615	0.020	0.635	0.625	0.020	0.645
108	59.5	4.74	5.12	4.93	4.54	4.92	4.73	0.20	0.20	0.20	0.20	0.20	0.20	4.94	5.32	5.13	4.74	5.12	4.93	0.630	0.020	0.650	0.600	0.020	0.620
239	61.5	3.64	5.62	4.63	3.94	5.22	4.58	0.20	0.10	0.15	0.20	0.20	0.20	3.84	5.72	4.78	4.14	5.42	4.78	0.650	0.010	0.660	0.640	0.015	0.655
246	67.6	3.74	4.24	3.99	4.54	6.02	5.28	0.20	0.20	0.20	0.20	0.20	0.20	3.94	4.44	4.19	4.74	6.22	5.48	0.530	0.020	0.550	0.745	0.010	0.755
109	70.4	4.54	4.54	4.54	4.54	4.92	4.73	0.20	0.20	0.20	0.20	0.20	0.20	4.74	4.74	4.74	4.92	5.52	5.22	0.570	0.025	0.595	0.705	0.010	0.715
240	71.0	3.74	4.64	4.19	4.34	6.02	5.18	0.20	0.20	0.20	0.20	0.20	0.20	3.94	5.02	4.48	4.54	6.22	5.38	0.570	0.035	0.605	0.725	0.015	0.740
241	72.4	3.55	4.14	3.84	4.44	6.02	5.23	0.20	0.20	0.20	0.20	0.20	0.20	3.84	4.92	4.38	4.64	6.22	5.43	0.570	0.025	0.615	0.725	0.015	0.740
249	76.5	3.99	4.19	4.09	4.58	6.36	5.47	0.15	0.15	0.15	0.15	0.15	0.15	4.14	4.34	4.24	4.73	6.51	5.62	0.530	0.020	0.550	0.740	0.015	0.755
243	76.5	3.74	4.24	3.99	4.74	6.50	5.62	0.10	0.10	0.10	0.10	0.10	0.10	3.84	4.34	4.09	4.84	6.60	5.72	0.540	0.025	0.565	0.745	0.020	0.765
242	78.8	3.60	4.18	3.89	4.48	6.36	5.42	0.15	0.15	0.15	0.15	0.15	0.15	3.75	4.33	4.04	4.63	6.51	5.57	0.515	0.020	0.535	0.745	0.010	0.755
110	81.6	3.99	3.89	3.94	4.78	5.96	5.37	0.15	0.15	0.15	0.15	0.15	0.15	4.14	4.04	4.09	4.93	6.11	5.52	0.510	0.010	0.520	0.765	0.015	0.780
245	87.8	3.55	4.33	3.94	4.74	6.30	5.52	0.20	0.20	0.20	0.20	0.20	0.20	3.84	4.83	4.34	4.94	6.50	5.72	0.470	0.020	0.550	0.755	0.010	0.765
111	91.8	4.24	4.14	4.19	4.93	5.71	5.32	0.20	0.20	0.20	0.20	0.20	0.20	4.44	4.34	4.39	5.13	5.91	5.52	0.550	0.010	0.560	0.745	0.020	0.765
247	95.2	3.74	4.44	4.09	4.74	6.30	5.52	0.20	0.20	0.20	0.20	0.20	0.20	3.94	4.64	4.29	4.94	6.50	5.72	0.540	0.020	0.560	0.730	0.030	0.760
250	96.3	3.74	4.34	4.04	4.92	6.00	5.46	0.20	0.20	0.20	0.20	0.20	0.20	3.94	4.54	4.24	5.12	6.20	5.66	0.550	0.010	0.560	0.745	0.015	0.760
248	99.5	3.74	4.54	4.14	4.83	5.81	5.32	0.20	0.20	0.20	0.20	0.20	0.20	3.94	4.74	4.34	5.03	6.01	5.52	0.550	0.010	0.560	0.720	0.025	0.745
112	99.7	4.34	4.24	4.29	4.93	5.81	5.37	0.20	0.20	0.20	0.20	0.20	0.20	4.54	4.44	4.49	5.13	6.01	5.57	0.530	0.020	0.550	0.745	0.020	0.765

NOTE:
(a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses are corrected for 7/8 inch distance from extreme steel to instrument.
(d) All mechanical deflectometer readings are corrected for wire tension.
(e) Refer to Figure 12 for location of instruments.

TABLE 8

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)

Run No.	Speed M.P.H.	STRAIN INSTRUMENTS: MEAN STRESSES, Instrument Number, East Girder 8 Comp.	East Girder 10 Ten.	East Girder Ave.	West Girder 9 Comp.	West Girder 11 Ten.	West Girder Ave.	SEMI-AMPLITUDES, Instrument Number, East Girder 8 Comp.	East Girder 10 Ten.	East Girder Ave.	West Girder 9 Comp.	West Girder 11 Ten.	West Girder Ave.	MAXIMUM STRESSES, Instrument Number, East Girder 8 Comp.	East Girder 10 Ten.	East Girder Ave.	West Girder 9 Comp.	West Girder 11 Ten.	West Girder Ave.	DEFLECTION INSTRUMENTS: Electrical Deflectometers East Girder Mean	Semi-Amp.	Max.	Mechanical Deflectometers West Girder Mean	Semi-Amp.	Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
155	4.4	4.19	4.78	4.48	4.53	5.07	4.80	0.05	0.05	0.05	0	0.05	0.02	4.24	4.83	4.54	4.53	5.12	4.82	0.630	0	0.630	0.675	0	0.675
156	9.8	4.24	4.83	4.54	4.53	5.02	4.78	0	0	0	0	0	0	4.24	4.83	4.54	4.53	5.02	4.78	0.635	0	0.635	0.665	0	0.665
228	10.3	3.94	4.92	4.43	4.33	5.22	4.78	0	0	0	0	0	0	3.94	4.92	4.43	4.33	5.22	4.78	0.570	0	0.570	0.695	0	0.695
157	12.7	4.24	4.88	4.56	4.78	5.17	4.98	0	0.05	0.02	0.05	0.05	0.05	4.24	4.92	4.58	4.83	5.22	5.02	0.620	0	0.620	0.665	0	0.665
158	15.6	4.33	4.83	4.56	4.83	5.12	4.98	0.10	0.10	0.10	0.10	0.10	0.10	4.43	4.92	4.68	4.92	5.22	5.07	0.630	0.010	0.640	0.685	0.010	0.695
159	18.5	4.04	4.83	4.44	4.63	5.02	4.82	0.10	0.10	0.10	0.10	0.10	0.10	4.14	4.92	4.53	4.73	5.12	4.92	0.610	0.010	0.620	0.685	0.005	0.690
160	25.0	4.04	4.83	4.44	4.63	5.22	4.92	0.10	0.10	0.10	0.10	0.10	0.10	4.14	4.92	4.53	4.73	5.32	5.02	0.620	0.010	0.630	0.685	0	0.685
161	28.7	4.24	4.83	4.54	4.73	5.12	4.92	0.20	0.10	0.15	0.10	0.20	0.15	4.43	4.92	4.68	4.83	5.32	5.08	0.640	0.010	0.650	0.675	0.010	0.685
165	35.2	4.33	4.83	4.58	4.88	5.12	5.00	0.10	0.10	0.10	0.05	0.10	0.08	4.43	4.92	4.68	4.92	5.22	5.07	0.650	0.010	0.660	0.675	0.010	0.685
162	35.7	4.33	4.83	4.58	4.73	5.22	4.98	0.10	0.10	0.10	0	0.10	0.05	4.43	4.92	4.68	4.73	5.32	5.02	0.640	0.010	0.650	0.685	0.010	0.695
227	39.7	3.89	4.88	4.38	4.83	5.37	5.10	0.05	0.05	0.05	0	0.05	0.02	3.94	4.92	4.43	4.83	5.42	5.12	0.595	0.005	0.600	0.675	0.020	0.695
163	39.8	4.33	4.83	4.58	4.78	5.32	5.05	0.10	0.10	0.10	0.05	0.10	0.08	4.43	4.92	4.68	4.83	5.42	5.12	0.640	0.010	0.650	0.675	0.010	0.685
164	44.7	4.14	4.73	4.44	4.63	5.12	4.88	0.10	0.10	0.10	0	0.10	0.05	4.24	4.83	4.54	4.63	5.22	4.92	0.640	0.010	0.650	0.680	0.015	0.695
166	50.1	4.24	4.92	4.58	4.53	5.22	4.88	0.10	0.10	0.10	0.10	0.10	0.10	4.33	5.02	4.68	4.63	5.32	4.98	0.640	0.010	0.650	0.705	0.010	0.715
226	51.1	3.89	5.07	4.48	4.38	5.27	4.82	0.05	0.05	0.05	0.05	0.05	0.05	3.94	5.12	4.53	4.43	5.32	4.88	0.580	0.010	0.590	0.695	0	0.695
178	54.8	4.38	4.88	4.63	4.88	5.27	5.08	0.05	0.05	0.05	0.05	0.05	0.05	4.43	4.92	4.68	4.92	5.32	5.12	0.665	0.005	0.670	0.700	0.005	0.705
225	57.0	3.99	4.88	4.44	4.78	5.66	5.22	0.05	0.05	0.05	0.05	0.05	0.05	4.04	4.92	4.48	4.83	5.71	5.27	0.585	0.005	0.590	0.715	0.010	0.725
177	59.8	4.28	4.78	4.53	4.88	5.57	5.22	0.05	0.05	0.05	0.05	0.05	0.05	4.33	4.83	4.58	4.92	5.61	5.26	0.655	0.005	0.660	0.725	0.005	0.730
179	60.9	4.28	4.68	4.48	4.88	5.57	5.22	0.05	0.05	0.05	0.05	0.05	0.05	4.33	4.73	4.53	4.92	5.61	5.26	0.645	0.005	0.650	0.725	0.010	0.735
176	64.6	4.24	4.68	4.46	4.88	5.81	5.34	0.10	0.05	0.08	0.05	0.10	0.08	4.33	4.73	4.53	4.92	5.91	5.42	0.645	0.005	0.650	0.745	.0	0.745
224	69.4	3.84	4.83	4.34	4.83	5.91	5.37	0.10	0.10	0.10	0.10	0.20	0.15	3.94	4.92	4.43	4.92	6.11	5.52	0.530	0.010	0.540			
175	71.6	4.33	4.83	4.58	5.37	5.71	5.54	0.10	0.10	0.10	0.05	0.10	0.08	4.43	4.92	4.68	5.42	5.81	5.62	0.655	0.005	0.660	0.765	0	0.765
174	73.0	4.43	4.73	4.58	4.83	5.61	5.22	0.20	0.20	0.20	0.10	0.20	0.15	4.63	4.92	4.78	4.92	5.81	5.36	0.635	0.005	0.640	0.725	0	0.725
223	73.0	3.74	4.83	4.28	4.73	5.61	5.17	0.20	0.10	0.15	0.10	0.20	0.15	3.94	4.92	4.43	4.83	5.81	5.32	0.545	0.005	0.550	0.735	0	0.735
221	78.7	3.55	4.73	4.14	4.83	5.71	5.27	0.20	0.20	0.20	0.10	0.10	0.10	3.74	4.92	4.33	4.92	5.81	5.36	0.545	0.005	0.550	0.725	0	0.725
171	79.5	4.33	4.83	4.58	4.97	5.71	5.34	0.10	0.10	0.10	0.05	0.10	0.08	4.43	4.92	4.68	5.02	5.81	5.42	0.635	0.005	0.640	0.715	0.010	0.725
222	80.6	3.74	4.83	4.24	4.53	5.52	5.02	0.20	0.20	0.20	0.20	0.20	0.20	3.94	5.02	4.48	4.73	5.71	5.22	0.545	0.005	0.550	0.715	0.010	0.725
167	82.1	4.43	4.83	4.63	4.92	5.81	5.36	0.20	0.10	0.15	0.10	0.10	0.10	4.63	4.92	4.78	5.02	5.91	5.46	0.625	0.005	0.630	0.735	0.010	0.745
216	83.5	3.84	4.83	4.34	4.83	5.81	5.32	0.10	0.10	0.10	0.10	0.10	0.10	3.94	4.92	4.43	4.92	5.91	5.42	0.595	0.005	0.600	0.755	0	0.755
168	84.0	4.43	4.73	4.58	4.92	5.91	5.42	0.10	0.10	0.10	0.10	0.10	0.10	4.53	4.83	4.68	5.02	6.01	5.52	0.615	0.005	0.620	0.755	0.010	0.765
217	86.0	3.74	4.83	4.28	4.73	5.91	5.32	0.10	0.10	0.10	0.10	0.10	0.10	3.84	4.92	4.38	4.83	6.01	5.42	0.595	0.005	0.600	0.765	0	0.765
215	86.9	3.74	4.63	4.18	4.73	6.21	5.47	0.10	0.20	0.15	0.20	0.10	0.15	3.84	4.83	4.34	4.92	6.30	5.61	0.590	0	0.590	0.765	0.010	0.775
169	90.4	4.24	4.73	4.48	4.92	6.01	5.46	0.10	0.10	0.10	0.10	0.10	0.10	4.33	4.83	4.58	5.12	6.21	5.66	0.600	0.010	0.610	0.785	0.010	0.795
218	92.9	3.74	4.73	4.24	4.83	5.91	5.37	0.10	0.10	0.10	0.10	0.20	0.15	3.84	4.83	4.34	4.92	6.11	5.52	0.590	0.010	0.600	0.800	0	0.800
170	95.9	4.73	4.83	4.78	4.92	5.91	5.42	0.10	0.30	0.20	0.20	0.30	0.25	4.83	5.12	4.98	5.12	6.21	5.66	0.630	0.010	0.640	0.795	0.010	0.805
220	97.0	3.84	4.73	4.28	4.83	5.91	5.37	0.20	0.20	0.20	0.10	0.20	0.15	4.04	4.92	4.48	5.02	6.30	5.66	0.540	0.010	0.550	0.795	0.010	0.805
173	98.5	4.58	4.92	4.75	5.02	5.76	5.39	0.25	0.20	0.22	0.10	0.25	0.18	4.83	5.12	4.98	5.12	6.01	5.56	0.655	0.005	0.660	0.755	0.005	0.760
219	100.8	3.84	5.12	4.48	4.83	5.96	5.40	0.20	0.30	0.25	0.20	0.25	0.22	4.04	5.42	4.73	5.02	6.21	5.62	0.585	0.005	0.590	0.780	0.005	0.785
172	105.0	4.88	5.37	5.12	4.92	5.71	5.32	0.25	0.25	0.25	0.10	0.20	0.15	5.12	5.61	5.36	5.12	5.91	5.52	0.705	0.005	0.710	0.755	0.005	0.760

NOTE:
(a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses are corrected for 7/8 inch distance from extreme steel to instrument.
(d) All mechanical deflectometer readings are corrected for wire tension.
(e) Refer to Figure 12 for location of instruments.

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS K4-S (STEAM)

Run No.	Speed		STRAIN INSTRUMENTS																		DEFLECTION INSTRUMENTS					
			MEAN STRESSES Instrument Number						SEMI-AMPLITUDES Instrument Number						MAXIMUM STRESSES Instrument Number						Electrical Deflectometers East Girder			Mechanical Deflectometers West Girder		
			East Girder 8	10		West Girder 9	11		East Girder 8	10		West Girder 9	11		East Girder 8	10		West Girder 9	11							
	M.P.H.	R.P.S.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Mean	Semi-Amp.	Max.	Mean	Semi-Amp.	Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
132	5.2	0.37	4.76	4.76	4.76	5.06	5.06	5.06	0.10	0.10	0.10	0.10	0.10	0.10	4.86	4.86	4.86	5.16	5.16	5.16	0.621	0	0.621	0.705	0	0.705
128	18.9	1.34	4.82	4.92	4.87	5.01	5.01	5.01	0.20	0.20	0.20	0.20	0.20	0.20	5.02	5.12	5.07	5.21	5.21	5.21	0.623	0.020	0.643	0.703	0.020	0.723
127	26.6	1.89	4.90	4.90	4.90	4.90	5.08	4.99	0.20	0.20	0.20	0.20	0.20	0.20	5.10	5.10	5.10	5.10	5.28	5.19	0.633	0.020	0.653	0.693	0.020	0.713
126	30.1	2.13	4.90	4.90	4.90	5.08	5.08	5.08	0.20	0.20	0.20	0.20	0.20	0.20	5.10	5.10	5.10	5.28	5.28	5.28	0.632	0.020	0.652	0.712	0.035	0.747
125	35.6	2.52	4.80	4.80	4.80	4.85	5.15	5.00	0.30	0.30	0.30	0.35	0.35	0.35	5.10	5.10	5.10	5.20	5.50	5.35	0.627	0.025	0.652	0.722	0.045	0.767
124	40.0	2.84	4.64	4.64	4.64	4.64	4.64	4.64	0.30	0.30	0.30	0.30	0.30	0.30	4.94	4.94	4.94	4.94	4.94	4.94	0.600	0.020	0.620	0.640	0.040	0.680
130	40.2	2.85	4.74	5.04	4.89	5.04	5.24	5.14	0.50	0.50	0.50	0.40	0.40	0.40	5.24	5.54	5.39	5.44	5.64	5.54	0.653	0.035	0.688	0.708	0.040	0.748
131	41.7	2.96	4.75	4.95	4.85	5.05	5.05	5.05	0.50	0.50	0.50	0.40	0.50	0.45	5.25	5.45	5.35	5.45	5.55	5.50	0.638	0.030	0.688	0.703	0.050	0.753
129	42.6	3.02	4.93	4.93	4.93	4.93	5.03	4.98	0.50	0.50	0.50	0.30	0.30	0.30	5.43	5.43	5.43	5.23	5.33	5.28	0.631	0.040	0.671	0.683	0.050	0.733
123	44.2	3.13	4.79	5.09	4.94	4.79	5.01	4.90	0.40	0.30	0.35	0.40	0.50	0.45	5.19	5.39	5.29	5.19	5.51	5.35	0.647	0.040	0.687	0.707	0.045	0.752
214	45.8	3.25	4.50	5.30	4.90	5.00	5.38	5.19	0.70	0.70	0.70	0.60	0.70	0.65	5.20	6.00	5.60	5.60	6.08	5.84	0.668	0.045	0.713	0.693	0.070	0.763
122	52.3	3.70	4.76	4.76	4.76	5.06	5.46	5.26	0.70	0.70	0.70	0.50	0.50	0.50	5.46	5.46	5.46	5.56	5.96	5.76	0.658	0.050	0.708	0.708	0.075	0.783
121	55.5	3.93	4.84	4.94	4.89	4.94	5.44	5.19	0.60	0.60	0.60	0.50	0.40	0.45	5.44	5.54	5.49	5.44	5.84	5.64	0.664	0.045	0.709	0.724	0.060	0.784
208	57.5	4.07	4.55	5.05	4.80	5.15	5.83	5.49	0.70	0.80	0.75	0.70	0.70	0.70	5.25	5.85	5.55	5.85	6.53	6.19	0.699	0.070	0.739	0.759	0.090	0.849
195	59.3	4.21	4.50	5.10	4.80	4.90	6.08	5.49	0.60	0.60	0.60	0.50	0.70	0.60	5.10	5.70	5.40	5.40	6.78	6.09	0.696	0.055	0.751	0.831	0.070	0.901
209	60.0	4.25	4.57	4.97	4.77	4.97	5.95	5.46	0.60	0.60	0.60	0.90	0.90	0.90	5.17	5.57	5.37	5.87	6.85	6.36	0.677	0.040	0.717	0.737	0.085	0.822
196	60.3	4.28	4.52	4.90	4.71	5.00	6.18	5.59	0.60	0.60	0.60	0.50	0.60	0.55	5.12	5.50	5.31	5.50	6.78	6.14	0.689	0.050	0.734			
119	62.2	4.41	4.75	4.75	4.75	4.85	5.63	5.24	0.50	0.50	0.50	0.60	0.80	0.70	5.25	5.25	5.25	5.45	6.43	5.94	0.626	0.050	0.676	0.741	0.070	0.811
210	63.3	4.49	4.50	4.70	4.60	5.09	5.67	5.38	0.60	0.60	0.60	0.60	0.70	0.65	5.10	5.30	5.20	5.69	6.37	6.03	0.666	0.040	0.706	0.761	0.070	0.831
197	63.9	4.53	4.66	4.96	4.81	5.16	6.16	5.66	0.40	0.40	0.40	0.30	0.50	0.40	5.06	5.36	5.21	5.46	6.66	6.06	0.667	0.030	0.697	0.772	0.055	0.827
211	65.5	4.64	4.62	4.72	4.67	5.11	5.71	5.41	0.50	0.50	0.50	0.50	0.50	0.50	5.12	5.22	5.17	5.61	6.21	6.01	0.666	0.040	0.706	0.746	0.070	0.816
120	67.0	4.75	4.70	4.70	4.70	5.09	5.67	5.38	0.40	0.40	0.40	0.40	0.40	0.40	5.10	5.10	5.10	5.49	6.07	5.78	0.620	0.025	0.645	0.735	0.050	0.785
198	67.7	4.80	4.56	4.86	4.71	4.86	6.04	5.45	0.50	0.50	0.50	0.40	0.50	0.45	5.06	5.36	5.21	5.26	6.54	5.90	0.665	0.040	0.705	0.810	0.045	0.855
212	68.4	4.85	4.56	4.66	4.61	5.16	5.76	5.46	0.50	0.50	0.50	0.50	0.60	0.55	5.06	5.16	5.11	5.66	6.36	6.01	0.650	0.035	0.685	0.755	0.060	0.815
199	69.0	4.89	4.66	5.06	4.86	5.06	6.04	5.55	0.50	0.50	0.50	0.50	0.60	0.55	5.16	5.56	5.36	5.56	6.64	6.10	0.661	0.035	0.696	0.766	0.065	0.831
213	70.6	5.00	4.58	4.78	4.68	4.88	5.86	5.37	0.40	0.40	0.40	0.50	0.50	0.50	4.98	5.18	5.08	5.38	6.36	5.87	0.629	0.035	0.664	0.764	0.060	0.824
118	71.0	5.04	4.52	4.52	4.52	5.12	5.90	5.51	0.50	0.40	0.45	0.40	0.60	0.50	5.02	4.92	4.97	5.52	6.50	6.01	0.595	0.040	0.635	0.780	0.055	0.835
200	72.1	5.12	4.60	4.80	4.70	4.99	6.27	5.63	0.50	0.50	0.50	0.50	0.50	0.50	5.10	5.30	5.20	5.49	6.77	6.13	0.622	0.040	0.662	0.772	0.065	0.837
117	76.3	5.40	4.70	4.50	4.60	5.09	5.87	5.48	0.50	0.60	0.55	0.50	0.60	0.55	5.20	5.10	5.15	5.59	6.47	6.03	0.619	0.035	0.654	0.784	0.065	0.849
201	77.3	5.48	4.54	4.92	4.73	5.22	6.30	5.76	0.50	0.60	0.55	0.40	0.40	0.40	5.04	5.52	5.28	5.62	6.70	6.16	0.642	0.045	0.687	0.782	0.060	0.842
202	79.4	5.64	4.66	4.96	4.81	5.25	6.43	5.84	0.60	0.50	0.55	0.50	0.50	0.50	5.26	5.46	5.36	5.75	6.93	6.34	0.626	0.045	0.671	0.796	0.080	0.876
116	80.8	5.73	4.74	4.74	4.74	5.04	5.92	5.48	0.60	0.60	0.60	0.50	0.70	0.60	5.34	5.34	5.34	5.54	6.62	6.08	0.639	0.050	0.689	0.794	0.065	0.859
203	82.2	5.83	4.58	4.68	4.63	4.88	5.66	5.27	0.70	0.60	0.65	0.60	0.80	0.70	5.28	5.28	5.28	5.48	6.46	5.97	0.629	0.065	0.694	0.759	0.110	0.869
113	84.0	5.95	4.96	5.34	5.15	5.34	6.04	5.69	1.00	0.80	0.90	0.70	0.80	0.75	5.96	6.14	6.05	6.04	6.84	6.44	0.706	0.090	0.796	0.831	0.085	0.916
204	85.0	6.03	4.62	5.00	4.81	5.00	6.10	5.55	0.70	0.70	0.70	0.80	0.80	0.80	5.32	5.70	5.51	5.80	6.90	6.35	0.675	0.055	0.730	0.780	0.115	0.895
114	85.0	6.03	5.11	5.59	5.35	5.11	6.19	5.65	1.00	0.80	0.90	0.90	1.00	0.95	6.11	6.29	6.20	6.01	7.07	6.54	0.720	0.090	0.810	0.810	0.105	0.915
115	87.0	6.17	5.00	5.18	5.09	5.29	6.17	5.73	1.00	0.80	0.90	0.80	0.90	0.85	6.00	5.98	5.99	6.09	7.07	6.58	0.700	0.070	0.770	0.805	0.085	0.890
207	88.0	6.24	5.10	5.10	5.10	5.10	5.78	5.44	0.90	0.70	0.80	0.80	0.90	0.85	6.00	5.80	5.90	5.90	6.68	6.29	0.711	0.070	0.781	0.746	0.100	0.846
206	88.3	6.26	4.75	4.95	4.85	5.05	5.75	5.40	0.60	0.60	0.60	0.70	0.60	0.65	5.35	5.55	5.45	5.75	6.35	6.05	0.671	0.045	0.716	0.766	0.090	0.856
205	89.4	6.34	4.48	5.06	4.77	5.26	6.26	5.76	0.80	0.80	0.80	0.60	0.80	0.70	5.28	5.86	5.57	5.86	7.06	6.46	0.665	0.050	0.715	0.735	0.140	0.875

NOTE:
(a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses and deflections are corrected for actual coal and water deductions.
(d) All stresses are corrected for 7/8 inch distance from extreme steel to instrument.
(e) All mechanical deflectometer readings are corrected for wire tension.
(f) Refer to Figure 12 for location of instruments

TABLE 10

TABULATION OF STRESSES AND VERTICAL DEFLECTIONS

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS M1-A (STEAM)

Run No.	Speed		STRAIN INSTRUMENTS																		DEFLECTION INSTRUMENTS					
			MEAN STRESSES Instrument Number						SEMI-AMPLITUDES Instrument Number						MAXIMUM STRESSES Instrument Number						Electrical Deflectometers East Girder			Mechanical Deflectometers West Girder		
			East Girder			West Girder			East Girder			West Girder			East Girder			West Girder								
			1	3		2	4		1	3		2	4		1	3		2	4							
	M.P.H.	R.P.S.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Comp.	Ten.	Ave.	Mean	Semi-Amp.	Max.	Mean	Semi-Amp.	Max.
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
133	4.8	0.38	5.95	6.10	6.02	5.85	5.85	5.85	0	0.05	0.02	0	0.10	0.05	5.95	6.15	6.05	5.85	5.95	5.90	0.855	0	0.855	0.870	0	0.870
134	9.0	0.71	6.29	5.99	6.14	5.99	6.38	6.18	0.10	0.10	0.10	0	0.10	0.05	6.39	6.09	6.24	5.99	6.48	6.24	0.870	0	0.870	0.875	0.010	0.885
135	13.3	1.05	6.11	6.36	6.24	5.96	6.65	6.30	0.15	0.10	0.12	0.20	0.30	0.25	6.26	6.46	6.36	6.16	6.95	6.56	0.870	0.010	0.880	0.880	0.015	0.895
137	25.0	1.98	6.51	6.51	6.51	6.32	6.61	6.46	0.39	0.20	0.30	0.30	0.30	0.30	6.90	6.71	6.80	6.62	6.91	6.76	0.875	0.025	0.900	0.925	0.030	0.955
150	25.2	1.99	6.11	6.16	6.14	6.01	6.40	6.20	0.30	0.34	0.32	0.10	0.20	0.15	6.41	6.50	6.46	6.11	6.60	6.36	0.840	0.015	0.855	0.900	0.050	0.950
149	29.4	2.32	6.29	6.15	6.22	6.29	6.39	6.34	0.39	0.44	0.42	0.30	0.20	0.25	6.68	6.59	6.64	6.59	6.59	6.59	0.850	0.020	0.870	0.885	0.030	0.915
148	34.8	2.75	6.28	6.09	6.18	6.33	6.58	6.46	0.69	0.69	0.69	0.54	0.49	0.52	6.97	6.78	6.88	6.87	7.07	6.97	0.830	0.070	0.900	0.900	0.065	0.965
147	40.3	3.18	6.46	6.26	6.36	6.26	6.46	6.36	0.79	0.59	0.69	0.69	0.59	0.64	7.25	6.85	7.05	6.95	7.05	7.00	0.860	0.060	0.920	0.905	0.090	0.995
153	41.5	3.28	6.27	6.18	6.22	6.18	6.18	6.18	0.69	0.49	0.59	0.59	0.49	0.54	6.96	6.67	6.82	6.77	6.67	6.72	0.850	0.055	0.905	0.890	0.080	0.970
193	42.0	3.32	5.93	6.33	6.13	5.93	6.62	6.28	0.30	0.39	0.34	0.30	0.30	0.30	6.23	6.72	6.48	6.23	6.92	6.58	0.900	0.010	0.910	0.925	0.070	0.995
189	43.9	3.47	6.14	6.34	6.24	6.01	6.11	6.06	0.59	0.49	0.54	0.39	0.49	0.44	6.73	6.83	6.78	6.40	6.60	6.50	0.930	0.050	0.980	0.925	0.060	0.985
154	46.2	3.65	6.21	6.30	6.26	6.11	6.21	6.16	0.39	0.39	0.39	0.49	0.39	0.44	6.60	6.69	6.64	6.60	6.60	6.60	0.815	0.060	0.875	0.880	0.080	0.960
188	46.6	3.67	5.92	6.51	6.22	5.92	6.71	6.32	0.59	0.49	0.54	0.49	0.49	0.49	6.51	7.00	6.76	6.41	7.20	6.80	0.945	0.050	0.995	0.915	0.055	0.970
187	47.0	3.71	5.90	6.49	6.20	6.00	6.49	6.24	0.49	0.49	0.49	0.49	0.49	0.49	6.39	6.98	6.68	6.49	6.98	6.74	0.935	0.040	0.975	0.915	0.065	0.980
146	47.0	3.71	6.06	6.35	6.20	6.06	6.55	6.30	0.69	0.49	0.59	0.79	0.69	0.74	6.75	6.84	6.80	6.85	7.24	7.04	0.855	0.050	0.905	0.880	0.090	0.970
152	47.2	3.72	5.94	6.33	6.14	6.14	6.63	6.38	0.69	0.49	0.59	0.69	0.59	0.64	6.63	6.82	6.72	6.83	7.22	7.02	0.830	0.060	0.890	0.880	0.095	0.975
151	47.4	3.74	6.52	6.32	6.42	6.47	6.52	6.50	0.69	0.59	0.64	0.64	0.59	0.62	7.21	6.91	7.06	7.11	7.11	7.11	0.855	0.050	0.905	0.880	0.095	0.975
191	49.5	3.91	5.83	6.08	5.96	5.78	7.16	6.47	0.64	0.79	0.72	0.89	0.49	0.69	6.47	6.87	6.67	6.67	7.65	7.16	0.875	0.050	0.925	0.940	0.100	1.040
143	50.2	3.96	6.54	6.29	6.42	6.39	6.14	6.26	0.44	0.29	0.36	0.20	0.44	0.32	6.98	6.58	6.78	6.59	6.58	6.58	0.865	0.030	0.895	0.900	0.030	0.930
192	51.4	4.06	6.06	6.60	6.33	6.01	6.70	6.36	0.54	0.49	0.52	0.49	0.49	0.49	6.60	7.09	6.85	6.50	7.19	6.85	0.930	0.040	0.970	0.975	0.110	1.085
190	53.8	4.25	6.06	6.36	6.21	6.16	6.95	6.56	0.39	0.69	0.54	0.59	0.79	0.69	6.45	7.05	6.75	6.75	7.74	7.24	0.840	0.060	0.900	0.925	0.060	0.985
145	54.3	4.29	6.44	6.34	6.39	6.14	6.74	6.44	0.20	0.10	0.15	0.39	0.39	0.39	6.64	6.44	6.54	6.53	7.13	6.83	0.895	0.010	0.905	0.920	0.040	0.960
141	57.0	4.50	6.20	6.00	6.10	6.30	6.54	6.42	0.49	0.39	0.44	0.49	0.54	0.52	6.69	6.39	6.54	6.79	7.08	6.94	0.870	0.055	0.925	0.960	0.050	1.010
140	58.5	4.62	6.65	6.21	6.43	6.36	6.36	6.36	0.30	0.44	0.37	0.30	0.49	0.40	6.95	6.65	6.80	6.66	6.85	6.76	0.910	0.030	0.940	0.935	0.050	0.985
185	60.0	4.74	6.09	6.39	6.24	6.68	7.08	6.88	0.49	0.49	0.49	0.49	0.69	0.59	6.58	6.88	6.73	7.17	7.77	7.47	0.980	0.045	1.025	0.990	0.070	1.060
186	62.8	4.96	5.83	6.52	6.18	5.88	6.52	6.20	0.44	0.54	0.49	0.49	0.54	0.52	6.27	7.06	6.67	6.37	7.06	6.72	0.930	0.050	0.980	0.905	0.070	0.975
144	64.8	5.12	6.11	5.82	5.96	6.31	6.75	6.53	0.49	0.39	0.44	0.49	0.54	0.52	6.60	6.21	6.40	6.80	7.29	7.04	0.825	0.035	0.860	0.895	0.050	0.945
139	66.5	5.25	6.02	5.88	5.95	5.97	6.52	6.24	0.30	0.44	0.37	0.44	0.39	0.42	6.32	6.32	6.32	6.41	6.91	6.66	0.870	0.045	0.915	0.930	0.070	1.000
184	67.7	5.34	5.75	6.63	6.19	5.75	6.63	6.19	0.49	0.59	0.54	0.59	0.69	0.64	6.24	7.22	6.73	6.34	7.32	6.83	0.945	0.050	0.995	0.960	0.070	1.030
182	68.1	5.38	5.68	6.17	5.92	5.92	7.25	6.58	0.49	0.39	0.44	0.44	0.69	0.56	6.17	6.56	6.36	6.36	7.94	7.15	0.875	0.070	0.945	0.970	0.080	1.050
183	69.9	5.52	5.82	6.21	6.02	7.20	7.59	7.40	0.49	0.39	0.44	0.30	0.39	0.34	6.31	6.60	6.46	7.50	7.98	7.74	0.905	0.050	0.955	1.005	0.045	1.050
138	71.2	5.62	5.57	5.77	5.67	6.55	6.95	6.75	0.59	0.49	0.54	0.59	0.39	0.49	6.16	6.26	6.21	7.14	7.34	7.24	0.825	0.070	0.895	0.975	0.075	1.050
181	72.8	5.75	5.75	6.44	6.10	6.44	7.72	7.08	0.79	0.49	0.64	0.20	0.39	0.30	6.54	6.93	6.74	6.64	8.11	7.38	0.895	0.075	0.970	0.985	0.060	1.045
180	75.7	5.98	5.82	6.61	6.22	6.32	7.79	7.06	1.08	0.59	0.84	0.49	0.69	0.59	6.90	7.20	7.06	6.81	8.48	7.64	0.895	0.105	1.000	0.990	0.075	1.065
142	77.9	6.15	6.16	5.92	6.04	6.46	6.34	6.40	0.69	0.54	0.62	0.69	0.69	0.69	6.85	6.46	6.66	7.15	7.03	7.09	0.830	0.055	0.885	0.980	0.070	1.050

NOTE:
(a) All stresses are in kips per square inch.
(b) All deflections are in inches.
(c) All stresses and deflections are corrected for actual coal and water deductions.
(d) All stresses are corrected for 7/8 inch distance from extreme steel to instrument.
(e) All mechanical deflectometer readings are corrected for wire tension.
(f) Refer to Figure 12 for location of instruments.

TABLE 11

ANALYSIS OF STRAIN GAGE READINGS
(Stresses at Center of Span)
55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)

Run No.	SPEED M.P.H.	MEAN STRESSES East Girder	MEAN STRESSES West Girder	MEAN STRESSES Average East and West	Speed Effect Stress	Speed Effect Per Cent	Roll Effect Stress	Roll Effect Per Cent	SEMI-AMPLITUDES East Girder Track Effect Stress	East Girder Track Effect Per Cent	West Girder Track Effect Stress	West Girder Track Effect Per Cent	Average Track Effect Stress	Average Track Effect Per Cent	MAXIMUM STRESSES East Girder	West Girder	East Girder Total Impact Stress	East Girder Total Impact Per Cent	West Girder Total Impact Stress	West Girder Total Impact Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
100	4.3	7.24	7.52	7.38					0.29	4.0	0.29	3.7	0.29	3.8	7.52	7.81	0.24	3.3	0.05	0.6
229	4.6	7.38	8.45	7.92					0.24	3.3	0.53	6.7	0.39	5.2	7.62	8.93	0.34	4.7	1.07	13.6
101	4.9	7.24	7.62	7.43					0.29	4.0	0.39	5.0	0.34	4.5	7.53	8.01	0.25	3.4	0.15	1.9
102	5.6	7.43	7.72	7.58	0.01	0	0.16 E	2.1 E	0.39	5.4	0.39	5.0	0.39	5.2	7.82	8.11	0.54	7.4	0.25	3.2
230	7.5	7.38	8.35	7.87	0.30	4.0	0.16 W	2.1 W	0.29	4.0	0.49	6.2	0.39	5.2	7.67	8.84	0.39	5.4	0.98	12.4
232	10.2	7.28	8.64	7.96	0.39	5.2	0.36 W	4.8 W	0.25	3.4	0.63	8.0	0.44	5.8	7.58	9.32	0.30	4.1	1.46	18.6
231	13.4	7.23	8.25	7.74	0.17	2.2	0.20 W	2.6 W	0.78	10.7	1.02	13.0	0.90	11.9	8.02	9.29	0.74	10.2	1.43	18.2
333	13.8	7.14	8.36	7.75	0.18	2.4	0.30 W	4.0 W	0.63	8.6	0.83	10.6	0.73	9.6	7.78	9.18	0.50	6.9	1.32	16.8
253	14.2	7.09	7.92	7.51			0.11 W	1.5 W	0.63	8.6	0.83	10.6	0.73	9.6	7.73	8.75	0.45	6.2	0.89	11.3
234	20.8	7.24	8.26	7.75	0.18	2.4	0.20 W	2.6 W	0.63	8.6	0.63	8.0	0.63	8.3	7.88	8.89	0.60	8.2	1.03	13.1
235	26.1	7.34	8.51	7.93	0.36	4.8	0.26 W	3.4 W	0.43	6.7	1.07	13.6	0.78	10.3	7.83	9.57	0.55	7.5	1.71	21.7
236	28.7	7.34	8.41	7.88	0.31	4.1	0.21 W	2.8 W	0.53	7.3	0.92	11.7	0.73	9.6	7.88	9.33	0.60	8.2	1.47	18.7
237	29.3	7.34	8.40	7.87	0.30	4.0	0.22 W	2.9 W	0.63	8.6	0.87	11.1	0.75	9.9	7.96	9.27	0.68	9.3	1.41	17.9
104	32.3	7.96	7.57	7.77	0.20	2.6	0.51 E	6.7 E	0.97	13.3	0.53	6.7	0.75	9.9	8.93	8.11	1.65	22.6	0.25	3.2
252	34.9	7.48	8.40	7.94	0.37	4.9	0.15 W	2.0 W	0.82	11.2	0.77	9.8	0.80	10.6	8.30	9.18	1.02	14.0	1.32	16.8
251	31.3	7.38	8.11	7.75	0.18	2.4	0.05 W	0.7 W	0.92	12.6	0.97	12.3	0.95	12.5	8.30	9.08	1.02	14.0	1.22	15.5
105	42.3	7.77	7.52	7.65	0.08	1.1	0.43 E	5.7 E	0.97	13.3	0.87	11.1	0.92	12.2	8.75	8.40	1.47	20.2	0.54	6.9
238	46.5	7.77	8.16	7.97	0.40	5.3	0.12 E	1.6 E	0.78	10.7	1.07	13.6	0.93	12.3	8.54	9.23	1.26	17.3	1.37	17.4
107	43.5	7.87	7.43	7.65	0.08	1.1	0.52 E	6.9 E	0.87	11.9	0.82	10.4	0.85	11.2	8.74	8.25	1.46	20.0	0.39	5.0
106	51.1	7.77	7.38	7.58	0.01	0	0.50 E	6.6 E	0.97	13.3	0.97	12.3	0.97	12.8	8.75	8.35	1.47	20.2	0.49	6.2
108	59.5	7.77	7.62	7.70	0.13	1.7	0.18 E	2.4 E	0.58	8.0	0.92	11.7	0.75	9.9	8.35	8.55	1.07	14.7	0.69	8.8
239	61.5	7.67	8.21	7.94	0.37	4.9	0.04 E	0.5 E	0.58	8.0	1.16	14.7	0.87	11.5	8.25	10.04	0.97	13.3	2.18	27.7
246	67.6	6.22	10.45	8.34	0.77	10.2	1.87 W	24.7 W	0.97	13.3	1.17	14.9	1.07	14.1	7.73	11.63	0.45	6.2	3.77	47.9
109	70.4	6.37	9.14	7.76	0.19	2.5	1.14 W	15.1 W	1.12	15.4	0.92	11.7	1.02	13.5	7.48	10.45	0.20	2.8	2.58	32.8
240	71.0	6.47	9.81	8.14	0.57	7.5	0.35 W	4.6 W	1.07	14.7	0.83	10.6	0.95	12.5	7.53	10.60	0.25	3.4	2.74	34.8
241	72.4	6.56	10.16	8.36	0.79	10.4	1.47 W	19.4 W	1.12	15.4	0.97	12.3	1.05	13.9	7.68	11.14	0.40	5.5	3.28	41.6
243	76.5	6.65	10.35	8.50	0.93	12.3	1.61 W	21.3 W	1.07	14.7	1.17	14.9	1.12	14.8	7.68	11.43	0.40	5.5	3.57	45.4
249	76.5	6.27	10.19	8.23	0.66	8.7	1.64 W	21.7 W	0.97	13.3	0.92	11.7	0.95	12.5	7.23	11.14	0.05	0.7	3.28	41.6
242	78.8	6.51	10.22	8.36	0.79	10.4	1.59 W	21.0 W	0.97	13.3	1.07	13.6	1.02	13.5	7.58	11.27	0.30	4.1	3.41	43.4
244	85.4	6.66	11.23	8.94	1.37	18.1	2.01 W	26.6 W	0.92	12.6	0.97	12.3	0.94	12.4	8.20	12.19	0.92	12.6	4.33	55.0
245	87.8	7.52	10.26	8.89	1.32	17.4	1.07 W	14.1 W	1.12	15.4	1.16	14.7	1.14	15.1	8.64	11.95	1.36	18.7	4.09	52.0
111	91.8	6.36	9.18	7.77	0.20	2.6	1.16 W	15.3 W	0.58	8.0	1.07	13.6	0.82	10.8	8.35	10.24	1.07	14.7	2.38	30.2
248	99.5	8.69	9.44	9.07	1.50	19.8	0.02 W	0.3 W	0.92	12.6	1.26	16.0	1.09	14.4	9.62	10.69	2.34	32.2	2.83	36.0
112	99.7	8.45	8.65	8.55	0.98	12.9	0.24 E	3.2 E	1.17	16.1	1.02	13.0	1.10	14.5	9.62	9.52	2.34	32.2	1.66	21.1

NOTE: (a) All stresses shown in Columns 3, 4, 10, 12, 16 and 17 are taken from Table 3 and are the average of the top and bottom flange stress for each girder.

(b) All stresses shown are in kips per square inch.

(c) The average of the mean stresses for the first three runs are considered as the "static stresses" in the east and west girders and their comparisons with the theoretical stresses are as follows:

MEASURED STATIC STRESSES		THEORETICAL STATIC STRESSES (Based on gross moment of inertia)		STRESS FACTORS (Measured/Theoretical)	
East girder	7.28	East girder	7.30	East girder	0.997
West girder	7.86	West girder	8.10	West girder	0.971
Average	7.57	Average	7.70	Average	0.984
Eccentricity	3.80 Per Cent	Eccentricity	5.10 Per Cent		

(d) The loaded frequency "n", based on a static deflection of 0.493 inch, is 4.56 vibrations per second.

(e) The theoretical dead load deflection, based on the gross moment of inertia at the center, is 0.065 in.

TABLE 12

ANALYSIS OF STRAIN GAGE READINGS
(Stresses at Center of Span)
55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)

		MEAN STRESSES							SEMI-AMPLITUDES						MAXIMUM STRESSES					
				Aver. East and West	Speed Effect		Roll Effect		East Girder Track Effect		West Girder Track Effect		Average Track Effect				East Girder Total Impact		West Girder Total Impact	
Run No.	Speed M.P.H.	East Gir.	West Gir.		Stress	Per Cent	Stress	Per Cent	Stress	Per Cent	Stress	Per Cent	Stress	Per Cent	East Gir.	West Gir.	Stress	Per Cent	Stress	Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
155	4.4	5.98	6.66	6.32	0	0	0	0	0.19	3.2	0.14	2.1	0.16	2.5	6.18	6.80	0.20	3.3	0.14	2.1
156	9.8	6.17	7.19	6.68	0.36	5.7	0.14 W	2.2 W	0.14	2.3	0.19	2.9	0.16	2.5	6.32	7.19	0.34	5.7	0.53	8.0
228	10.3	6.08	7.24	6.66	0.34	5.4	0.20 W	3.2 W	0.14	2.3	0.20	3.0	0.17	2.7	6.22	7.44	0.24	4.0	0.78	11.7
157	12.7	6.03	6.90	6.46	0.14	2.2	0.08 W	1.3 W	0.24	4.0	0.24	3.6	0.24	3.8	6.27	7.14	0.29	4.8	0.48	7.2
158	15.6	6.02	6.70	6.36	0.04	0.6	0.01 E	0.2 E	0.24	4.0	0.24	3.6	0.24	3.8	6.26	6.95	0.28	4.7	0.29	4.4
159	18.5	5.98	6.90	6.44	0.12	1.9	0.11 W	1.7 W	0.34	5.7	0.34	5.1	0.34	5.4	6.32	7.24	0.34	5.7	0.58	8.7
160	25.0	6.61	7.00	6.80	0.48	7.6	0.17 E	2.8 E	0.29	4.8	0.54	8.1	0.42	6.6	6.90	7.54	0.92	15.4	0.88	13.2
161	28.7	6.71	6.76	6.74	0.42	6.6	0.35 E	5.5 E	0.44	7.4	0.58	8.7	0.51	8.1	7.15	7.34	1.17	19.6	0.68	10.2
165	35.2	6.32	7.04	6.68	0.36	5.7	0.01 E	0.2 E	0.49	8.2	0.68	10.2	0.58	9.2	6.80	7.72	0.82	13.7	1.06	15.9
162	35.7	6.36	6.90	6.63	0.31	4.9	0.09 E	1.4 E	0.49	8.2	0.54	8.1	0.52	8.2	6.86	7.44	0.88	14.7	0.78	11.7
227	39.7	6.08	7.48	6.78	0.46	7.3	0.33 W	5.2 W	0.39	6.5	0.44	6.6	0.42	6.6	6.46	7.92	0.48	8.0	1.26	18.9
163	39.8	6.22	7.00	6.61	0.29	4.6	0.02 W	0.3 W	0.44	7.4	0.44	6.6	0.44	7.0	6.66	7.44	0.68	11.4	0.78	11.7
164	44.7	6.61	7.14	6.88	0.56	8.9	0.12 E	1.9 E	0.54	9.0	0.58	8.7	0.56	8.9	7.14	7.72	1.16	19.4	1.06	15.9
166	50.1	6.27	7.20	6.74	0.42	6.6	0.10 W	1.6 W	0.63	10.5	0.78	11.7	0.70	11.1	6.90	7.98	0.92	15.4	1.32	19.8
226	51.1	6.46	7.38	6.92	0.60	9.5	0.08 W	1.3 W	0.34	5.7	0.87	13.0	0.60	9.5	6.80	8.26	0.82	13.7	1.60	24.0
178	54.8	6.51	7.20	6.86	0.54	8.5	0.04 E	0.6 E	0.49	8.2	0.78	11.7	0.64	10.1	7.00	7.97	1.02	17.1	1.31	19.6
225	57.0	6.12	7.82	6.97	0.65	10.3	0.47 W	7.5 W	0.44	7.4	0.92	13.8	0.68	10.8	6.56	8.74	0.58	9.7	2.08	31.2
177	59.8	6.02	7.44	6.73	0.41	6.5	0.33 W	5.2 W	0.49	8.2	0.82	12.3	0.66	10.4	6.52	8.26	0.54	9.0	1.60	24.0
179	60.9	6.02	7.38	6.70	0.38	6.0	0.31 W	4.9 W	0.48	8.0	0.58	8.7	0.53	8.4	6.51	7.97	0.53	8.9	1.31	19.6
176	64.6	5.68	7.39	6.54	0.22	3.5	0.50 W	7.9 W	0.34	5.7	0.92	13.8	0.63	10.0	6.02	8.31	0.04	0.7	1.65	24.8
224	69.4	5.98	8.31	7.14	0.82	13.0	0.79 W	12.5 W	0.49	8.2	0.68	10.2	0.58	9.2	6.47	8.99	0.49	8.2	2.33	35.0
175	71.6	5.93	7.53	6.73	0.41	6.5	0.43 W	6.8 W	0.44	7.4	0.72	11.8	0.58	9.2	6.46	8.24	0.48	8.0	1.58	23.7
174	73.0	5.88	7.98	6.93	0.61	9.6	0.68 W	10.8 W	0.49	8.2	0.68	10.2	0.58	9.2	7.24	8.66	1.26	21.2	2.00	30.0
223	73.0	5.74	8.31	7.02	0.70	11.1	0.91 W	14.4 W	0.68	11.4	0.54	8.1	0.61	9.6	6.80	8.84	0.82	13.7	2.18	32.7
221	78.7	6.18	8.36	7.27	0.95	15.0	0.70 W	11.1 W	0.39	6.5	0.64	9.6	0.52	8.2	7.24	9.00	1.26	21.1	2.34	35.1
171	79.5	6.02	7.48	6.75	0.43	6.8	0.36 W	5.7 W	0.44	7.4	0.72	11.8	0.58	9.2	7.29	8.21	1.31	21.9	1.55	23.2
167	82.1	7.24	7.86	7.55	1.23	19.5	0.10 E	1.6 E	0.34	5.7	0.88	13.2	0.61	9.6	7.58	8.16	1.60	26.8	1.50	22.5
168	84.0	7.54	7.00	7.27	0.95	15.0	0.64 E	10.1 E	0.44	7.4	0.68	10.2	0.56	8.9	7.98	7.18	2.00	33.4	0.52	7.8
169	90.4	7.68	6.80	7.24	0.92	14.6	0.82 E	13.0 E	0.54	9.0	0.49	7.3	0.52	8.2	8.21	7.63	2.23	37.3	0.97	14.6
170	95.9	7.04	7.10	7.07	0.75	11.9	0.34 E	5.4 E	0.58	9.7	0.49	7.3	0.54	8.5	7.78	8.16	1.80	30.1	1.50	22.5
173	98.5	6.76	7.34	7.05	0.73	10.4	0.08 E	1.3 E	0.68	11.4	0.82	12.3	0.75	11.9	8.70	8.84	2.72	45.5	2.18	32.7
172	105.0	6.42	8.16	7.29	0.97	15.3	0.48 W	7.6 W	0.64	10.7	0.82	12.3	0.73	11.5	7.05	9.28	1.07	17.9	2.62	39.3

NOTE: (a) All stresses shown in columns 3, 4, 10, 12, 16 and 17 are taken from Table 4 and are the average of the top and bottom flange stress for each girder.
(b) All stresses shown are in kips per square inch.
(c) The mean stresses for the first run are considered as the "static stresses" in the east and west girders and their comparisons with the theoretical stresses are as follows:

MEASURED STATIC STRESSES		THEORETICAL STATIC STRESSES (Based on gross moment of inertia)		STRESS FACTORS (Measured/Theoretical)	
East girder	= 5.98	East girder	= 6.20	East girder	= 0.966
West girder	= 6.66	West girder	= 6.86	West girder	= 0.970
Average	= 6.32	Average	= 6.53	Average	= 0.968
Eccentricity	= +5.50 Per Cent	Eccentricity	= +5.10 Per Cent		

(d) The loaded frequency "n", based on a mean static deflection of 0.412 inch, is 4.94 vibrations per second.

TABLE 13

ANALYSIS OF STRAIN GAGE READINGS
(Stresses at Center of Span)
55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS M4-6 (STEAM)

Run No.	SPEED M.P.H.	SPEED R.P.S.	DIMENSION "X" Feet	Average Mean Deflection Inches	Theoretical Loaded Frequency "n" V.P.S.	MEAN STRESSES: East Girder	MEAN STRESSES: West Girder	MEAN STRESSES: Average East and West	Speed Effect: Stress	Speed Effect: Per Cent	Roll Effect: Stress	Roll Effect: Per Cent	SEMI-AMPLITUDES: East Girder Track and Hammer Blow Effect: Stress	East: $D_H N^2$	East: Dynamic Magnifier	West Girder Track and Hammer Blow Effect: Stress	West: $D_H N^2$	West: Dynamic Magnifier	Average Both Girders Track and Hammer Blow Effect: Stress	Average: $D_H N^2$	Average: Dynamic Magnifier	MAXIMUM STRESSES: East Girder	MAXIMUM STRESSES: West Girder	East Girder Total Impact: Stress	East Girder Total Impact: Per Cent	West Girder Total Impact: Stress	West Girder Total Impact: Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
132	5.2	0.37		0.479	4.63	7.04	8.12	7.58	0	0	0	0	0.20	0.01		0.20	0.01		0.20	0.010		7.24	8.32	0.20	2.8	0.20	2.5
128	18.9	1.34				7.09	8.40	7.75	0.17	2.2	0.10W	1.3W	0.68	0.07	9.70	0.59	0.10	5.90	0.64	0.085	7.53	7.77	8.98	0.73	10.4	0.86	10.6
127	26.6	1.89		0.475	4.65	7.04	8.59	7.82	0.24	3.2	0.22W	2.9W	0.73	0.14	5.20	0.92	0.19	4.84	0.83	0.165	5.03	7.87	9.43	0.83	11.8	1.31	16.1
126	30.1	2.13				7.24	8.01	7.63	0.05	0.7	0.15E	2.0E	0.97	0.18	4.83	1.31	0.25	5.24	1.09	0.215	5.07	8.11	9.32	1.07	15.2	1.20	14.8
125	35.6	2.52		0.464	4.70	7.28	8.49	7.89	0.31	4.1	0.04W	0.5W	0.93	0.25	3.32	0.87	0.34	2.56	0.85	0.295	2.88	8.10	9.37	1.06	15.1	1.25	15.4
124	40.0	2.84		0.475	4.65	6.70	8.64	7.67	0.09	1.2	0.42W	5.5W	0.92	0.32	2.88	1.36	0.44	3.09	1.14	0.380	3.00	7.92	10.01	0.88	12.5	1.89	23.5
130	40.2	2.85		0.461	4.71	6.70	8.54	7.62	0.04	0.5	0.38W	5.0W	0.87	0.33	2.64	0.87	0.44	1.98	0.87	0.385	2.26	7.57	9.42	0.53	7.5	1.40	17.2
131	41.7	2.96		0.481	4.62	6.89	8.69	7.79	0.21	2.8	0.35W	4.6W	0.97	0.35	2.77	1.56	0.47	3.32	1.27	0.410	3.10	7.87	10.25	0.83	11.8	2.13	26.2
129	42.6	3.02		0.468	4.68	6.65	8.25	7.45	-0.13	-1.7	0.27W	3.6W	0.87	0.37	2.36	0.97	0.49	1.98	0.92	0.430	2.14	7.52	9.22	0.48	6.8	1.10	13.6
123	44.2	3.13		0.466	4.69	6.75	8.59	7.67	0.09	1.2	0.37W	4.9W	0.73	0.39	1.87	1.46	0.53	2.76	1.10	0.460	2.39	7.47	10.05	0.43	6.1	1.93	23.8
214	45.8	3.25		0.478	4.64	6.31	9.76	8.04	0.46	6.1	1.16W	15.3W	1.22	0.42	2.90	2.33	0.57	4.09	1.78	0.505	3.56	7.53	12.09	0.49	7.0	3.97	48.9
122	52.3	3.70	10.0 S	0.461	4.71	6.26	8.74	7.50	-0.08	-1.1	0.70W	9.2W	0.58	0.55	1.06	1.02	0.74	1.38	0.80	0.645	1.24	7.09	9.77	0.05	0.7	1.65	20.3
121	55.5	3.93	8.3 N	0.460	4.71	6.70	9.18	7.94	0.36	4.7	0.68W	9.0W	0.78	0.62	1.26	0.58	0.83	0.70	0.68	0.725	0.94	7.47	9.77	0.43	6.1	1.65	20.3
208	57.5	4.07	5.7 S	0.451	4.75	6.36	9.16	7.76	0.18	2.4	0.84W	11.1W	1.12	0.66	1.70	1.99	0.89	2.24	1.56	0.775	2.02	7.42	11.66	0.38	5.4	3.54	43.6
195	59.3	4.20	7.5 S	0.444	4.79	6.31	8.84	7.58	0	0	0.60W	7.9W	1.22	0.71	1.72	2.14	0.95	2.25	1.68	0.830	2.03	7.52	10.99	0.48	6.8	2.87	35.4
209	60.0	4.25	1.9 S	0.494	4.57	7.09	10.40	8.75	1.17	15.4	1.03W	13.6W	1.70	0.72	2.35	3.26	0.98	3.33	2.48	0.850	2.92	8.79	13.60	1.75	24.9	5.48	67.5
196	60.3	4.28	9.5 S	0.461	4.71	6.32	9.42	7.87	0.29	3.8	0.98W	12.9W	0.78	0.74	1.05	1.16	0.99	1.27	0.97	0.865	1.18	7.19	10.89	0.15	2.1	2.77	34.1
210	63.3	4.48	1.9 N	0.518	4.48	7.09	9.81	8.45	0.87	11.5	0.76W	10.0W	1.31	0.81	1.62	2.67	1.09	2.45	1.99	0.850	2.34	8.40	12.49	1.36	19.3	4.37	53.8
197	63.9	4.53	1.9 S	0.519	4.47	6.70	9.86	8.28	0.70	9.2	1.00W	13.2W	1.56	0.82	1.90	2.87	1.11	2.58	2.22	0.965	2.30	8.25	12.72	1.21	17.2	4.60	56.7
211	65.5	4.64	5.9 N	0.480	4.63	6.46	8.84	7.65	0.07	0.9	0.64W	8.4W	1.60	0.86	1.86	1.80	1.16	1.55	1.70	1.010	1.68	8.06	10.65	1.02	14.5	2.53	31.2
120	67.0	4.75	5.6 N	0.463	4.70	7.00	8.26	7.63	0.05	0.7	0.09W	1.2W	0.97	0.90	1.08	1.89	1.22	1.55	1.43	1.060	1.35	8.55	10.16	1.51	21.4	2.04	25.1
198	67.7	4.80	2.2 S	0.519	4.47	6.71	9.86	8.29	0.71	9.3	0.98W	12.9W	1.46	0.92	1.59	2.38	1.24	1.92	1.92	1.080	1.78	8.50	12.25	1.46	20.7	4.13	50.9
212	68.4	4.85	10.3 S	0.436	4.82	7.00	8.06	7.53	-0.05	-0.7	0	0	1.31	0.94	1.40	1.80	1.27	1.42	1.56	1.105	1.41	8.31	9.85	1.27	18.0	1.73	21.3
199	69.0	4.89	6.3 N	0.498	4.56	6.85	9.32	8.09	0.51	6.7	0.66W	8.7W	1.60	0.96	1.67	1.99	1.29	1.54	1.80	1.130	1.59	8.44	11.32	1.40	19.9	3.20	39.4
213	70.6	5.00		0.484	4.61	6.75	8.50	7.63	0.05	0.7	0.32W	4.2W	1.41	1.00	1.41	2.24	1.35	1.66	1.88	1.175	1.60	8.16	10.75	1.12	15.9	2.63	32.4
118	71.0	5.04	5.3 S	0.476	4.65	7.47	8.69	8.08	0.50	6.6	0.03W	0.4W	0.97	1.01	0.96	2.24	1.37	1.63	1.61	1.190	1.35	8.45	10.94	1.41	20.0	2.82	34.7
200	72.1	5.12	6.2 S	0.463	4.70	6.22	8.74	7.48	-0.10	-1.3	0.72W	9.5W	0.78	1.05	0.92	1.65	1.42	1.16	1.22	1.235	0.99	8.16	10.40	1.12	15.9	2.28	28.1
201	77.3	5.47	4.0 S	0.531	4.43	7.96	9.72	8.84	1.26	16.6	0.26W	3.4W	1.51	1.20	1.26	1.85	1.62	1.14	1.68	1.410	1.19	9.47	11.57	2.43	34.5	3.45	42.5
202	79.4	5.63	0.4 N	0.498	4.56	8.21	9.27	8.74	1.16	15.3	0.10E	1.3E	1.56	1.27	1.23	2.87	1.71	1.68	2.22	1.490	1.49	9.77	12.14	2.73	38.8	4.02	49.5
116	80.8	5.72	0.1 S	0.470	4.67	7.67	8.88	8.28	0.70	9.2	0	0	1.80	1.31	1.37	2.82	1.77	1.59	2.31	1.540	1.50	9.47	11.72	2.43	34.5	3.60	44.4
203	82.2	5.82	4.3 N			7.13	9.18	8.16	0.58	7.6	0.43W	5.7W	1.60	1.36	1.18	2.72	1.83	1.49	2.16	1.595	1.36	8.74	11.90	1.70	24.1	3.78	46.6
113	84.0	5.96		0.460	4.71	6.70	8.89	7.80	0.22	2.9	0.54W	7.1W	1.70	1.43	1.19	2.14	1.93	1.11	1.92	1.680	1.14	8.40	11.02	1.36	19.3	2.90	35.7
114	85.0	6.03		0.466	4.69	6.60	9.80	8.20	0.62	8.2	1.02W	13.4W	1.94	1.46	1.33	2.82	1.97	1.43	2.38	1.715	1.39	8.55	12.15	1.51	21.4	4.05	49.6
204	85.0	6.03	8.5 N	0.485	4.61	7.33	9.67	8.50	0.92	12.1	0.57W	7.5W	1.70	1.46	1.16	3.01	1.97	1.53	2.36	1.715	1.38	9.05	12.68	2.01	28.5	4.56	56.2
115	87.0	6.16	8.4 S	0.438	4.81	7.10	8.86	7.98	0.40	5.3	0.30W	4.0W	1.94	1.52	1.28	2.04	2.05	0.99	1.99	1.785	1.12	8.26	10.64	1.22	17.3	2.52	31.0
207	88.0	6.23	7.2 S	0.477	4.64	6.61	9.14	7.88	0.30	4.0	0.69W	9.1W	1.80	1.55	1.16	2.72	2.10	1.30	2.26	1.825	1.24	8.40	11.86	1.36	19.3	3.74	46.1
206	88.3	6.26	1.1 N	0.490	4.59	7.24	9.84	8.54	0.96	12.6	0.70W	9.2W	1.21	1.57	0.77	2.97	2.12	1.40	2.09	1.845	1.13	8.45	12.79	1.41	20.0	4.67	57.5
205	89.4	6.33	4.8 S	0.498	4.56	6.99	9.38	8.19	0.61	8.0	0.61W	8.0W	1.56	1.60	0.98	2.87	2.16	1.33	2.22	1.880	1.18	8.55	12.26	1.51	21.4	4.14	51.0

NOTE: (a) All stresses shown in Columns 7, 8, 14, 17, 23 and 24 are taken from Table 5 and are the average of the top and bottom flange stress for each girder.
(b) All stresses shown are in kips per square inch.
(c) Dimension "X" in Column 4 is the distance, either North or South, from the center of the span to the main drivers at the time the crank pins are in position for maximum hammer blow effect on the span. Locomotive headed south.
(d) The mean stresses for the first run are considered as the "static stresses" in the east and west girders and their comparison with the theoretical stresses are as follows:

MEASURED STATIC STRESSES		THEORETICAL STATIC STRESSES (Based on gross moment of inertia)		STRESS FACTORS (Measured / Theoretical)	
East girder	7.04	East Girder	7.50	East girder	0.939
West girder	8.12	West girder	8.30	West girder	0.979
Average	7.58	Average	7.90	Average	0.959
Eccentricity	+7.10 per cent	Eccentricity	+5.10 per cent		

(e) The "hammer blow stresses" at one revolution per second are as follows:

East girder	0.043	x	0.939	=	0.040
West girder	0.055	x	0.979	=	0.054
Average					0.047

Note: [illegible] are [illegible] columns 7, [illegible], 14, 17, [illegible] and [illegible], are taken from Table 6 and are the average of the top and bottom flange stress for each girder.

[illegible] to nearest [illegible] per square inch.

[illegible] is the distance, either north or south, from the center of the span [illegible] the main driver at the time the pins are in position for max[illegible] [illegible] of the span [illegible]

[illegible] The same stresses for the [illegible] were considered as the "static stresses" in the east and west girders and [illegible] compare [illegible] with the [illegible] stress [illegible]

East girder	[illegible]
West girder	[illegible]
Average	[illegible]

East girder	[illegible]
West girder	[illegible]
Average	[illegible]

Measured [illegible]

[illegible] "static stresses" [illegible] per square inch [illegible]

[illegible] girder	0.[illegible]	[illegible]	[illegible]
East girder	0.[illegible]	[illegible]	1.[illegible]
Average			

TABLE 15

ANALYSIS OF STRAIN GAGE READINGS
(Stresses at Center of Span)
122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)

		MEAN STRESSES							SEMI-AMPLITUDES						MAXIMUM STRESSES					
Run No.	SPEED M.P.H.	East Girder	West Girder	Average East and West	Speed Effect Stress	Speed Effect Per Cent	Roll Effect Stress	Roll Effect Per Cent	East Girder Track Effect Stress	East Girder Track Effect Per Cent	West Girder Track Effect Stress	West Girder Track Effect Per Cent	Average both Girders Track Effect Stress	Average both Girders Track Effect Per Cent	East Girder	West Girder	East Girder Total Stress	East Girder Impact Per Cent	West Girder Total Stress	West Girder Impact Per Cent
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
100	4.3	4.39	4.48	4.44					0.10	2.3	0.10	2.3	0.10	2.3	4.49	4.58	0.15	3.4	0.06	1.3
229	4.6	4.24	4.63	4.44					0.10	2.3	0.10	2.3	0.10	2.3	4.34	4.73	0	0	0.21	4.6
101	4.9	4.39	4.44	4.42					0.10	2.3	0.10	2.3	0.10	2.3	4.49	4.54	0.15	3.4	0.02	0.4
102	5.6	4.34	4.44	4.39	-0.04	-0.9	0.04E	0.9E	0.10	2.3	0.10	2.3	0.10	2.3	4.44	4.68	0.10	2.3	0.16	3.5
230	7.5	4.28	4.68	4.48	0.05	1.1	0.11W	2.5W	0.15	3.5	0.15	3.3	0.15	3.4	4.43	4.83	0.09	2.1	0.31	6.9
232	10.2	4.24	4.68	4.46	0.03	0.7	0.13W	2.9W	0.20	4.6	0.20	4.4	0.20	4.5	4.44	4.88	0.10	2.3	0.36	8.0
231	13.4	4.24	4.63	4.44	0.01	0.2	0.11W	2.5W	0.20	4.6	0.20	4.4	0.20	4.5	4.44	4.83	0.10	2.3	0.31	6.9
233	13.8	4.24	4.63	4.44	0.01	0.2	0.11W	2.5W	0.20	4.6	0.20	4.4	0.20	4.5	4.44	4.83	0.10	2.3	0.31	6.9
253	14.2	4.24	4.63	4.44	0.01	0.2	0.11W	2.5W	0.20	4.6	0.20	4.4	0.20	4.5	4.44	4.83	0.10	2.3	0.31	6.9
103	17.2	4.44	4.59	4.52	0.09	2.0	0.01E	0.2E	0.35	8.1	0.35	7.8	0.35	7.9	4.79	4.94	0.45	10.4	0.42	9.3
234	20.8	4.19	4.73	4.46	0.03	0.7	0.18W	4.1W	0.40	9.2	0.40	8.9	0.40	9.0	4.59	5.13	0.25	5.8	0.61	13.5
235	26.1	4.24	4.72	4.48	0.05	1.1	0.15W	3.4W	0.25	5.8	0.25	5.5	0.25	5.6	4.49	4.97	0.15	3.4	0.45	10.0
236	28.7	4.29	4.73	4.51	0.08	1.8	0.13W	2.9W	0.25	5.8	0.25	5.5	0.25	5.6	4.54	4.98	0.20	4.6	0.46	10.2
237	29.3	4.29	4.88	4.59	0.16	3.6	0.20W	4.5W	0.20	4.6	0.20	4.4	0.20	4.5	4.49	5.08	0.15	3.4	0.50	11.1
104	32.3	4.44	4.73	4.59	0.16	3.6	0.05W	1.1W	0.20	4.6	0.20	4.4	0.20	4.5	4.64	4.93	0.30	6.9	0.41	9.1
252	34.9	4.38	4.77	4.58	0.15	3.4	0.10W	2.3W	0.25	5.8	0.25	5.5	0.25	5.6	4.63	5.02	0.29	6.7	0.50	11.1
251	41.3	4.24	4.78	4.51	0.08	1.8	0.18W	4.1W	0.30	6.9	0.20	4.4	0.25	5.6	4.54	4.98	0.20	4.6	0.46	10.2
105	42.3	4.49	4.68	4.59	0.16	3.6	0	0	0.25	5.8	0.20	4.4	0.23	5.2	4.74	4.88	0.40	9.2	0.36	8.0
238	46.5	4.34	4.73	4.59	0.16	3.6	0.05W	1.1W	0.20	4.6	0.20	4.4	0.20	4.5	4.54	4.93	0.20	4.6	0.41	9.1
107	49.5	4.68	4.63	4.63	0.20	4.5	0.09E	2.0E	0.20	4.6	0.20	4.4	0.20	4.5	4.88	4.83	0.54	12.4	0.31	6.9
106	51.1	4.73	4.63	4.68	0.25	5.6	0.10E	3.2E	0.25	5.8	0.25	5.5	0.25	5.6	4.98	4.88	0.64	14.8	0.36	8.0
108	59.5	4.93	4.73	4.83	0.40	9.0	0.29E	6.5E	0.20	4.6	0.20	4.4	0.20	4.5	5.13	4.93	0.79	18.2	0.41	9.1
239	61.5	4.63	4.58	4.61	0.18	4.1	0.12E	2.7E	0.15	3.5	0.20	4.4	0.18	4.1	4.78	0.78	0.44	10.1	0.26	5.8
246	67.6	3.99	5.28	4.64	0.21	4.7	0.55W	12.4W	0.20	4.6	0.20	4.4	0.20	4.5	4.19	5.48	-0.15	-3.4	0.96	21.2
109	70.4	4.54	4.73	4.64	0.21	4.7	0	0	0.20	4.6	0.20	4.4	0.20	4.5	4.74	5.22	0.40	9.2	0.70	15.5
240	71.0	4.19	5.18	4.69	0.26	5.9	0.40W	9.0W	0.20	4.6	0.20	4.4	0.20	4.5	4.48	5.38	0.14	3.2	0.86	19.0
241	72.4	3.84	5.23	4.54	0.11	2.5	0.62W	14.0W	0.20	4.6	0.20	4.4	0.20	4.5	4.38	5.43	0.04	0.9	0.91	20.2
249	76.5	4.09	5.47	4.78	0.35	7.9	0.39W	13.3W	0.15	3.5	0.15	3.3	0.15	3.4	4.24	5.62	-0.10	-2.3	1.10	24.4
243	76.5	3.99	5.62	4.81	0.38	8.6	0.72W	16.3W	0.10	2.3	0.10	2.3	0.10	2.3	4.09	5.72	-0.25	-5.8	1.20	26.6
242	78.8	3.89	5.42	4.66	0.23	5.2	0.67W	15.1W	0.15	3.5	0.15	3.3	0.15	3.4	4.04	5.57	-0.30	-6.9	1.05	23.3
110	81.6	3.94	5.37	4.66	0.23	5.2	0.62W	14.0W	0.15	3.5	0.15	3.3	0.15	3.4	4.09	5.52	-0.25	-5.8	1.00	22.2
245	87.8	3.94	5.52	4.73	0.30	6.8	0.70W	15.8W	0.20	4.6	0.20	4.4	0.20	4.5	4.34	5.72	0	0	1.20	26.6
111	91.8	4.19	5.32	4.76	0.33	7.5	0.47W	10.6W	0.20	4.6	0.20	4.4	0.20	4.5	4.39	5.52	0.05	1.2	1.00	22.2
247	95.2	4.09	5.52	4.81	0.38	8.6	0.62W	14.0W	0.20	4.6	0.20	4.4	0.20	4.5	4.29	5.72	-0.05	-1.2	1.20	26.6
250	96.3	4.04	5.46	4.75	0.32	7.2	0.62W	14.0W	0.20	4.6	0.20	4.4	0.20	4.5	4.24	5.66	-0.10	-2.3	1.14	25.2
248	99.5	4.14	5.32	4.73	0.30	6.8	0.50W	11.3W	0.20	4.6	0.20	4.4	0.20	4.5	4.34	5.52	0	0	1.00	22.2
112	99.7	4.29	5.37	4.83	0.40	9.0	0.45W	10.2W	0.20	4.6	0.20	4.4	0.20	4.5	4.49	5.57	0.15	3.4	1.05	23.3

NOTE: (a) All stresses shown in Columns 3, 4, 10, 12, 16 and 17 are taken from Table 7 and are the average of the top and bottom flange stress for each girder.
(b) All stresses shown are in kips per square inch.
(c) The average of the mean stresses for the first three runs are considered as the "static stresses" in the east and west girders and their comparisons with the theoretical stresses are as follows:

MEASURED STATIC STRESSES

East girder	4.34
West girder	4.52
Average	4.43
Eccentricity	2.00 per cent

THEORETICAL STATIC STRESSES (Based on gross moment of inertia)

East girder	5.37
West girder	5.53
Average	5.45
Eccentricity	1.60 per cent

STRESS FACTORS (Measured/Theoretical)

East girder	0.807
West girder	0.817
Average	0.812

(d) The loaded frequency "n", based on a measured static deflection of 0.624 inch, is 3.59 vibrations per second.
(e) The theoretical dead load deflection, based on the gross moment of inertia at the center, is 0.278 in.

TABLE 16

ANALYSIS OF STRAIN GAGE READINGS
(Stresses at center of Span)
122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)

Run No.	Speed M.P.H.	MEAN STRESSES East Gir.	MEAN STRESSES West Gir	MEAN STRESSES Aver. East and West	Speed Effect Stress	Speed Effect Per Cent	Roll Effect Stress	Roll Effect Per Cent	SEMI-AMPLITUDES East Girder Track Effect Stress	East Girder Track Effect Per Cent	West Girder Track Effect Stress	West Girder Track Effect Per Cent	Average Track Effect Stress	Average Track Effect Per Cent	MAXIMUM STRESSES East Gir.	West Gir.	East Girder Total Impact Stress	East Girder Total Impact Per Cent	West Girder Total Impact Stress	West Girder Total Impact Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
155	4.4	4.48	4.80	4.64	0	0	0	0	0.06	1.3	0.02	0.4	0.04	0.8	4.54	4.82	0.06	1.3	0.02	0.4
156	9.8	4.54	4.78	4.66	0.02	0.4	0.05 E	1.1 E	0	0	0	0	0	0	4.54	4.78	0.06	1.3	-0.02	-0.4
228	10.3	4.43	4.78	4.60	-0.04	-0.9	0.02 W	0.4 W	0	0	0	0	0	0	4.43	4.78	-0.05	-1.1	-0.02	-0.4
157	12.7	4.56	4.98	4.77	0.13	2.8	0.04 W	0.9 W	0	0	0.05	1.0	0.02	0.4	4.58	5.02	0.10	2.2	0.22	4.6
158	15.6	4.56	4.98	4.77	0.13	2.8	0.04 W	0.9 W	0.10	2.2	0.10	2.1	0.10	2.2	4.68	5.07	0.20	4.5	0.27	5.6
159	18.5	4.44	4.82	4.63	-0.01	-0.2	0.03 W	0.6 W	0.10	2.2	0.10	2.1	0.10	2.2	4.53	4.92	0.05	1.1	0.12	2.5
160	25.0	4.44	4.92	4.68	0.04	0.9	0.07 W	1.5 W	0.10	2.2	0.10	2.1	0.10	2.2	4.53	5.02	0.05	1.1	0.22	4.6
161	28.7	4.54	4.92	4.73	0.09	1.9	0.02 W	0.4 W	0.15	3.3	0.15	3.1	0.15	3.2	4.68	5.08	0.20	4.5	0.28	5.8
165	33.2	4.58	5.00	4.79	0.15	3.2	0.05 W	1.1 W	0.10	2.2	0.08	1.7	0.09	1.9	4.68	5.07	0.20	4.5	0.27	5.6
162	33.7	4.58	4.98	4.78	0.14	3.0	0.02 W	0.4 W	0.10	2.2	0.05	1.0	0.08	1.7	4.68	5.02	0.20	4.5	0.22	4.6
227	39.7	4.38	5.10	4.74	0.10	2.2	0.20 W	4.3 W	0.05	1.1	0.02	0.4	0.04	0.8	4.43	5.12	-0.05	-1.1	0.32	6.7
163	39.8	4.58	5.05	4.82	0.18	3.9	0.06 W	1.3 W	0.10	2.2	0.08	1.7	0.09	1.9	4.68	5.12	0.20	4.5	0.32	6.7
164	44.7	4.44	4.88	4.68	0.04	0.9	0.03 W	0.6 W	0.10	2.2	0.05	1.0	0.08	1.7	4.54	4.92	0.06	1.3	0.12	2.5
166	50.1	4.58	4.88	4.73	0.09	1.9	0.02 E	0.4 E	0.10	2.2	0.10	2.1	0.10	2.2	4.68	4.98	0.20	4.5	0.18	3.7
226	51.1	4.48	4.82	4.65	0.01	0.2	0	0	0.05	1.1	0.05	1.0	0.05	1.1	4.53	4.88	0.05	1.1	0.08	1.7
178	54.8	4.63	5.08	4.86	0.22	4.7	0.04 W	0.9 W	0.05	1.1	0.05	1.0	0.05	1.1	4.68	5.12	0.20	4.5	0.32	6.7
225	57.0	4.44	5.22	4.83	0.19	4.1	0.22 W	4.7 W	0.05	1.1	0.05	1.0	0.05	1.1	4.48	5.27	0	0	0.47	9.8
177	59.8	4.53	5.22	4.88	0.24	5.2	0.17 W	3.7 W	0.05	1.1	0.05	1.0	0.05	1.1	4.83	5.26	0.35	7.8	0.46	9.6
179	60.9	4.48	5.22	4.85	0.21	4.5	0.20 W	4.3 W	0.05	1.1	0.05	1.0	0.05	1.1	4.53	5.26	0.05	1.1	0.46	9.6
176	64.6	4.46	5.34	4.90	0.26	5.6	0.27 W	5.8 W	0.08	1.8	0.08	1.7	0.08	1.7	4.53	5.42	0.05	1.1	0.62	12.9
224	69.4	4.34	5.37	4.86	0.22	4.7	0.33 W	7.1 W	0.10	2.2	0.15	3.1	0.12	2.6	4.43	5.52	-0.05	-1.1	0.72	15.0
175	71.6	4.58	5.54	5.06	0.42	9.0	0.30 W	6.5 W	0.10	2.2	0.08	1.7	0.09	1.9	4.68	5.62	0.20	4.5	0.82	17.1
174	73.0	4.58	5.22	4.90	0.26	5.6	0.15 W	3.2 W	0.20	4.5	0.15	3.1	0.18	3.9	4.78	5.36	0.30	6.7	0.56	11.7
223	73.0	4.28	5.17	4.72	0.08	1.7	0.28 W	6.0 W	0.15	3.3	0.15	3.1	0.15	3.2	4.43	5.32	-0.05	-1.1	0.52	10.8
221	78.7	4.14	5.27	4.70	0.06	1.3	0.41 W	8.8 W	0.20	4.5	0.10	2.1	0.15	3.2	4.33	5.36	-0.15	-3.3	0.56	11.7
171	79.5	4.58	5.34	4.96	0.32	6.9	0.20 W	4.3 W	0.10	2.2	0.08	1.7	0.09	1.9	4.68	5.42	0.20	4.5	0.62	12.9
222	80.6	4.24	5.02	4.63	-0.01	-0.2	0.23 W	5.0 W	0.20	4.5	0.20	4.2	0.20	4.3	4.48	5.22	0	0	0.42	8.7
167	82.1	4.63	5.36	5.00	0.36	7.8	0.19 W	4.1 W	0.15	3.3	0.10	2.1	0.12	2.6	4.78	5.46	0.30	6.7	0.66	13.7
216	83.5	4.34	5.32	4.83	0.19	4.1	0.32 W	6.9 W	0.10	2.2	0.10	2.1	0.10	2.2	4.43	5.42	-0.05	-1.1	0.62	12.9
168	84.0	4.58	5.42	5.00	0.36	7.8	0.25 W	5.4 W	0.10	2.2	0.10	2.1	0.10	2.2	4.68	5.52	0.20	4.5	0.72	15.0
217	86.0	4.28	5.32	4.80	0.16	3.4	0.36 W	7.8 W	0.10	2.2	0.10	2.1	0.10	2.2	4.38	5.42	-0.10	-2.2	0.62	12.9
215	86.9	4.18	5.47	4.82	0.18	3.9	0.49 W	10.6 W	0.15	3.3	0.15	3.1	0.15	3.2	4.34	5.61	-0.14	-3.1	0.81	16.9
169	90.4	4.48	5.46	4.97	0.33	7.1	0.31 W	6.7 W	0.10	2.2	0.10	2.1	0.10	2.2	4.58	5.66	0.10	2.2	0.86	17.9
218	92.9	4.24	5.37	4.80	0.16	3.4	0.40 W	8.6 W	0.10	2.2	0.15	3.1	0.12	2.6	4.34	5.52	-0.14	-3.1	0.72	15.0
170	95.9	4.78	5.42	5.10	0.46	9.9	0.14 W	3.0 W	0.20	4.5	0.25	5.2	0.22	4.8	4.98	5.66	0.50	11.2	0.86	17.9
220	97.0	4.28	5.37	4.82	0.18	3.9	0.38 W	8.0 W	0.20	4.5	0.15	3.1	0.18	3.9	4.48	5.66	0	0	0.86	17.9
173	98.5	4.75	5.39	5.07	0.43	9.3	0.14 W	3.0 W	0.22	4.9	0.18	3.8	0.20	4.3	4.98	5.56	0.50	11.2	0.76	15.8
219	100.8	4.48	5.40	4.94	0.30	6.5	0.29 W	6.2 W	0.25	5.6	0.22	4.6	0.24	5.2	4.73	5.62	0.25	5.6	0.82	17.1
172	105.0	5.12	5.32	5.22	0.58	12.5	0.08 E	1.7 E	0.25	5.6	0.15	3.1	0.20	4.3	5.36	5.22	0.88	19.6	0.42	8.7

NOTE: (a) All stresses shown in Columns 3, 4, 10, 12, 16 and 17 are taken from Table 8 and are the average of the top and bottom flange stress for each girder.
(b) All stresses shown are in kips per square inch.
(c) The mean stresses for the first run are considered as the "static stresses" in the east and west girders and their comparisons with the theoretical stresses are as follows:

MEASURED STATIC STRESSES

East Girder	= 4.48
West Girder	= 4.80
Average	= 4.64
Eccentricity	= +3.30 Per Cent

THEORETICAL STATIC STRESSES
(Based on gross moment of inertia)

East Girder	= 5.56
West Girder	= 5.76
Average	= 5.66
Eccentricity	= +1.60 Per Cent

STRESS FACTORS
(Measured/Theoretical)

East Girder	= 0.806
West Girder	= 0.832
Average	= 0.818

(d) The loaded frequency "n", based on a measured static deflection of 0.652 inch, is 3.56 vibrations per second.

TABLE 17

ANALYSIS OF STRAIN GAGE READINGS
(STRESSES AT CENTER OF SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS K4-S (STEAM)

Run No.	Speed M.P.H.	Speed R.P.S.	Dimension "X" Feet	Theoretical Loaded Frequency "n" V.P.S.	MEAN STRESSES East Girder	West Girder	Average East and West	Speed Effect Stress	Speed Effect Per Cent	Roll Effect Stress	Roll Effect Per Cent
1	2	3	4	5	6	7	8	9	10	11	12
132	5.2	0.37		3.54	4.76	5.06	4.91	0	0	0	0
128	15.9	1.14		3.54	4.87	5.01	4.94	0.03	0.6	0.08 F	1.7 F
127	28.0	1.99		3.54	4.90	4.99	4.95	0.04	0.8	0.11 E	2.2 E
126	30.1	2.13		3.53	4.70	5.08	4.89	0.08	1.6	0.06 E	1.2 E
125	35.6	2.52		3.52	4.80	5.00	4.90	-0.01	-0.2	0.05 E	1.0 E
124	40.0	2.84			4.64	4.64	4.64	-0.27	-5.5	0.13 F	2.6 F
130	40.2	2.85		3.51	4.89	5.14	5.02	0.11	2.2	0.02 E	0.4 E
131	41.7	2.96		3.53	4.85	5.05	4.95	0.04	0.8	0.05 E	1.0 F
129	42.6	3.02		3.56	4.93	4.98	4.96	0.05	1.0	0.13 E	2.6 E
123	44.2	3.13		3.52	4.94	4.90	4.92	0.01	0.2	0.16 E	3.3 E
214	45.8	3.25		3.51	4.90	5.19	5.05	0.14	2.8	0.01 E	0.2 E
122	52.3	3.70	3.5 S	3.50	4.76	5.26	5.01	0.10	2.0	0.10 W	2.0 W
121	55.5	3.93	6.0 S	3.48	4.99	5.19	5.04	0.13	2.6	0	0
208	57.5	4.07	0.8 N	3.42	4.80	5.49	5.15	0.24	4.9	0.19 W	3.9 W
195	59.3	4.21	6.8 S	3.37	4.80	5.49	5.15	0.24	4.9	0.19 W	3.9 W
209	60.0	4.25	4.6 N	3.46	4.77	5.46	5.12	0.21	4.3	0.20 W	4.1 W
196	60.3	4.28	2.8 S		4.71	5.59	5.15	0.24	4.9	0.29 W	5.9 W
119	62.2	4.41	6.9 N	3.50	4.75	5.24	5.00	0.09	1.8	0.09 W	1.8 W
210	63.3	4.49	8.7 N	3.45	4.60	5.38	4.99	0.08	1.6	0.24 W	4.9 W
197	63.9	4.53	4.7 N	3.44	4.81	5.66	5.24	0.33	6.7	0.26 W	5.3 W
211	64.5	4.64	7.9 S	3.46	4.67	5.41	5.04	0.13	2.6	0.23 W	4.7 W
120	67.0	4.75	8.6 S	3.52	4.70	5.38	5.04	0.13	2.6	0.20 W	4.1 W
198	67.7	4.80	9.8 N	3.42	4.71	5.45	5.08	0.17	3.5	0.21 W	4.3 W
212	68.4	4.85	3.7 S	3.47	4.61	5.46	5.04	0.13	2.6	0.28 W	5.7 W
199	69.0	4.89	7.9 S	3.45	4.86	5.55	5.21	0.30	6.1	0.19 W	3.9 W
213	70.6	5.00		3.48	4.68	5.37	5.03	0.12	2.4	0.19 W	3.9 W
118	71.0	5.04	1.9 N	3.50	4.52	5.51	5.02	0.11	2.2	0.35 W	7.1 W
200	72.1	5.12	2.6 S	3.48	4.70	5.63	5.17	0.26	5.3	0.31 W	6.3 W
117	76.3	5.40	4.1 S	3.47	4.60	5.48	5.04	0.13	2.6	0.30 W	6.1 W
201	77.3	5.48	2.5 N	3.45	4.73	5.76	5.25	0.34	6.9	0.36 W	7.3 W
202	79.4	5.64	7.1 N	3.45	4.81	5.84	5.33	0.42	8.5	0.35 W	7.1 W
116	80.8	5.73	6.4 N	3.45	4.74	5.48	5.11	0.20	4.1	0.22 W	4.5 W
203	82.2	5.83	9.8 N	3.48	4.63	5.27	4.95	0.04	0.8	0.17 W	3.5 W
113	84.0	5.95	1.8 S	3.37	5.15	5.69	5.42	0.51	10.4	0.10 W	2.0 W
204	85.0	6.03	5.6 S	3.43	4.81	5.55	5.18	0.27	5.5	0.21 W	4.3 W
114	85.0	6.03	4.5 S	3.37	5.35	5.65	5.50	0.59	12.0	0	0
115	87.0	6.17	1.9 S	3.39	5.09	5.73	5.41	0.50	10.2	0.15 W	3.1 W
207	88.0	6.24	0.6 S	3.42	5.10	5.44	5.27	0.36	7.3	0.02 W	0.4 W
206	88.3	6.26	7.7 N	3.44	4.85	5.40	5.13	0.22	4.5	0.12 W	2.4 W
205	89.4	6.34	1.8 N	3.47	4.77	5.76	5.27	0.36	7.3	0.33 W	6.7 W

Run No.	SEMI-AMPLITUDES East Girder Track and Hammer Blow Effect Stress	$D_H N^2$	Dynamic Magnifier	West Girder Track and Hammer Blow Effect Stress	$D_H N^2$	Dynamic Magnifier	Average - Both Girders Track and Hammer Blow Effect Stress	$D_H N^2$	Dynamic Magnifier	MAXIMUM STRESSES East Girder	West Girder	East Girder Total Impact Stress	Per Cent	West Girder Total Impact Stress	Per Cent
1	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
132	0.10			0.10						4.86	5.16	0.10	2.1	0.10	2.0
128	0.20			0.20			0.20			5.07	5.21	0.31	6.5	0.15	3.0
127	0.20	0.07	2.86	0.20	0.08	2.50	0.20	0.08	2.50	5.10	5.19	0.34	7.1	0.13	2.6
126	0.20	0.09	2.22	0.20	0.10	2.00	0.20	0.09	2.22	5.10	5.28	0.34	7.1	0.22	4.3
125	0.30	0.12	2.50	0.35	0.15	2.33	0.32	0.13	2.46	5.10	5.35	0.34	7.1	0.29	5.7
124	0.30	0.15	2.00	0.30	0.19	1.58	0.30	0.17	1.77	4.94	4.94	0.18	3.8	-0.12	-2.4
130	0.50	0.15	3.33	0.40	0.19	2.10	0.45	0.17	2.63	5.39	5.54	0.63	13.2	0.48	9.5
131	0.50	0.17	2.94	0.45	0.20	2.25	0.48	0.18	2.58	5.35	5.50	0.59	12.4	0.44	8.7
129	0.50	0.17	2.94	0.30	0.21	1.43	0.40	0.19	2.08	5.43	5.28	0.67	14.1	0.22	4.3
123	0.35	0.19	1.84	0.45	0.22	2.04	0.40	0.21	1.94	5.29	5.35	0.53	11.1	0.29	5.7
214	0.70	0.20	3.50	0.65	0.24	2.71	0.68	0.22	3.04	5.60	5.84	0.84	17.6	0.78	15.4
122	0.70	0.26	2.70	0.50	0.31	1.62	0.60	0.29	2.08	5.46	5.76	0.70	14.7	0.70	13.8
121	0.60	0.29	2.07	0.45	0.36	1.25	0.52	0.32	1.62	5.49	5.64	0.73	15.3	0.58	11.5
208	0.75	0.31	2.42	0.70	0.38	1.84	0.72	0.35	2.08	5.55	6.19	0.79	16.6	1.13	22.3
195	0.60	0.34	1.76	0.60	0.41	1.46	0.60	0.37	1.61	5.40	6.09	0.64	13.4	1.03	20.4
209	0.60	0.34	1.76	0.90	0.42	2.14	0.75	0.38	1.98	5.37	6.36	0.61	12.8	1.30	25.7
196	0.60	0.35	1.71	0.55	0.42	1.31	0.58	0.39	1.49	5.31	6.14	0.55	11.6	1.08	21.3
119	0.50	0.37	1.35	0.70	0.45	1.56	0.60	0.41	1.47	5.25	5.94	0.49	10.3	0.88	17.4
210	0.60	0.38	1.58	0.65	0.46	1.41	0.62	0.42	1.48	5.20	6.03	0.44	9.2	0.97	19.2
197	0.40	0.39	1.03	0.40	0.47	0.96	0.40	0.43	0.93	5.21	6.06	0.45	9.5	1.00	19.8
211	0.50	0.41	1.22	0.50	0.50	1.00	0.50	0.45	1.11	5.17	6.01	0.41	8.6	0.95	18.8
120	0.40	0.43	0.93	0.40	0.52	0.77	0.40	0.48	0.84	5.10	5.78	0.34	7.1	0.72	14.2
198	0.50	0.44	1.14	0.45	0.53	0.85	0.48	0.48	0.98	5.21	5.90	0.45	9.5	0.84	16.6
212	0.50	0.45	1.11	0.55	0.54	1.02	0.52	0.50	1.06	5.11	6.01	0.35	7.4	0.95	18.8
199	0.50	0.45	1.11	0.55	0.55	1.00	0.52	0.50	1.04	5.36	6.10	0.60	12.6	1.04	20.6
213	0.40	0.48	0.83	0.50	0.58	0.86	0.45	0.52	0.86	5.08	5.87	0.32	6.7	0.81	16.0
118	0.45	0.48	0.94	0.50	0.58	0.86	0.48	0.53	0.89	4.97	6.01	0.21	4.4	0.95	18.8
200	0.50	0.50	1.00	0.50	0.60	0.83	0.50	0.55	0.91	5.20	6.13	0.44	9.2	1.07	21.1
117	0.55	0.55	1.00	0.55	0.67	0.82	0.55	0.61	0.90	5.15	6.03	0.39	8.2	0.97	19.2
201	0.55	0.57	0.96	0.40	0.69	0.58	0.48	0.63	0.75	5.28	6.16	0.52	10.9	1.10	21.7
202	0.55	0.60	0.92	0.50	0.73	0.68	0.52	0.67	0.79	5.36	6.34	0.60	12.6	1.28	25.3
116	0.60	0.62	0.97	0.60	0.76	0.79	0.60	0.69	0.87	5.34	6.08	0.58	12.2	1.02	20.2
203	0.65	0.65	1.00	0.70	0.78	0.90	0.68	0.72	0.94	5.28	5.97	0.52	10.9	0.91	18.0
113	0.90	0.67	1.34	0.75	0.81	0.93	0.82	0.74	1.11	6.05	6.44	1.29	27.1	1.38	27.3
204	0.70	0.69	1.01	0.80	0.84	0.95	0.75	0.76	0.98	5.51	6.35	0.75	15.8	1.29	25.5
114	0.90	0.69	1.30	0.95	0.84	1.13	0.92	0.76	1.21	6.20	6.54	1.44	30.2	1.48	29.2
115	0.90	0.72	1.25	0.85	0.88	0.97	0.88	0.80	1.09	5.99	6.58	1.23	25.8	1.52	30.0
207	0.80	0.74	1.08	0.85	0.90	0.94	0.82	0.82	1.01	5.90	6.29	1.14	24.0	1.23	24.3
206	0.60	0.74	0.81	0.65	0.90	0.72	0.62	0.83	0.76	5.45	6.05	0.69	14.5	0.99	19.6
205	0.80	0.76	1.05	0.70	0.92	0.76	0.75	0.84	0.89	5.57	6.46	0.81	17.0	1.40	27.6

NOTE: (a) All stresses shown in columns 6, 7, 13, 16, 22, and 23 are taken from Table 9 and are the average of the top and bottom flange stress for each girder.
(b) All stresses shown are in kips per square inch.
(c) Dimension "X" in column 4 is the distance, either north or south, from the center of the span to the main driver at the time the pins are in position for maximum hammer blow effect on the span. Locomotive headed south.
(d) The mean stresses for the first run are considered as the "static stresses" in the east and west girders and their comparisons with the theoretical stresses are as follows:

Measured Static Stresses		Theoretical Static Stresses (Based on gross moment of inertia)		Stress Factors (Measured/Theoretical)	
East girder	= 4.76	East girder	= 5.98	East girder	= 0.796
West girder	= 5.06	West girder	= 6.14	West girder	= 0.826
Average	= 4.91	Average	= 6.06	Average	= 0.811
Eccentricity	= +3.10 per cent	Eccentricity	= +1.60 per cent		

(e) The "hammer blow stresses" at one revolution per second are as follows:

East girder = 0.024 x 0.796 = 0.019
West girder = 0.028 x 0.826 = 0.023
Average = 0.021

TABLE 18

ANALYSIS OF STRAIN GAGE READINGS
(STRESSES AT CENTER OF SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS M1-A (STEAM)

Run No.	Speed M.P.H.	Speed R.P.S.	Dimension "X" Feet	Theoretical Loaded Frequency "n" R.P.S.	Mean Stresses: East Girder	Mean Stresses: West Girder	Mean Stresses: Average East and West	Speed Effect: Stress	Speed Effect: Per Cent	Roll Effect: Stress	Roll Effect: Per Cent	Semi-Amplitudes: East Girder Track and Hammer Blow Effect: Stress	D_HN^2	Dynamic Magnifier	Semi-Amplitudes: West Girder Track and Hammer Blow Effect: Stress	D_HN^2	Dynamic Magnifier	Semi-Amplitudes: Average - Both Girders Track and Hammer Blow Effect: Stress	D_HN^2	Dynamic Magnifier	Maximum Stresses: East Girder	Maximum Stresses: West Girder	East Girder Total Impact: Stress	East Girder Total Impact: Per Cent	West Girder Total Impact: Stress	West Girder Total Impact: Per Cent
Col. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
133	[illegible]	0.38		3.22	6.02	5.85	5.94	0	0	0	0	0.02			0.05			0.04			6.04	5.90	0.02	0.3	0.05	0.8
134	[illegible]	0.71		3.21	6.14	6.18	6.16	0.22	3.7	0.10 W	1.7 W	0.10			0.05			0.08			6.24	6.24	0.22	3.6	0.39	6.7
135	[illegible]	1.04		3.21	6.24	6.30	6.27	0.33	5.6	0.11 W	1.8 W	0.12	0.03	4.00	0.25	0.03	8.33	0.19	0.03	6.33	6.36	6.56	0.34	5.6	0.71	12.1
[illegible]	[illegible]	1.38		3.17	6.51	6.46	6.48	0.54	9.1	0.06 W	1.0 W	0.30	0.09	3.19	0.30	0.10	3.00	0.30	0.10	3.00	6.80	6.76	0.78	13.0	0.91	15.6
152	[illegible]	1.00		3.21	6.14	6.20	6.17	0.23	3.9	0.11 W	1.8 W	0.32	0.10	3.37	0.15	0.10	1.50	0.24	0.10	2.40	6.46	6.36	0.44	7.3	0.51	8.7
[illegible]	[illegible]	2.32		3.21	6.22	6.34	6.28	0.34	5.7	0.14 W	2.4 W	0.42	0.13	3.26	0.25	0.14	1.79	0.34	0.14	2.52	6.64	6.59	0.62	10.3	0.74	12.6
[illegible]	[illegible]	2.75		3.22	6.18	6.46	6.32	0.38	6.4	0.22 W	3.7 W	0.69	0.18	3.79	0.52	0.20	2.64	0.60	0.19	3.18	6.88	6.97	0.86	14.3	1.12	19.1
[illegible]	[illegible]	3.18		3.20	6.36	6.36	6.36	0.42	7.1	0.08 W	1.3 W	0.69	0.24	2.88	0.64	0.26	2.46	0.66	0.25	2.61	7.05	7.00	1.03	17.1	1.15	19.7
[illegible]	[illegible]	3.29		3.21	6.22	6.18	6.20	0.26	4.4	0.06 W	1.0 W	0.59	0.26	2.27	0.54	0.28	1.93	0.56	0.27	2.07	6.82	6.72	0.80	13.3	0.87	14.9
[illegible]	[illegible]	3.32		3.15	6.13	6.28	6.20	0.26	4.4	0.05 W	0.8 W	0.34	0.26	1.31	0.30	0.29	1.03	0.32	0.28	1.06	6.48	6.58	0.46	7.6	0.73	12.5
[illegible]	[illegible]	3.47		3.14	6.24	6.06	6.15	0.21	3.5	0.01 E	0.2 E	0.54	0.29	1.86	0.44	0.31	1.42	0.49	0.30	1.62	6.78	6.50	0.76	12.6	0.65	11.1
[illegible]	[illegible]	3.65		3.24	6.26	6.16	6.21	0.27	4.5	0.03 W	0.5 W	0.39	0.32	1.22	0.44	0.35	1.26	0.42	0.33	1.26	6.64	6.60	0.62	10.3	0.75	12.8
[illegible]	[illegible]	3.67		3.14	6.22	6.32	6.27	0.33	5.6	0.11 W	1.8 W	0.54	0.32	1.69	0.49	0.35	1.40	0.52	0.34	1.54	6.76	6.80	0.74	12.3	0.95	16.2
[illegible]	[illegible]	3.71		3.14	6.20	6.24	6.22	0.28	4.7	0.10 W	1.7 W	0.49	0.33	1.48	0.49	0.36	1.36	0.49	0.35	1.42	6.68	6.74	0.66	11.0	0.89	15.2
[illegible]	[illegible]	3.71		3.22	6.20	6.30	6.25	0.31	5.2	0.13 W	2.2 W	0.59	0.33	1.79	0.74	0.36	2.06	0.66	0.35	1.91	6.80	7.04	0.78	13.0	1.19	20.3
[illegible]	[illegible]	3.72		3.23	6.14	6.38	6.26	0.32	5.4	0.20 W	3.4 W	0.59	0.33	1.79	0.64	0.36	1.78	0.62	0.35	1.79	6.72	7.02	0.70	11.6	1.17	20.0
151	[illegible]	3.74		3.22	6.42	6.50	6.46	0.52	8.8	0.13 W	2.2 W	0.64	0.34	1.88	0.62	0.36	1.72	0.63	0.35	1.80	7.06	7.11	1.04	17.3	1.26	21.5
191	[illegible]	3.91		3.15	5.96	6.47	6.22	0.28	4.7	0.34 W	5.7 W	0.72	0.37	1.95	0.69	0.40	1.72	0.70	0.38	1.83	6.67	7.16	0.65	10.8	1.31	22.4
[illegible]	50.2	3.96	7.7 S	3.20	6.42	6.26	6.34	0.40	6.7	0.01 W	0.2 W	0.36	0.38	0.95	0.32	0.41	0.78	0.34	0.39	0.87	6.78	6.58	0.76	12.6	0.73	12.5
192	51.4	4.06	3.6 N	3.10	6.33	6.36	6.34	0.40	6.7	0.09 W	1.5 W	0.52	0.40	1.30	0.49	0.43	1.14	0.50	0.41	1.21	6.85	6.85	0.83	13.8	1.00	17.1
190	53.8	4.25		3.20	6.21	6.56	6.38	0.44	7.4	0.25 W	4.2 W	0.54	0.43	1.26	0.69	0.47	1.47	0.62	0.45	1.37	6.75	7.24	0.73	12.1	1.39	23.8
[illegible]	54.3	4.29	3.2 N	3.15	6.39	6.44	6.42	0.48	8.1	0.12 W	2.0 W	0.15	0.44	0.34	0.39	0.48	0.81	0.27	0.46	0.59	6.54	6.83	0.52	8.6	0.98	16.7
[illegible]	57.0	4.50	0.5 N	3.15	6.10	6.42	6.26	0.32	5.4	0.24 W	4.0 W	0.44	0.49	0.90	0.52	0.53	0.98	0.48	0.51	0.95	6.54	6.94	0.52	8.6	1.09	18.6
[illegible]	58.5	4.62	3.5 S	3.14	6.43	6.36	6.40	0.46	7.7	0.06 W	1.0 W	0.37	0.51	0.72	0.40	0.55	0.73	0.38	0.53	0.71	6.80	6.76	0.78	13.0	0.91	15.6
155	60.0	4.74	2.0 N	3.06	6.24	6.88	6.56	0.62	10.4	0.40 W	6.7 W	0.49	0.54	0.91	0.59	0.58	1.02	0.54	0.56	0.96	6.73	7.47	0.71	11.8	1.62	27.7
156	62.8	4.96	9.0 S	3.15	6.18	6.20	6.19	0.25	4.2	0.09 W	1.5 W	0.49	0.59	0.83	0.52	0.64	0.81	0.50	0.62	0.81	6.67	6.72	0.65	10.8	0.87	14.9
[illegible]	64.8	5.12	5.7 N	3.22	5.96	6.53	6.24	0.30	5.0	0.36 W	6.1 W	0.44	0.63	0.70	0.52	0.68	0.76	0.48	0.66	0.73	6.40	7.04	0.38	6.3	1.19	20.3
139	66.5	5.25	7.0 S	3.17	5.95	6.24	6.10	0.16	2.7	0.23 W	3.9 W	0.37	0.66	0.56	0.42	0.72	0.58	0.40	0.69	0.58	6.32	6.66	0.30	5.0	0.81	13.8
134	67.7	5.34	1.2 N	3.10	6.19	6.19	6.19	0.25	4.2	0.08 W	1.3 W	0.54	0.68	0.79	0.64	0.74	0.86	0.59	0.71	0.83	6.73	6.93	0.71	11.8	0.98	16.7
182	68.1	5.38	9.2 N	3.14	5.92	6.58	6.25	0.31	5.2	0.44 W	6.9 W	0.44	0.69	0.64	0.56	0.75	0.75	0.50	0.73	0.69	6.36	7.15	0.34	5.6	1.30	22.2
183	69.9	5.52	4.2 N	3.10	6.02	7.40	6.71	0.77	13.0	0.77 W	13.0 W	0.44	0.73	0.60	0.34	0.79	0.43	0.39	0.76	0.51	6.46	7.74	0.44	7.3	1.89	32.3
138	71.2	5.62	3.9 N	3.17	5.67	6.75	6.21	0.27	4.5	0.62 W	10.4 W	0.54	0.76	0.71	0.49	0.82	0.60	0.52	0.79	0.66	6.21	7.24	0.19	3.2	1.39	23.8
131	72.8	5.75	4.1 S	3.12	6.10	7.08	6.59	0.65	10.9	0.57 W	9.6 W	0.64	0.79	0.81	0.30	0.86	0.35	0.47	0.83	0.57	6.74	7.38	0.72	12.0	1.53	26.1
130	75.7	5.98	1.1 N	3.12	6.22	7.06	6.64	0.70	11.8	0.48 W	8.1 W	0.84	0.86	0.97	0.59	0.93	0.63	0.72	0.90	0.81	7.06	7.64	1.04	17.3	1.79	30.6
142	77.4	6.15	8.6 N	3.17	6.04	6.40	6.22	0.28	4.7	0.26 W	4.4 W	0.62	0.91	0.68	0.69	0.98	0.70	0.66	0.95	0.70	6.66	7.09	0.64	10.6	1.24	21.2

NOTE: a) All stresses shown in columns 6, 7, 13, 16, 22, and 23 are taken from Table 10 and are the average of the top and bottom flange stress for each girder.

b) All stresses shown are in kips per square inch.

c) Dimension "X" in column 4 is the distance, either north or south, from the center of the span to the main driver at the time the pins are in position for **maximum** hammer blow effect on the span. Locomotive headed south.

d) The mean stresses for the first run are considered as the "static stresses" in the east and west girders and their comparisons with the theoretical static stresses are as follows:

Measured Static Stresses		Theoretical Static Stresses (Based on gross moment of inertia)		Stress Factors (Measured/Theoretical)	
East Girder	= 6.02	East Girder	= 7.46	East girder	= 0.806
West girder	= 5.85	West girder	= 7.70	West girder	= 0.760
Average	= 5.94	Average	= 7.58	Average	= 0.783
Eccentricity	= +1.40 per cent	Eccentricity	= +1.60 per cent		

e) The "hammer blow stresses" at one revolution per second are as follows:

East girder = 0.030 x 0.806 = 0.024
West girder = 0.034 x 0.760 = 0.026
Average = 0.025

discrepancy may be the lateral forces. Assuming that these lateral forces are resisted by the span acting as a horizontal truss, tensile stresses will be produced in both flanges of one girder resulting in a decrease in the vertical compressive stress of the top flange and an increase in the vertical tensile stress of the lower flange, whereas the reverse would be true in the other girder. By using the average of the top and bottom flange stresses, this lateral effect can also be eliminated to a large extent.

The stresses in the west girder of both spans are usually found to be larger than in the east girder. A part of this increase is due to eccentric application of the load in this direction as has been pointed out. The remainder can only be ascribed to the rolling of the locomotive which was, for some reason, usually to the west. In a few instances the average stress in the east girder is the larger, indicating that the roll in that direction was more than enough to counteract the eccentricity in the opposite direction.

The basic tables of stress and deflection tabulation (Tables 3 to 10, inclusive) have been broken down to show more clearly the various impact effects which will be considered later. Tables 11 to 18, inclusive, refer to stresses in both girders of either span, for the four classes of locomotives. Tables 23 to 26 deal with deflections as measured in the east girder of the 55-ft. 10-in. span and Tables 27 to 30 give the deflections as measured in both girders of the 122-ft. span.

At the bottom of these tables will be found the stress and deflection factors, which are the ratio of the measured stress or deflection at crawl speed, to the theoretical values. The theoretical values were computed, as previously mentioned, from the gross moment of inertia at the center of the span, assuming a constant section throughout, and using the average of the left and right wheel loads.

These stress or deflection factors, as might be expected, are not unity and vary with each of the locomotives even on the same span. They may be affected by either the change in span length under load when the girders have flat bearings as in the case of the short span, or by the change in actual axle loads. The axle loads used in the computations are the scale weights obtained when the wheels were all at the same elevation, but as the span deflects under load, the center wheels have a tendency to drop and the equalizing system transfers a portion of their load to the end axles.

The measured deflections should obviously exceed the theoretical values as they include any settlement of bearings or shortening of the piers under compression and the girders are not of uniform section throughout their length as assumed in computing the theoretical values. The deflection factors as found for these two spans agree closely with the average found for all similar girders formerly tested and reported in the AREA Proceedings for 1936, Vol. 37, page 794.

The theoretical loaded frequencies for the 122-ft. span are based on the average deflection in the east and west girders as measured by the electrical and mechanical deflectometer. These frequencies, for all runs of the two steam locomotives, are shown in column 5 of Tables 17 and 18. The frequencies of this span for the two electric locomotives, under static loading, are given in note "d" at the bottom of Tables 15 and 16.

As previously pointed out, both deflection instruments were on the east girder of the 55-ft. 10-in. span so that in computing the loaded frequencies for this span, it was necessary to correct the measured deflections by the roll percentages as found by the strain gages. These corrected deflections and the theoretical loaded frequencies for all runs of the two steam locomotives are shown in columns 5 and 6 of Tables 13 and 14. The frequencies for the two electric locomotives, under static loading, are given in note "d" at the bottom of Tables 11 and 12.

9. Impact Effects as Found From the Test Data

The data, as taken from the field records and summarized in Tables 3 to 10, inclusive, were analyzed for the particular purpose of segregating and determining the magnitude of the various dynamic or impact effects of the moving loads. The results of this study are as follows:

Speed Effect

In taking off and recording the mean stresses and deflections, it soon became evident that the mean stress or deflection increased with speed. In column 5 of Table 11 the average mean stress, for the first three runs, which were at crawl speed, is 7.57 kips per sq. in. An increase in speed is seemingly accompanied by an increase in mean stress and for run 248 at 99.5 m.p.h., the average mean stress has increased from 7.57 to 9.07 kips per sq. in., or an increase of 19.8 percent as shown in Col. 7. A corresponding increase, although to a lesser degree on the long span, is found for the other locomotives as will be seen from Tables 12 to 18, inclusive.

This increase can be partly accounted for by the centrifugal force, resulting from the load running over the deflected span. This force increases with the square of the speed, and may be approximately expressed by the equation:

$$F = P\left[\frac{1}{\left(\frac{g\,L^2}{16\;v^2 d}\right) - 3}\right]$$

in which:

F = Centrifugal force in pounds
P = The moving concentrated force producing the same central deflection as the distributed static wheel loads in pounds
v = Velocity in feet per second
d = Static deflection of the span in feet
L = Length of span in feet
g = Acceleration due to gravity (32.2 ft. per sec. per sec.)

The measured speed effects, in percent of the crawl stress, as given in the tables, have been plotted for all four locomotives on both spans in the upper diagrams of figures 28 to 35, inclusive. For comparison, the theoretical values as determined from the above equation are represented by the smooth curve. It will be seen that except for the Class P5–A electric locomotive, the agreement between the actual and theoretical values is not close, the former frequently exceeding the latter. On the 122-ft. span the discrepancy is more marked. While the measured effects are not as large as in the short span, nearly all of them are greater than the theoretical values.

As a further study of this interesting phenomena, the theoretical influence stress curves were computed for the two electrical locomotives on both spans, these curves representing the stress at the center for any position of the locomotive. The ordinates of the actual average stress curves were scaled from several records at intervals of 20 ft. for the long span and 10 ft. for the short span, and are given in Tables 19 to 22, inclusive.

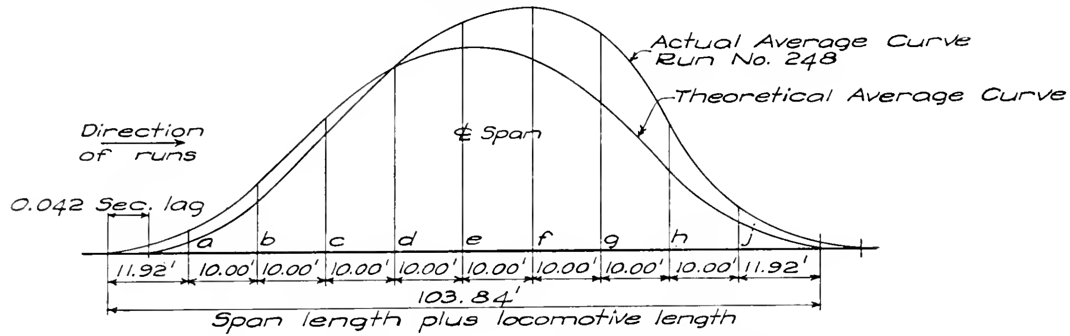
The area of these stress curves, which may be represented by the sum of the ordinates, is a measure of the total work done, and here again, it will be noted that the sum or area increased with speed. For test 248 with the P5–A locomotive running at 99.5 m.p.h. over the 55-ft. 10-in. span (see Table 19), the average sum of the scaled ordinates is 44.55. The sum of the ordinates of the theoretical stress curve, for this locomotive

(Text continued on page 457)

TABLE 19

COMPARISON OF ACTUAL AND THEORETICAL INFLUENCE STRESS CURVES
(MEAN STRESS AT CENTER AS LOCOMOTIVE CROSSES SPAN)

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)



Ordinates of Influence Stress Curve — East Girder

Run No.	Speed M.P.H.	a	b	c	d	e	f	g	h	j	Total a to j
Theor.	Values	0.76	2.47	4.66	6.27	7.30	6.56	5.14	2.76	0.95	36.87
100	4.3	0.40	2.40	4.70	6.60	7.40	6.80	5.20	2.70	0.90	37.10
234	20.8	0.80	2.30	4.80	6.30	7.20	6.60	5.10	2.70	0.60	36.40
237	29.3	0.10	2.50	4.40	6.20	7.40	7.00	5.40	2.90	0.90	36.80
238	46.5	0.20	2.00	3.90	6.00	7.60	7.60	6.40	3.10	1.00	37.80
108	59.5	0.50	1.90	4.10	6.10	7.40	7.60	6.00	3.00	1.00	37.60
240	71.0	0.40	2.10	4.30	5.70	6.40	6.40	5.60	3.30	1.20	35.40
242	78.8	0.40	1.80	4.70	6.00	6.60	6.40	5.60	3.80	1.70	37.00
245	87.8	0.70	2.20	4.90	6.80	7.30	6.40	4.80	2.90	1.20	37.20
248	99.5	0.70	1.70	4.60	6.20	8.00	8.50	7.00	4.20	1.20	42.10

Ordinates of Influence Stress Curve — West Girder

Run No.	Speed M.P.H.	a	b	c	d	e	f	g	h	j	Total a to j
Theor.	Values	0.84	2.73	5.14	6.93	8.10	7.24	5.66	3.04	1.05	40.73
100	4.3	0.40	2.50	5.20	6.70	7.40	7.20	5.60	3.50	1.30	39.80
234	20.8	0.20	2.50	5.00	7.00	8.10	8.00	6.20	3.30	1.00	41.30
237	29.3	0.10	2.60	5.10	6.60	7.80	8.40	7.00	3.70	1.40	42.70
238	46.5	0.20	2.50	5.40	7.20	8.10	7.80	6.90	4.10	1.60	43.80
108	59.5	0.30	2.20	5.40	7.00	8.00	7.30	5.60	2.90	1.10	39.80
240	71.0	0.20	2.50	5.60	8.60	9.60	9.30	6.80	2.70	1.00	46.30
242	78.8	0.70	2.40	5.80	8.40	9.70	10.20	8.60	3.80	1.10	50.70
245	87.8	0.40	1.80	5.90	8.60	10.30	10.20	8.60	3.30	1.20	50.30
248	99.5	0.40	1.70	4.90	7.00	8.60	9.10	8.80	4.90	1.60	47.00

Ordinates of Influence Stress Curve — Average - Both Girders

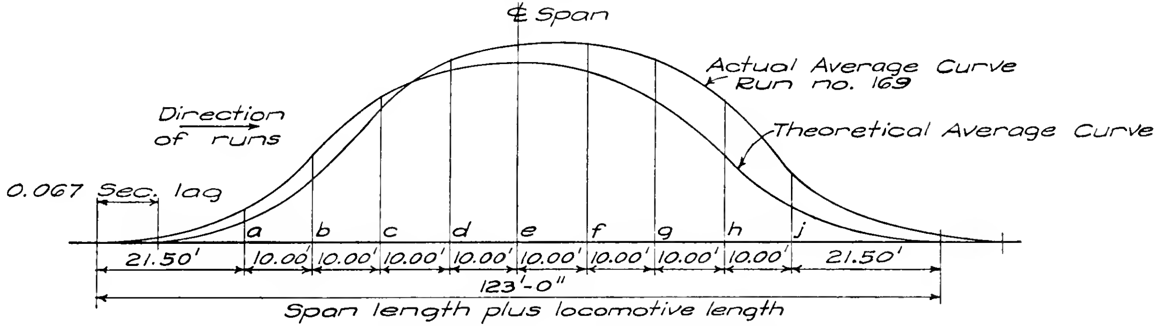
Run No.	Speed M.P.H.	a	b	c	d	e	f	g	h	j	Total a to j
Theor.	Values	0.80	2.60	4.90	6.60	7.70	6.90	5.40	2.90	1.00	38.80
100	4.3	0.40	2.45	4.95	6.65	7.40	7.00	5.40	3.10	1.10	38.45
234	20.8	0.50	2.40	4.90	6.65	7.65	7.30	5.65	3.00	0.80	38.85
237	29.3	0.10	2.55	4.75	6.40	7.60	7.70	6.20	3.33	1.15	39.78
238	46.5	0.20	2.25	4.65	6.60	7.85	7.70	6.65	3.60	1.30	40.80
108	59.5	0.40	2.05	4.75	6.55	7.70	7.45	5.80	2.95	1.05	38.70
240	71.0	0.30	2.30	4.95	7.15	8.00	7.85	6.20	3.00	1.10	40.85
242	78.8	0.55	2.10	5.25	7.20	8.15	8.30	7.10	3.80	1.40	43.85
245	87.8	0.55	2.00	5.40	7.70	8.80	8.30	6.70	3.10	1.20	43.75
248	99.5	0.55	1.70	4.75	6.60	8.30	8.80	7.90	4.55	1.40	44.55

NOTE: (a) All stresses shown are in kips per square inch.
(b) All stresses shown are corrected for 7/8 inch distance from extreme steel to instrument.
(c) All stresses shown are the average of the top and bottom flange stress for each girder.

TABLE 20

COMPARISON OF ACTUAL AND THEORETICAL INFLUENCE STRESS CURVES
(MEAN STRESS AT CENTER AS LOCOMOTIVE CROSSES SPAN)

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)



Run No.	Speed M.P.H.	East Girder a	b	c	d	e	f	g	h	j	Total a to j	West Girder a	b	c	d	e	f	g	h	j	Total a to j	Average - Both Girders a	b	c	d	e	f	g	h	j	Total a to j
Theor.	Values	0.95	3.04	5.05	5.98	6.20	5.89	4.94	3.04	0.95	36.04	1.05	3.36	5.56	6.61	6.86	6.50	5.46	3.36	1.05	39.81	1.00	3.20	5.30	6.30	6.53	6.20	5.20	3.20	1.00	37.93
155	4.4	0.80	2.60	4.60	6.00	6.20	6.00	5.00	3.10	1.00	35.30	0.80	2.60	5.30	6.50	6.80	6.80	5.50	3.60	1.20	39.10	0.80	2.60	4.95	6.25	6.50	6.40	5.25	3.35	1.10	37.20
156	9.8	0.80	2.50	4.90	6.00	6.10	6.00	5.10	3.20	1.10	35.70	0.80	2.70	5.40	6.70	6.80	6.90	6.20	3.50	1.10	40.10	0.80	2.60	5.15	6.35	6.45	6.45	5.65	3.35	1.10	37.90
160	25.0	0.70	2.30	4.80	5.90	6.20	6.20	5.60	3.30	1.40	36.40	0.70	3.10	5.30	6.80	6.80	6.80	6.50	4.10	1.70	41.80	0.70	2.70	5.05	6.35	6.50	6.50	6.05	3.70	1.55	39.10
227	39.7	0.40	2.20	4.50	5.90	6.20	5.80	5.90	3.90	1.40	36.20	0.60	3.00	5.50	7.40	7.20	7.20	6.80	4.50	1.70	43.90	0.50	2.60	5.00	6.65	6.70	6.50	6.35	4.20	1.55	40.05
226	51.1	0.50	2.70	5.40	6.00	6.20	6.20	5.10	3.30	0.90	36.30	0.50	2.90	5.80	7.40	7.40	7.00	6.20	3.10	1.00	41.30	0.50	2.80	5.60	6.70	6.80	6.60	5.65	3.20	0.95	38.80
177	59.8	0.60	2.90	4.90	5.80	6.10	6.10	5.90	3.80	1.60	37.70	0.60	2.80	5.50	7.20	7.40	7.20	6.50	4.30	1.80	43.30	0.60	2.85	5.20	6.50	6.75	6.65	6.20	4.05	1.70	40.50
224	69.4	0.90	2.70	5.30	5.90	6.00	6.00	5.70	4.30	1.60	38.40	0.90	2.90	6.00	7.60	8.20	8.20	7.40	4.90	2.00	48.10	0.90	2.80	5.65	6.75	7.10	7.10	6.55	4.60	1.80	43.25
167	82.1	0.80	2.70	5.30	7.00	7.20	7.00	6.20	3.90	1.40	41.50	0.80	2.90	5.50	6.40	6.80	7.20	7.00	4.30	1.50	42.40	0.80	2.80	5.40	6.70	7.00	7.10	6.60	4.10	1.45	41.95
169	90.4	0.80	2.10	4.30	6.20	7.20	7.60	6.90	5.40	2.30	42.80	0.90	2.50	5.40	7.20	7.20	6.80	6.50	5.20	2.20	43.90	0.85	2.30	4.85	6.70	7.20	7.20	6.70	5.30	2.25	43.35
172	105.0	1.00	2.20	4.30	6.20	6.30	6.40	6.00	4.10	1.40	37.90	1.00	2.80	6.20	8.60	8.40	8.10	7.60	4.60	1.70	49.00	1.00	2.50	5.25	7.40	7.35	7.25	6.80	4.35	1.55	43.45

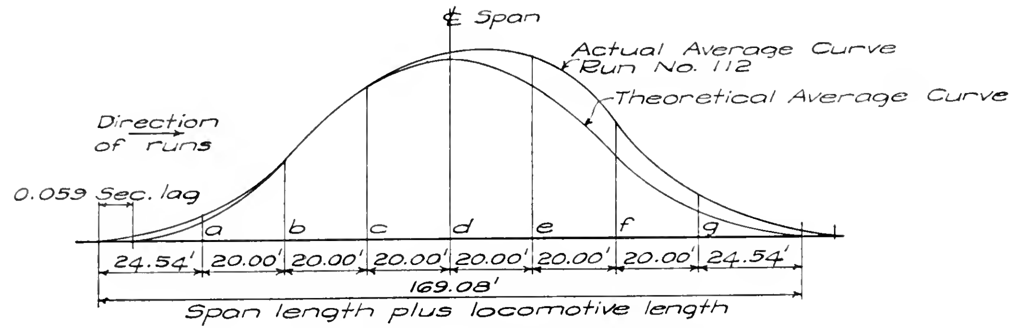
Ordinates of Influence Stress Curve

NOTE: (a) All stresses shown are in kips per square inch.
(b) All stresses shown are corrected for 7/8 inch distance from extreme steel to instrument.
(c) All stresses shown are the average of the top and bottom flange stress for each girder.

TABLE 21

COMPARISON OF ACTUAL AND THEORETICAL INFLUENCE STRESS CURVES
(MEAN STRESS AT CENTER AS LOCOMOTIVE CROSSES SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)



Run No.	Speed M.P.H.	East Girder a	b	c	d	e	f	g	Total a to g	West Girder a	b	c	d	e	f	g	Total a to g	Average - Both Girders a	b	c	d	e	f	g	Total a to g
Theor.	Values	0.59	1.82	3.54	4.34	3.64	1.97	0.59	16.49	0.61	1.88	3.66	4.46	3.76	2.03	0.61	17.01	0.60	1.85	3.60	4.40	3.70	2.00	0.60	16.75
100	4.3	0.40	1.60	3.30	4.30	3.70	2.20	0.80	16.30	0.30	1.60	3.50	4.50	3.90	2.40	1.00	17.20	0.35	1.60	3.40	4.40	3.80	2.30	0.90	16.75
233	13.8	0.30	1.40	3.00	4.10	3.50	2.00	0.60	14.90	0.30	1.60	3.40	4.50	4.00	2.40	0.80	17.00	0.30	1.50	3.20	4.30	3.75	2.20	0.70	15.95
235	26.1	0.40	1.30	3.10	4.20	3.70	1.80	0.60	15.10	0.50	1.60	3.60	4.90	4.10	2.20	0.80	17.70	0.45	1.45	3.35	4.55	3.90	2.00	0.70	16.40
105	42.3	0.50	1.60	3.50	4.30	3.90	2.20	0.60	16.60	0.60	1.80	3.60	4.50	4.10	2.20	0.70	17.50	0.55	1.70	3.55	4.40	4.00	2.20	0.65	17.05
106	51.1	0.60	1.60	3.40	4.60	3.90	2.20	0.70	17.00	0.50	2.00	3.70	4.50	4.20	2.40	0.70	18.00	0.55	1.80	3.55	4.55	4.05	2.30	0.70	17.50
108	59.5	0.70	1.60	3.50	4.70	4.30	2.20	0.70	17.70	0.60	2.00	3.90	4.70	4.00	2.50	0.80	18.50	0.65	1.80	3.70	4.70	4.15	2.35	0.75	18.10
239	61.5	0.50	1.40	3.20	4.50	3.80	1.70	0.60	15.70	0.40	2.00	4.10	4.50	3.80	2.50	0.90	18.20	0.45	1.70	3.65	4.50	3.80	2.10	0.75	16.95
109	70.4	0.40	1.60	3.20	4.10	4.30	2.80	0.70	17.10	0.30	1.70	3.90	4.90	3.70	2.10	0.80	17.40	0.35	1.65	3.55	4.50	4.00	2.45	0.75	17.25
243	76.5	0.40	1.50	3.10	3.90	3.70	2.40	0.40	15.40	0.50	2.00	4.20	5.50	4.50	2.22	0.80	19.72	0.45	1.75	3.65	4.72	4.10	2.31	0.60	17.58
245	87.8	0.40	1.60	3.20	3.90	3.40	2.30	0.90	15.70	0.40	1.80	3.80	5.30	5.10	2.40	0.80	19.60	0.40	1.70	3.50	4.62	4.25	2.35	0.85	17.67
112	99.7	0.50	1.80	3.20	4.10	3.90	2.50	0.90	16.90	0.50	1.90	4.00	5.10	5.10	3.00	1.10	20.70	0.50	1.85	3.60	4.60	4.45	2.75	1.00	18.75

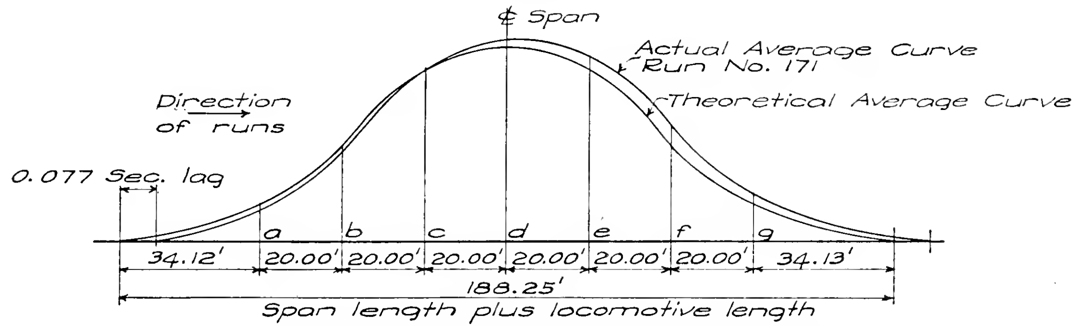
Ordinates of Influence Stress Curve

NOTE: (a) All stresses shown are in kips per square inch.
(b) All stresses shown are corrected for 7/8 inch distance from extreme steel to instrument.
(c) All stresses shown are the average of the top and bottom flange stress for each girder.

TABLE 22

COMPARISON OF ACTUAL AND THEORETICAL INFLUENCE STRESS CURVES
(MEAN STRESS AT CENTER AS LOCOMOTIVE CROSSES SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)



Run No.	Speed M.P.H.	East Girder a	East Girder b	East Girder c	East Girder d	East Girder e	East Girder f	East Girder g	East Girder Total a to g	West Girder a	West Girder b	West Girder c	West Girder d	West Girder e	West Girder f	West Girder g	West Girder Total a to g	Average - Both Girders a	Average - Both Girders b	Average - Both Girders c	Average - Both Girders d	Average - Both Girders e	Average - Both Girders f	Average - Both Girders g	Average - Both Girders Total a to g
Theor.	Values	0.91	2.22	4.14	4.63	4.14	2.22	0.90	19.16	0.93	2.28	4.26	4.77	4.26	2.28	0.92	19.70	0.92	2.25	4.20	4.70	4.20	2.25	0.91	19.43
155	4.4	0.80	1.90	3.50	4.50	4.10	2.70	1.10	18.60	0.80	2.20	3.90	4.80	4.50	2.70	1.10	20.00	0.80	2.05	3.70	4.65	4.30	2.70	1.10	19.30
158	15.6	0.80	2.00	3.60	4.50	4.00	2.60	1.00	18.50	0.80	2.20	3.70	4.70	4.60	2.80	1.20	20.00	0.80	2.10	3.65	4.60	4.30	2.70	1.10	19.25
161	28.7	0.70	2.00	3.40	4.60	4.10	2.80	1.10	18.70	0.80	2.20	3.90	4.80	4.40	2.80	1.30	20.20	0.75	2.10	3.65	4.70	4.25	2.80	1.20	19.45
163	39.8	0.80	2.20	3.80	4.50	4.10	2.80	1.00	19.20	0.80	2.40	4.10	5.00	4.40	3.00	1.20	20.90	0.80	2.30	3.95	4.75	4.25	2.90	1.10	20.05
166	50.1	0.80	2.10	3.70	4.60	4.10	2.50	1.00	18.80	0.90	2.50	4.10	4.90	4.40	2.80	1.20	20.80	0.85	2.30	3.90	4.75	4.25	2.65	1.10	19.80
177	59.8	0.80	1.70	3.60	4.40	4.20	2.70	1.20	18.60	0.80	2.40	4.10	5.10	4.50	2.70	1.40	21.00	0.80	2.05	3.85	4.75	4.35	2.70	1.30	19.80
175	71.6	0.80	2.00	4.00	4.50	4.10	2.80	1.00	19.20	1.00	2.40	4.30	5.30	4.50	2.80	1.10	21.40	0.90	2.20	4.15	4.90	4.30	2.80	1.05	20.30
171	79.5	0.80	1.90	3.90	4.50	4.10	2.80	1.00	19.00	0.80	2.40	4.50	5.30	4.80	2.80	1.20	21.80	0.80	2.15	4.20	4.90	4.45	2.80	1.10	20.40
169	90.4	0.80	2.10	3.70	4.20	3.70	2.60	1.00	18.10	0.90	2.20	4.40	5.60	5.10	2.90	1.00	22.10	0.85	2.15	4.05	4.90	4.40	2.75	1.00	20.10
172	105.0	0.80	2.40	3.90	4.90	4.10	2.50	1.00	19.60	0.70	2.20	4.20	5.50	4.90	3.20	1.20	21.90	0.75	2.30	4.05	5.20	4.50	2.85	1.10	20.75

All columns a to g and Total a to g are Ordinates of Influence Stress Curve.

NOTE: (a) All stresses shown are in kips per square inch.
(b) All stresses shown are corrected for 7/8 inch distance from extreme steel to instrument.
(c) All stresses shown are the average of the top and bottom flange stress for each girder.

(Vertical Deflection at Center of Span)
55' - 10" GIRDER SPAN (EAST GIRDER)
LOCOMOTIVE CLASS P5-A (ELECTRIC)

Run No.	SPEED M.P.H.	MEAN DEFLECTIONS – East Girder – Electrical Instrument	Mechanical Instrument	Average both Instruments	SEMI-AMPLITUDES – East Girder Track Effect – Electrical Instrument Def.	Electrical Instrument Per Cent	Mechanical Instrument Def.	Mechanical Instrument Per Cent	Average both Instruments Def.	Average both Instruments Per Cent	MAXIMUM DEFLECTIONS – East Girder Total Impacts – Electrical Instrument Max. Def.	Electrical Instrument Impact Def.	Electrical Instrument Impact Per Cent	Mechanical Instrument Max. Def.	Mechanical Instrument Impact Def.	Mechanical Instrument Impact Per Cent	Average both Instruments Max. Def.	Average both Instruments Impact Def.	Average both Instruments Impact Per Cent
Col. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
100	4.3	0.480	0.500	0.490	0.010	2.2	0	0	0.005	1.1	0.490	0.030	6.5	0.500	0.012	2.5	0.495	0.021	4.4
229	4.6	0.420	0.470	0.445	0.010	2.2	0	0	0.005	1.1	0.430	-0.030	-6.5	0.470	-0.018	-3.9	0.450	-0.024	-5.1
101	4.9	0.480	0.495	0.488	0.010	2.2	0	0	0.005	1.1	0.490	0.030	6.5	0.495	0.007	1.4	0.497	0.023	4.9
102	5.6	0.480	0.505	0.492	0.020	4.3	0	0	0.010	2.1	0.500	0.040	8.7	0.505	0.017	3.5	0.502	0.028	5.9
230	7.5	0.420	0.480	0.450	0.010	2.2	0.015	3.1	0.012	2.5	0.430	-0.030	-6.5	0.495	0.007	1.4	0.462	-0.012	-2.5
232	10.2	0.415	0.470	0.442	0.015	3.3	0.020	4.1	0.018	3.8	0.930	-0.030	-6.5	0.490	0.002	0.4	0.460	-0.014	-3.0
231	13.4	0.410	0.460	0.435	0.050	10.9	0.070	14.3	0.060	12.7	0.460	0	0	0.530	0.042	8.6	0.495	0.021	4.4
333	13.8	0.420	0.455	0.437	0.030	6.5	0.045	9.2	0.038	8.0	0.450	-0.010	-2.2	0.500	0.002	0.4	0.475	0.001	0.2
253	14.2	0.410	0.485	0.447	0.030	6.5	0.045	9.2	0.038	8.0	0.440	-0.020	-4.4	0.530	0.042	8.6	0.485	0.011	2.3
234	20.8	0.425	0.460	0.442	0.025	5.4	0.040	8.2	0.032	6.8	0.450	-0.010	-2.2	0.500	0.012	2.5	0.475	0.001	0.2
235	26.1	0.430	0.475	0.452	0.020	4.3	0.025	5.1	0.022	4.6	0.450	-0.010	-2.2	0.500	0.012	2.5	0.475	0.001	0.2
236	28.7	0.430	0.480	0.455	0.020	4.3	0.030	6.1	0.025	5.3	0.450	-0.010	-2.2	0.510	0.022	4.5	0.480	0.006	1.3
237	29.3	0.420	0.480	0.450	0.030	6.5	0.040	8.2	0.035	7.4	0.450	-0.010	-2.2	0.520	0.032	6.5	0.485	0.011	2.3
104	32.3	0.480	0.490	0.485	0.050	10.9	0.060	12.3	0.055	11.6	0.530	0.070	15.2	0.550	0.062	12.7	0.540	0.066	13.9
252	34.9	0.455	0.510	0.482	0.035	7.6	0.045	9.2	0.040	8.4	0.490	0.030	6.5	0.555	0.067	13.7	0.522	0.048	10.1
251	41.3	0.440	0.510	0.475	0.030	6.5	0.050	10.2	0.040	8.4	0.470	0.010	2.2	0.560	0.072	14.7	0.515	0.041	8.7
105	42.3	0.490	0.485	0.487	0.055	12.0	0.065	13.2	0.060	12.7	0.545	0.085	18.5	0.550	0.062	12.7	0.547	0.073	15.4
238	46.5	0.450	0.500	0.475	0.030	6.5	0.040	8.2	0.035	7.4	0.480	0.020	4.4	0.540	0.052	10.6	0.510	0.036	7.6
107	49.5	0.490	0.500	0.495	0.050	10.9	0.035	7.2	0.042	8.9	0.540	0.080	17.4	0.535	0.047	9.6	0.537	0.063	13.3
106	51.1	0.500	0.500	0.500	0.040	8.7	0.030	6.1	0.035	7.4	0.540	0.080	17.4	0.530	0.042	8.6	0.535	0.061	12.9
108	59.5	0.490	0.485	0.487	0.030	6.5	0.025	5.1	0.028	5.9	0.520	0.060	13.0	0.510	0.022	4.5	0.515	0.041	8.7
239	61.5	0.435	0.480	0.457	0.015	3.3	0.020	4.1	0.018	3.8	0.450	-0.010	-2.2	0.500	0.012	2.5	0.475	0.001	0.2
246	67.6	0.390	0.375	0.082	0.050	10.9	0.055	11.2	0.052	11.0	0.440	-0.020	-4.4	0.430	-0.058	-11.8	0.435	-0.039	-8.2
109	70.4	0.360	0.360	0.360	0.060	13.1	0.060	12.3	0.060	12.7	0.420	-0.020	-4.4	0.420	-0.068	-13.9	0.420	-0.054	-11.4
240	71.0	0.340	0.350	0.345	0.040	8.7	0.050	10.2	0.045	9.5	0.380	-0.080	-17.4	0.400	-0.088	-18.0	0.390	-0.084	-17.7
241	72.4	0.340	0.360	0.350	0.040	8.7	0.050	10.2	0.045	9.5	0.380	-0.080	-17.4	0.410	-0.078	-16.0	0.395	-0.079	-16.7
243	76.5	0.345	0.360	0.352	0.035	7.6	0.030	6.1	0.032	6.8	0.380	-0.080	-17.4	0.390	-0.098	-20.1	0.385	-0.089	-18.8
249	76.5	0.350	0.365	0.358	0.040	8.7	0.045	9.2	0.042	8.9	0.390	-0.070	-15.2	0.410	-0.078	-16.0	0.410	-0.064	-13.5
242	78.8	0.350	0.365	0.358	0.035	7.6	0.045	9.2	0.040	8.4	0.385	-0.075	-16.3	0.410	-0.078	-16.0	0.397	-0.077	-16.3
244	85.4	0.385	0.395	0.390	0.035	7.6	0.045	9.2	0.040	8.4	0.420	-0.040	-8.7	0.440	-0.048	-9.8	0.430	-0.044	-9.3
245	87.8	0.425	0.440	0.432	0.035	7.6	0.045	9.2	0.040	8.4	0.960	0	0	0.485	-0.003	-0.6	0.472	-0.002	-0.4
111	91.8	0.465	0.450	0.457	0.050	10.9	0.040	8.2	0.095	9.5	0.515	0.055	12.0	0.490	0.002	0.4	0.502	0.028	6.0
248	99.5	0.490	0.605	0.547	0.040	8.7	0.025	5.1	0.032	6.8	0.530	0.070	15.2	0.630	0.142	29.1	0.580	0.106	22.4
112	99.7	0.495	0.530	0.512	0 045	9.8	0.040	8.2	0.042	8.9	0 540	0.080	17.4	0.570	0.082	16.8	0.555	0.081	17.1

NOTE: (a) All deflections shown in Columns 3, 4, 6, 8, 12 and 15 are taken from Table 3.
(b) All deflections shown are in inches.
(c) The average of the mean deflections for the first three runs are considered as the "static deflections" in the east girder for the electrical and mechanical delectometer and their comparisons with the theoretical deflections are as follows:

MEASURED STATIC DEFLECTIONS		THEORETICAL STATIC DEFLECTIONS (Based on gross moment of inertia at center)	DEFLECTION FACTORS (Measured/Theoretical)	
Electrical deflectometer	= 0.460	East Girder = 0.359	Electrical Deflectometer	= 1.282
Mechanical deflectometer	= 0.488		Mechanical deflectometer	= 1.360
Average	= 0.474		Average	= 1.321

(d) The loaded frequency "n", based on a static deflection of 0.493 inch, is 4.56 vibrations per second.
(e) The theoretical dead load deflection, based on the gross moment of inertia at the center, is 0.065 in.

TABLE 24

ANALYSIS OF VERTICAL DEFLECTOMETER READINGS
(Vertical Deflection at Center of Span)
55' - 10" GIRDER SPAN (EAST GIRDER).
LOCOMOTIVE CLASS GG-1 (ELECTRIC)

Run No.	SPEED M.P.H.	MEAN DEFLECTIONS East Girder: Electrical Instrument	MEAN DEFLECTIONS East Girder: Mechanical Instrument	MEAN DEFLECTIONS East Girder: Average both Instruments	SEMI-AMPLITUDES East Girder Track Effect: Electrical Instrument Def.	Electrical Instrument Per Cent	Mechanical Instrument Def.	Mechanical Instrument Per Cent	Average both Instruments Def.	Average both Instruments Per Cent	MAXIMUM DEFLECTIONS East Girder Total Impacts: Electrical Instrument Max. Def.	Electrical Instrument Impact Def.	Electrical Instrument Impact Per Cent	Mechanical Instrument Max. Def.	Mechanical Instrument Impact Def.	Mechanical Instrument Impact Per Cent	Average both Instruments Max. Def.	Average both Instruments Impact Def.	Average both Instruments Impact Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
155	4.4	0.370	0.410	0.390	0	0	0	0	0	0	0.370	0	0	0.410	0	0	0.390	0	0
156	9.8	0.370	0.400	0.385	0	0	0	0	0	0	0.370	0	0	0.400	-0.010	-2.4	0.385	-0.005	-1.3
228	10.3	0.370	0.400	0.385	0	0	0	0	0	0	0.370	0	0	0.400	-0.010	-2.4	0.385	-0.005	-1.3
157	12.7	0.370	0.400	0.385	0.010	2.7	0.020	4.9	0.015	3.8	0.380	0.010	2.7	0.420	0.010	2.4	0.400	0.010	2.6
158	15.6	0.370	0.400	0.385	0.010	2.7	0.010	2.4	0.010	2.6	0.380	0.010	2.7	0.410	0	0	0.395	0.005	1.3
159	18.5	0.370	0.380	0.375	0.010	2.7	0.020	4.9	0.015	3.8	0.380	0.010	2.7	0.400	-0.010	-2.4	0.390	0	0
160	25.0	0.390	0.410	0.400	0.010	2.7	0.010	2.4	0.010	2.6	0.400	0.030	8.1	0.420	0.010	2.4	0.410	0.020	5.1
161	28.7	0.380	0.410	0.395	0.020	5.4	0.020	4.9	0.020	5.1	0.400	0.030	8.1	0.430	0.020	4.9	0.415	0.025	6.4
165	35.2	0.380		0.380	0.020	5.4			0.020	5.1	0.400	0.030	8.1	-	-	-	0.400	0.010	2.6
162	35.7	0.390		0.390	0.010	2.7			0.010	2.6	0.400	0.030	8.1	-	-	-	0.400	0.010	2.6
227	39.7	0.380	0.410	0.395	0.010	2.7	0.020	4.9	0.015	3.8	0.390	0.020	5.4	0.430	0.020	4.9	0.410	0.020	5.1
163	39.8	0.390	0.410	0.400	0.010	2.7	0.020	4.9	0.015	3.8	0.400	0.030	8.1	0.430	0.020	4.9	0.415	0.025	6.4
164	44.7	0.390	0.420	0.405	0.020	5.4	0.030	7.3	0.025	6.4	0.410	0.040	10.8	0.450	0.040	9.8	0.430	0.040	10.3
166	50.1	0.390	0.410	0.400	0.020	5.4	0.020	4.9	0.020	5.1	0.410	0.040	10.8	0.430	0.020	4.9	0.420	0.030	7.7
226	51.1	0.380	0.420	0.400	0.020	5.4	0.020	4.9	0.020	5.1	0.400	0.030	8.1	0.440	0.030	7.3	0.420	0.030	7.7
178	54.8	0.390	0.400	0.395	0.020	5.4	0.020	4.9	0.020	5.1	0.410	0.040	10.8	0.420	0.010	2.4	0.415	0.025	6.4
225	57.0	0.380	0.400	0.390	0.020	5.4	0.030	7.3	0.025	6.4	0.400	0.030	8.1	0.430	0.020	4.9	0.415	0.025	6.4
177	59.8	0.370		0.370	0.020	5.4			0.020	5.1	0.390	0.020	5.4	-	-	-	0.390	0	0
179	60.9	0.380	0.370	0.375	0.010	2.7	0.020	4.9	0.015	3.8	0.390	0.020	5.4	0.390	-0.020	-4.9	0.390	0	0
176	64.6	0.350	0.350	0.350	0.020	5.4	0.020	4.9	0.020	5.1	0.370	0	0	0.370	-0.040	-9.8	0.370	-0.020	-5.1
224	69.4	0.340		0.340	0.010	2.7			0.010	2.6	0.350	-0.020	-5.4	-	-	-	0.350	-0.040	-10.3
175	71.6	0.370	0.380	0.375	0.010	2.7	0.020	4.9	0.015	3.8	0.400	0.030	8.1	0.400	-0.010	-2.4	0.400	0.010	2.6
174	73.0	0.370	0.370	0.370	0.020	5.4	0.020	4.9	0.020	5.1	0.420	0.050	13.5	0.450	0.040	9.8	0.435	0.045	11.6
223	73.0	0.350	0.370	0.360	0.010	2.7	0.030	7.3	0.020	5.1	0.380	0.010	2.7	0.420	0.010	2.4	0.400	0.010	2.6
221	78.7	0.330	0.390	0.360	0.020	5.4	0.030	7.3	0.025	6.4	0.420	0.050	13.5	0.460	0.050	12.2	0.440	0.050	12.8
171	79.5	0.380	0.380	0.380	0.010	2.7	0.020	4.9	0.015	3.8	0.420	0.050	13.5	0.450	0.040	9.8	0.435	0.045	11.6
167	82.1	0.430	0.460	0.445	0.010	2.7	0.020	4.9	0.015	3.8	0.440	0.070	18.9	0.480	0.070	17.1	0.460	0.070	18.0
168	84.0	0.430	0.440	0.435	0.010	2.7	0.020	4.9	0.015	3.8	0.440	0.070	18.9	0.460	0.050	12.2	0.450	0.060	15.4
169	90.4	0.430	0.420	0.425	0.010	2.7	0.020	4.9	0.015	3.8	0.440	0.070	18.9	0.440	0.030	7.3	0.440	0.050	12.8
170	95.9	0.420	0.440	0.430	0.020	5.4	0.020	4.9	0.020	5.1	0.440	0.070	18.9	0.460	0.050	12.2	0.450	0.060	15.4
173	98.5	0.400	0.380	0.390	0.020	5.4	0.030	7.3	0.025	6.4	0.420	0.050	13.5	0.410	0	0	0.415	0.025	6.4
172	105.0	0.380	0.370	0.375	0.030	8.1	0.030	7.3	0.030	7.7	0.410	0.040	10.8	0.400	-0.010	-2.4	0.405	0.015	3.8

NOTE: (a) All deflections shown in Columns 3, 4, 6, 8, 12 and 15 are taken from Table 4.
(b) All deflections shown are in inches.
(c) The mean deflections for the first run are considered as the "static deflections" in the east girder for the electrical and mechanical deflectometers and their comparisons with the theoretical deflection are as follows:

MEASURED STATIC DEFLECTION

Electrical deflectometer = 0.370
Mechanical deflectometer = 0.410
Average = 0.390

THEORETICAL STATIC DEFLECTION
(Based on gross moment of inertia at center)
East Girder = 0.313

DEFLECTION FACTOR
(Measured/Theoretical)
Electrical deflectometer = 1.182
Mechanical deflectometer = 1.310
Average = 1.246

(d) The loaded frequency "n", based on a mean static deflection of 0.412 inch, is 4.94 vibrations per second.

TABLE 23

ANALYSIS OF VERTICAL DEFLECTOMETER READINGS
(Vertical Deflections at Center of Span)
55' - 10" GIRDER SPAN (EAST GIRDER)
LOCOMOTIVE CLASS K4-8 (STEAM)

Run No.	Speed M.P.H.	Speed R.P.S.	Dimension "x" Feet	Aver. Mean Def. Inches	Theoretical Loaded Freqy. "a" V.P.S.	Mean Deflections, East Girder, Elect. Instr.	Mean Deflections, East Girder, Mech. Instr.	Mean Deflections, Aver. Both Instr.	Semi-Amplitudes, East Girder Track and Hammer Blow Effect, Electrical Instrument, Def.	Elect. $D_H N^2$	Elect. Dynam. Magnif.	Mechanical Instrument, Def.	Mech. $D_H N^2$	Mech. Dynam. Magnif.	Aver.-Both Instruments, Def.	Aver. $D_H N^2$	Aver. Dynam. Magnif.	Maximum Deflections, East Girder Total Impacts, Electrical Instrument, Max. Def.	Elect. Impact Def.	Elect. Impact Per Cent	Mechanical Instrument, Max. Def.	Mech. Impact Def.	Mech. Impact Per Cent	Aver. Both Instruments, Max. Def.	Aver. Impact Def.	Aver. Impact Per Cent
Col. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
132	5.2	0.37		0.479	4.63	0.410	0.480	0.445	0.015									0.425	0.015	5.7	0.480	0	0	0.453	0.008	1.8
128	18.9	1.34				0.405			0.025									0.430	0.020	4.9						
127	26.6	1.89		0.475	4.65	0.405	0.452	0.429	0.025	0.008	3.12	0.038	0.009	4.22	0.032	0.008	4.00	0.430	0.020	4.9	0.490	0.010	2.1	0.460	0.015	3.4
126	30.1	2.13				0.410			0.040	0.010	4.00							0.450	0.040	9.8						
125	35.6	2.52		0.464	4.70	0.410	0.445	0.428	0.030	0.014	2.14	0.045	0.016	2.81	0.038	0.015	2.54	0.440	0.030	7.3	0.490	0.010	2.1	0.465	0.020	4.5
124	40.0	2.84		0.475	4.65	0.410	0.420	0.415	0.040	0.017	2.35	0.050	0.021	2.38	0.045	0.019	2.37	0.440	0.030	7.3	0.470	-0.010	-2.1	0.455	0.010	2.2
130	40.2	2.85		0.461	4.71	0.390	0.420	0.405	0.040	0.017	2.35	0.040	0.021		0.040	0.019	2.10	0.430	0.020	4.9	0.460	-0.020	-4.2	0.445	0	0
131	41.7	2.96		0.481	4.62	0.400	0.450	0.425	0.040	0.019	2.10	0.050	0.023	2.17	0.045	0.021	2.14	0.440	0.030	7.3	0.500	0.020	4.2	0.470	0.025	5.6
129	42.6	3.02		0.468	4.68	0.395	0.420	0.408	0.045	0.020	2.25	0.050	0.024	2.08	0.048	0.022	2.18	0.440	0.030	7.3	0.470	-0.010	-2.1	0.455	0.010	2.2
123	44.2	3.13		0.466	4.69	0.390	0.430	0.410	0.030	0.021	1.43	0.050	0.025	1.20	0.030	0.025	1.31	0.420	0.010	2.4	0.460	-0.020	-4.2	0.440	-0.005	-1.1
214	45.8	3.25		0.478	4.64	0.360	0.390	0.375	0.050	0.023	2.17	0.060	0.027	2.22	0.055	0.025	2.20	0.410	0	0	0.450	-0.030	-6.2	0.430	-0.015	-3.4
122	52.3	3.70	10.0 S	0.461	4.71	0.370	0.400	0.385	0.020	0.030	0.67	0.030	0.035	0.86	0.025	0.033	0.76	0.390	-0.020	-4.9	0.430	-0.050	-10.4	0.410	-0.035	-7.9
121	55.5	3.93	8.3 N	0.460	4.71	0.365	0.410	0.388	0.055	0.034	1.62	0.050	0.040	1.25	0.053	0.037	1.43	0.420	0.010	2.4	0.460	-0.020	-4.2	0.440	-0.005	-1.1
208	57.5	4.07	5.7 S	0.451	4.75	0.360	0.380	0.370	0.050	0.036	1.39	0.070	0.042	1.67	0.060	0.039	1.54	0.410	0	0	0.440	-0.040	-8.5	0.425	-0.020	-4.5
195	59.5	4.20	7.5 N	0.444	4.79	0.340	0.400	0.370	0.060	0.039	1.54	0.060	0.045	1.33	0.060	0.042	1.43	0.400	-0.010	-2.4	0.460	-0.020	-4.2	0.430	-0.015	-3.4
209	60.0	4.25	1.9 S	0.494	4.57	0.400	0.400	0.400	0.050	0.040	1.25	0.070	0.046	1.52	0.060	0.043	1.40	0.450	0.040	8.9	0.470	-0.010	-2.1	0.460	0.015	3.4
196	60.3	4.28	9.5 S	0.461	4.71	0.370	0.370	0.370	0.050	0.040	1.25	0.070	0.047	1.49	0.060	0.044	1.36	0.400	-0.010	-2.4	0.430	-0.050	-10.4	0.415	-0.030	-6.7
210	63.3	4.48	1.9 N	0.518	4.48	0.400	0.470	0.435	0.060	0.044	1.36	0.045	0.052	0.87	0.053	0.048	1.10	0.460	0.050	12.2	0.515	0.035	7.3	0.488	0.043	9.7
197	63.9	4.53	1.9 S	0.519	4.47	0.410	0.430	0.420	0.050	0.045	1.11	0.060	0.053	1.13	0.055	0.049	1.12	0.460	0.050	12.2	0.490	0.010	2.1	0.475	0.030	6.7
211	65.3	4.64	3.9 N	0.480	4.63	0.390	0.420	0.405	0.070	0.047	1.49	0.080	0.055	1.46	0.075	0.051	1.47	0.460	0.050	12.2	0.500	0.020	4.2	0.480	0.035	7.9
120	67.0	4.75	5.6 N	0.463	4.70	0.400	0.450	0.425	0.040	0.049	0.82	0.070	0.058	1.21	0.055	0.054	1.02	0.480	0.070	17.1	0.550	0.050	10.4	0.505	0.060	13.5
198	67.7	4.80	2.2 N	0.519	4.47	0.400	0.440	0.420	0.060	0.050	1.20	0.060	0.059	1.02	0.060	0.055	1.09	0.460	0.050	12.2	0.500	0.020	4.2	0.480	0.035	7.9
212	68.4	4.85	10.3 S	0.436	4.82	0.395	0.415	0.405	0.055	0.051	1.08	0.085	0.060	1.42	0.070	0.056	1.25	0.450	0.040	9.8	0.500	0.020	4.2	0.475	0.030	6.7
199	69.0	4.89	6.3 N	0.498	4.56	0.400	0.445	0.423	0.070	0.052	1.35	0.085	0.061	1.39	0.078	0.057	1.37	0.470	0.060	14.6	0.530	0.050	10.4	0.500	0.055	12.4
213	70.6	5.00		0.484	4.61	0.415	0.440	0.428	0.055	0.055	1.00	0.060	0.064	0.94	0.058	0.059	0.98	0.470	0.060	14.6	0.500	0.020	4.2	0.485	0.040	9.0
118	71.0	5.04	5.5 S	0.476	4.65	0.420	0.460	0.440	0.040	0.055	0.73	0.050	0.065	0.77	0.045	0.060	0.75	0.460	0.050	12.2	0.510	0.050	6.2	0.485	0.040	9.0
200	72.1	5.12	6.2 S	0.463	4.70	0.370	0.400	0.385	0.030	0.057	0.53	0.060	0.067	0.90	0.045	0.062	0.73	0.430	0.020	4.9	0.500	0.020	4.2	0.465	0.020	4.5
201	77.3	5.47	4.0 S	0.531	4.43	0.450	0.505	0.478	0.070	0.065	1.08	0.085	0.078	1.09	0.078	0.071	1.10	0.520	0.110	26.8	0.590	0.110	22.9	0.555	0.110	24.7
202	79.4	5.63	0.4 N	0.498	4.56	0.445	0.490	0.468	0.085	0.069	1.23	0.110	0.081	1.56	0.098	0.075	1.31	0.530	0.120	29.3	0.600	0.120	25.0	0.565	0.120	27.0
116	80.8	5.72	0.1 S	0.470	4.67	0.420	0.450	0.435	0.070	0.071	0.99	0.090	0.084	1.07	0.080	0.078	1.03	0.490	0.080	19.5	0.540	0.060	12.5	0.515	0.070	15.7
203	82.2	5.82	4.3 N			0.415			0.055	0.074	0.74							0.470	0.060	14.6	0.500	0.020	4.2	0.485	0.040	9.0
113	84.0	5.96		0.460	4.71	0.400	0.390	0.395	0.080	0.078	1.03	0.080	0.091	0.88	0.080	0.084	0.95	0.480	0.070	17.1	0.470	-0.010	-2.1	0.475	0.030	6.7
114	85.0	6.03		0.466	4.69	0.380	0.370	0.375	0.080	0.079	1.01	0.110	0.093	1.18	0.095	0.086	1.11	0.460	0.050	12.2	0.480	0	0	0.470	0.025	5.6
204	85.0	6.03	8.5 N	0.485	4.61	0.405	0.430	0.418	0.075	0.079	0.95	0.100	0.093	1.08	0.088	0.086	1.02	0.480	0.070	17.1	0.530	0.050	10.4	0.505	0.060	13.5
115	87.0	6.16	8.4 S	0.438	4.81	0.390	0.390	0.390	0.080	0.083	0.97	0.090	0.097	0.93	0.085	0.090	0.94	0.470	0.060	14.6	0.480	0	0	0.475	0.030	6.7
207	88.0	6.23	7.2 S	0.477	4.64	0.400	0.400	0.400	0.060	0.085	0.71	0.080	0.099	0.81	0.070	0.092	0.76	0.460	0.050	12.2	0.480	0	0	0.470	0.025	5.6
206	88.3	6.26	1.1 N	0.490	4.59	0.400	0.430	0.415	0.070	0.086	0.81	0.080	0.101	0.79	0.075	0.093	0.81	0.470	0.060	14.6	0.510	0.030	6.2	0.490	0.045	10.1
205	89.4	6.33	4.8 S	0.498	4.56	0.420	0.430	0.425	0.060	0.087	0.69	0.080	0.103	0.78	0.070	0.095	0.74	0.480	0.070	17.1	0.510	0.030	6.2	0.495	0.050	11.2

NOTE. (a) All deflections shown in Columns 7, 8, 10, 13, 19 and 22 are taken from Table 5.

(b) All deflections shown are in inches.

(c) Dimension "x" in Column 4 is the distance, either north or south, from the center of the span to the main driver at the time the crank pins are in position for maximum hammer blow effect on the span. Locomotive headed south.

(d) The mean deflections for the first run are considered as the "static deflections" in the east girder for the electrical and mechanical deflectometers and their comparisons with the theoretical deflection are as follows:

MEASURED STATIC DEFLECTION

Electrical Deflectometer = 0.410
Mechanical Deflectometer = 0.480
Average = 0.445

THEORETICAL STATIC DEFLECTION
(Based on gross moment of inertia at center)
East Girder = 0.315

DEFLECTION FACTOR
(Measured/Theoretical)
Electrical Deflectometer = 1.140
Mechanical Deflectometer = 1.332
Average = 1.236

(e) The "hammer blow deflections" for the east girder at one revolution per second are as follows:

Electrical Deflectometer	0.00192 x 1.140	= 0.00218
Mechanical Deflectometer	0.00192 x 1.332	= 0.00256
Average		= 0.00237

TABLE 26

ANALYSIS OF VERTICAL DEFLECTOMETER READINGS
(Vertical Deflection at Center of Span)
55' - 10" GIRDER SPAN (EAST GIRDER)
LOCOMOTIVE CLASS M1-A (STEAM)

Run No.	SPEED M.P.H.	SPEED R.P.S.	DIMENSION "X" Feet	Average Mean Deflection Inches	Theoretical Loaded Frequency "n" V.P.S.	MEAN DEFLECTIONS East Girder Electrical Instrument	Mechanical Instrument	Average both Instruments	SEMI-AMPLITUDES East Girder Track and Hammer Blow Effect Electrical Instrument Def.	D_hN^2	Dynamic Magnifier	Mechanical Instrument Def.	D_hN^2	Dynamic Magnifier	Average both Instruments Def.	D_hN^2	Dynamic Magnifier	MAXIMUM DEFLECTIONS East Girder Total Impacts Electrical Instruments Max. Def.	Impact Def.	Per Cent	Mechanical Instruments Max. Def.	Impact Def.	Per Cent	Average both Instruments Max. Def.	Impact Def.	Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
133	4.8	0.38		0.536	4.41	0.480	0.540	0.510	0.010			0.020			0.015			0.490	0.010	2.1	0.560	0.020	3.7	0.525	0.015	2.9
134	9.0	0.71				0.470			0.020									0.490	0.010	2.1						
135	13.3	1.05		0.539	4.40	0.490	0.570	0.530	0.020			0.020			0.020			0.510	0.030	6.2	0.590	0.050	9.3	0.550	0.040	7.8
136	19.5	1.54		0.543	4.39	0.470	0.520	0.495	0.030	0.007	4.28	0.040	0.007	5.71	0.035	0.007	5.00	0.500	0.020	4.2	0.560	0.020	3.7	0.530	0.020	3.9
137	25.0	1.98		0.565	4.31	0.500	0.540	0.520	0.020	0.011	1.82	0.040	0.012	3.34	0.030	0.011	2.73	0.520	0.040	8.3	0.580	0.040	7.4	0.550	0.040	7.8
150	25.2	1.99		0.543	4.39	0.485	0.530	0.508	0.015	0.011	1.36	0.020	0.012	1.67	0.018	0.011	1.64	0.500	0.020	4.2	0.550	0.010	1.8	0.525	0.015	2.9
149	29.4	2.32		0.549	4.37	0.455	0.520	0.488	0.045	0.015	1.61	0.020	0.017	1.18	0.022	0.016	1.37	0.480	0	0	0.560	0.020	3.7	0.520	0.010	2.0
148	34.8	2.75		0.499	4.55	0.465	0.460	0.462	0.035	0.021	1.67	0.030	0.023	1.31	0.032	0.022	1.45	0.500	0.020	4.2	0.490	-0.050	-9.3	0.495	-0.015	-2.9
147	40.3	3.18		0.545	4.38	0.470	0.520	0.495	0.030	0.028	1.07	0.040	0.031	1.29	0.035	0.029	1.21	0.500	0.020	4.2	0.560	0.020	3.7	0.530	0.020	3.9
153	41.5	3.28		0.554	4.35	0.475	0.525	0.500	0.025	0.030	0.83	0.035	0.033	1.06	0.030	0.031	1.23	0.500	0.020	4.2	0.560	0.020	3.7	0.530	0.020	3.9
193	42.0	3.32		0.536	4.41	0.485	0.490	0.488	0.055	0.030	1.17	0.070	0.034	2.06	0.052	0.032	1.63	0.520	0.040	8.3	0.560	0.020	3.7	0.540	0.030	5.9
189	43.9	3.47		0.552	4.36	0.470	0.490	0.480	0.050	0.033	1.52	0.070	0.037	1.89	0.060	0.035	1.72	0.520	0.040	8.3	0.560	0.020	3.7	0.540	0.030	5.9
154	46.2	3.65		0.524	4.46	0.460	0.490	0.475	0.040	0.037	1.08	0.060	0.041	1.46	0.050	0.039	1.28	0.500	0.020	4.2	0.550	0.010	1.8	0.525	0.015	2.9
158	46.5	3.67		0.569	4.30	0.425	0.495	0.460	0.085	0.037	2.30	0.055	0.042	1.31	0.070	0.039	1.80	0.510	0.030	6.2	0.550	0.010	1.8	0.530	0.020	3.9
146	47.0	3.71		0.531	4.43	0.430	0.500	0.465	0.030	0.038	0.79	0.020	0.042	0.48	0.025	0.040	0.62	0.460	-0.020	-4.2	0.520	-0.020	-3.7	0.490	-0.020	-3.9
186	47.0	3.71		0.541	4.40	0.460	0.510	0.485	0.050	0.038	1.32	0.060	0.042	1.43	0.055	0.040	1.37	0.510	0.030	6.2	0.570	0.030	5.6	0.540	0.030	5.9
152	47.2	3.72		0.543	4.39	0.445	0.500	0.472	0.035	0.038	0.92	0.050	0.042	1.19	0.042	0.040	1.05	0.480	0	0	0.550	0.010	1.8	0.515	0.005	1.0
151	47.4	3.74		0.522	4.46	0.455	0.490	0.472	0.015	0.039	0.38	0.030	0.043	0.70	0.022	0.041	0.54	0.470	-0.010	-2.1	0.520	-0.020	-3.7	0.495	-0.015	-2.9
191	49.5	3.91		0.563	4.32	0.470	0.510	0.490	0.030	0.042	0.71	0.040	0.047	0.85	0.035	0.045	0.78	0.500	0.020	4.2	0.550	0.010	1.8	0.525	0.015	2.9
194	49.7	3.92	0.6S	0.508	4.52	0.470	0.490	0.480	0.050	0.042	1.19	0.070	0.047	1.49	0.060	0.045	1.33	0.520	0.040	8.3	0.560	0.020	3.7	0.540	0.030	5.9
143	50.2	3.96	2.5N	0.579	4.27	0.440	0.500	0.470	0.030	0.043	0.70	0.030	0.048	0.63	0.030	0.046	0.65	0.470	-0.010	-2.1	0.530	-0.010	-1.8	0.500	-0.010	-2.0
192	51.4	4.06	1.0S	0.429	4.86	0.380	0.350	0.365	0.090	0.046	1.96	0.060	0.051	1.18	0.075	0.048	1.56	0.470	-0.010	-2.1	0.410	-0.130	-24.1	0.440	-0.070	-13.7
190	53.8	4.25		0.528	4.44	0.455	0.485	0.470	0.025	0.050	0.50	0.035	0.056	0.62	0.030	0.053	0.57	0.480	0	0	0.520	-0.020	-3.7	0.500	-0.010	-2.0
145	54.3	4.29	3.1N	0.534	4.42	0.440	0.445	0.442	0.030	0.051	0.59	0.045	0.057	0.79	0.038	0.054	0.70	0.470	-0.010	-2.1	0.490	-0.050	-9.3	0.480	-0.030	-5.9
141	57.0	4.50	7.1N	0.528	4.44	0.450	0.500	0.475	0.040	0.056	0.72	0.060	0.062	0.97	0.050	0.059	0.85	0.490	0.010	2.1	0.560	0.020	3.7	0.525	0.015	2.9
140	58.5	4.62	2.0S	0.523	4.46	0.460	0.500	0.480	0.050	0.059	0.85	0.060	0.066	0.91	0.055	0.062	0.89	0.510	0.030	6.2	0.560	0.020	3.7	0.535	0.025	4.9
195	60.0	4.74	6.9N	0.525	4.45	0.470	0.500	0.485	0.040	0.062	0.65	0.060	0.069	0.87	0.050	0.066	0.76	0.510	0.030	6.2	0.560	0.020	3.7	0.535	0.025	4.9
144	64.8	5.12	2.2N	0.523	4.46	0.460	0.510	0.485	0.060	0.072	0.83	0.090	0.081	1.11	0.075	0.077	0.97	0.520	0.040	8.3	0.600	0.060	11.1	0.560	0.050	9.8
139	66.5	5.25	0.7S	0.526	4.45	0.480	0.510	0.495	0.060	0.076	0.79	0.080	0.085	0.94	0.070	0.081	0.86	0.540	0.060	12.5	0.590	0.050	9.3	0.565	0.055	10.8
182	68.1	5.38	5.4N	0.530	4.44	0.480	0.535	0.508	0.040	0.080	0.50	0.085	0.090	0.94	0.062	0.085	0.73	0.520	0.040	8.3	0.620	0.080	14.8	0.570	0.060	11.8
138	71.2	5.62	9.2N	0.544	4.39	0.490	0.530	0.510	0.050	0.087	0.57	0.080	0.097	0.83	0.065	0.092	0.71	0.540	0.060	12.5	0.610	0.070	13.0	0.575	0.065	12.7
181	72.8	5.75	9.7N	0.532	4.43	0.490	0.520	0.505	0.050	0.091	0.55	0.090	0.102	0.88	0.070	0.097	0.72	0.540	0.060	12.5	0.610	0.070	13.0	0.575	0.065	12.7
180	75.7	5.96	5.7N	0.539	4.40	0.500	0.570	0.535	0.050	0.099	0.51	0.100	0.111	0.90	0.075	0.105	0.71	0.550	0.070	14.6	0.670	0.130	24.0	0.610	0.100	19.8
142	77.9	6.15	3.6S	0.553	4.35	0.490	0.600	0.545	0.070	0.104	0.67	0.090	0.117	0.77	0.080	0.111	0.72	0.560	0.080	16.7	0.690	0.150	27.8	0.625	0.115	22.5

NOTE: (a) All deflections shown in Columns 7, 8, 10, 13, 19 and 22 are taken from Table 6.
(b) All deflections shown are in inches.
(c) Dimension "X" in Column 4 is the distance, either north or south, from the center of the span to the main driver at the time the pins are in position for maximum hammer blow effect on the span. Locomotive headed south.
(d) The mean deflections for the first run are considered as the "static deflections" in the east girder for the electrical and mechanical deflectometers and their comparisons with the theoretical deflection are as follows:

MEASURED STATIC DEFLECTION

Electrical deflectometer	0.480
Mechanical deflectometer	0.540
Average	0.510

THEORETICAL STATIC DEFLECTION
(Based on gross moment of inertia at center)

East girder 0.415

DEFLECTION FACTOR
(Measured/Theoretical)

Electrical deflectometer	1.156
Mechanical deflectometer	1.300
Average	1.228

(e) The "hammer blow deflections" for the east girder at one revolution per second are as follows:

Electrical deflectometer	0.00238 x 1.156	0.00276
Mechanical deflectometer	0.00238 x 1.300	0.00308
Average		0.00292

TABLE 27

ANALYSIS OF VERTICAL DEFLECTION READINGS
(Vertical Deflection at Center of Span)
122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)

Run No.	SPEED M.P.H.	MEAN DEFLECTIONS: Electrical Instrument East Girder	MEAN DEFLECTIONS: Mechanical Instrument West Girder	MEAN DEFLECTIONS: Average East and West	Speed Effect Deflection	Speed Effect Per Cent	Roll Effect Deflection	Roll Effect Per Cent	SEMI-AMPLITUDES: East Girder Track Effect Deflection	East Girder Track Effect Per Cent	West Girder Track Effect Deflection	West Girder Track Effect Per Cent	Average both Girders Track Effect Deflection	Average both Girders Track Effect Per Cent	MAXIMUM DEFLECTIONS: Electrical Instrument East Girder	MAXIMUM DEFLECTIONS: Mechanical Instrument West Girder	East Girder Total Deflection	East Girder Impact Per Cent	West Girder Total Deflection	West Girder Impact Per Cent
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
100	4.3	0.615	0.655	0.635					0.005	0.8	0	0	0.002	0.4	0.620	0.655	0.025	4.2	0.002	0.3
229	4.6	0.595	0.650	0.623					0.005	0.8	0	0	0.002	0.4	0.600	0.650	0.005	0.8	-0.005	-0.8
101	4.9	0.515	0.653	0.614					0.005	0.8	0	0	0.002	0.4	0.580	0.653	-0.015	-2.5	0.000	0
102	5.6	0.585	0.635	0.610	-0.014	-2.2	0.003E	0.5E	0.005	0.8	0	0	0.002	0.4	0.590	0.635	-0.005	-0.8	-0.018	-2.8
230	7.5	0.620	0.640	0.630	0.006	1.0	0.019E	3.1E	0.010	1.7	0.015	2.3	0.012	2.0	0.630	0.655	0.035	5.9	0.002	0.3
232	10.2	0.600	0.665	0.633	0.009	1.4	0.003W	0.5E	0.010	1.7	0.020	3.1	0.015	2.4	0.610	0.685	0.015	2.5	0.032	4.9
231	13.4	0.615	0.650	0.633	0.009	1.4	0.012E	1.9E	0.010	1.7	0.025	3.8	0.018	2.9	0.625	0.675	0.030	5.0	0.022	3.4
233	13.8	0.595	0.645	0.620	-0.004	-0.6	0.003E	0.5E	0.010	1.7	0.020	3.1	0.015	2.4	0.605	0.665	0.010	1.7	0.012	1.8
253	14.2	0.570	0.635	0.603	-0.021	-3.4	0.004W	0.6W	0.010	1.7	0.020	3.1	0.015	2.4	0.580	0.655	-0.015	-2.5	0.002	0.3
103	17.2	0.580	0.630	0.605	-0.019	-3.0	0.003E	0.5E	0.020	3.4	0.035	5.4	0.028	4.5	0.600	0.665	0.005	0.8	0.012	1.8
234	20.8	0.615	0.655	0.635	0.011	1.8	0.009E	1.4E	0.025	4.2	0.035	5.4	0.030	4.8	0.640	0.690	0.045	7.6	0.037	5.7
235	26.1	0.590	0.640	0.615	-0.009	-1.4	0.004E	0.6W	0.020	3.4	0.020	3.1	0.020	3.2	0.610	0.660	0.015	2.5	0.007	1.1
236	28.7	0.600	0.650	0.625	0.001	0.2	0.004E	0.6W	0.020	3.4	0.020	3.1	0.020	3.2	0.620	0.670	0.025	4.2	0.017	2.6
237	29.3	0.600	0.655	0.628	0.004	0.6	0.001E	0.2E	0.020	3.4	0.020	3.1	0.020	3.2	0.620	0.675	0.025	4.2	0.022	3.4
104	32.3	0.555	0.625	0.590	-0.034	-5.4	0.009W	1.4W	0.015	2.5	0.020	3.1	0.018	2.9	0.570	0.645	-0.025	-4.2	-0.008	-1.2
252	34.9	0.575	0.650	0.613	-0.011	-1.8	0.009W	1.4W	0.025	4.2	0.030	4.6	0.028	4.5	0.600	0.680	0.005	0.8	0.027	4.1
251	41.3	0.580	0.645	0.613	-0.011	-1.8	0.004W	0.6W	0.020	3.4	0.020	3.1	0.020	3.2	0.600	0.665	0.005	0.8	0.012	1.8
105	42.3	0.575	0.625	0.600	-0.024	-3.9	0.003E	0.5E	0.025	4.2	0.030	4.6	0.028	4.5	0.600	0.660	0.005	0.8	0.007	1.1
238	46.5	0.605	0.650	0.628	0.004	0.6	0.006E	1.0E	0.015	2.5	0.020	3.1	0.018	2.9	0.620	0.670	0.025	4.2	0.017	2.6
107	49.5	0.590	0.610	0.600	-0.024	-3.9	0.018E	2.9E	0.025	4.2	0.020	3.1	0.022	3.5	0.615	0.630	0.020	3.4	-0.023	-3.5
106	51.1	0.615	0.625	0.620	-0.004	-0.6	0.024E	3.9E	0.020	3.4	0.020	3.1	0.020	3.2	0.635	0.645	0.040	6.7	-0.008	-1.2
108	59.5	0.630	0.600	0.615	-0.009	-1.4	0.043E	6.9E	0.020	3.4	0.020	3.1	0.020	3.2	0.650	0.620	0.055	9.2	-0.033	-5.1
239	61.5	0.650	0.640	0.645	0.021	3.4	0.035E	5.6E	0.010	1.7	0.015	2.3	0.012	2.0	0.660	0.655	0.065	10.9	0.002	0.3
246	67.6	0.530	0.745	0.638	0.014	2.2	0.077W	12.3W	0.020	3.4	0.010	1.5	0.015	2.4	0.550	0.755	-0.045	-7.6	0.102	15.6
109	70.4	0.570	0.705	0.638	0.014	2.2	0.037W	5.9W	0.025	4.2	0.010	1.5	0.018	2.9	0.595	0.715	0	0	0.062	9.5
240	71.0	0.570	0.725	0.648	0.024	3.9	0.047W	7.5W	0.035	5.9	0.015	2.3	0.025	4.0	0.605	0.740	0.010	1.7	0.087	13.3
241	72.4	0.570	0.725	0.648	0.024	3.9	0.047W	7.5W	0.025	4.2	0.015	2.3	0.020	3.2	0.615	0.740	0.020	3.4	0.087	13.3
249	76.5	0.530	0.740	0.635	0.011	1.8	0.075W	12.0W	0.020	3.4	0.015	2.3	0.018	2.9	0.550	0.755	-0.045	-7.6	0.102	15.6
243	76.5	0.540	0.745	0.643	0.019	3.0	0.073W	11.7W	0.025	4.2	0.020	3.1	0.022	3.5	0.565	0.765	-0.030	-5.0	0.112	17.2
242	78.8	0.515	0.745	0.630	0.006	1.0	0.086W	13.8W	0.020	3.4	0.010	1.5	0.015	2.4	0.535	0.755	-0.060	-10.1	0.102	15.6
110	81.6	0.510	0.765	0.638	0.014	2.2	0.098W	15.7W	0.010	1.7	0.015	2.3	0.012	2.0	0.520	0.780	-0.075	-12.6	0.127	19.4
245	87.8	0.530	0.755	0.643	0.019	3.0	0.083W	13.3W	0.020	3.4	0.010	1.5	0.015	2.4	0.550	0.765	-0.045	-7.6	0.112	17.2
111	91.8	0.550	0.745	0.648	0.024	3.9	0.067W	10.7W	0.010	1.7	0.020	3.1	0.015	2.4	0.560	0.765	-0.035	-5.9	0.112	17.2
247	95.2	0.540	0.730	0.635	0.011	1.8	0.066W	10.6W	0.020	3.4	0.030	4.6	0.025	4.0	0.560	0.760	-0.035	-5.9	0.107	16.4
250	96.3	0.550	0.745	0.648	0.024	3.9	0.067W	10.7W	0.010	1.7	0.015	2.3	0.012	2.0	0.560	0.760	-0.035	-5.9	0.107	16.4
248	99.5	0.550	0.720	0.635	0.011	1.8	0.056W	9.0W	0.010	1.7	0.015	2.3	0.018	2.9	0.560	0.745	-0.035	-5.9	0.092	14.1
112	99.7	0.530	0.745	0.638	0.014	2.2	0.077W	12.3W	0.020	3.4	0.020	3.1	0.020	3.2	0.550	0.765	-0.045	-7.6	0.112	17.2

NOTE: (a) All deflections shown in Columns 3, 4, 10, 12, 16 and 17 are taken from Table 7.
(b) All deflections shown are in inches.
(c) The average of the mean deflections for the first three runs are considered as the "static deflections" in the east and west girders and their comparisons with the theoretical deflections are as follows:

MEASURED STATIC DEFLECTIONS		THEORETICAL STATIC DEFLECTIONS (Based on gross moment of inertia at center)		DEFLECTION FACTORS (Measured/Theoretical)	
East girder	0.595	East girder	0.544	East girder	1.096
West girder	0.653	West girder	0.564	West girder	1.160
Average	0.624	Average	0.554	Average	1.128
Eccentricity	+4.60 per cent	Eccentricity	+1.60 per cent		

(d) The loaded frequency "n", based on a measured static deflection of 0.624 inch, is 3.59 vibrations per second.
(e) The theoretical dead load deflection, based on the gross moment of inertia at the center, is 0.278 in.

TABLE 28

ANALYSIS OF VERTICAL DEFLECTOMETER READINGS
(Vertical Deflection at Center of Span)
122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)

Run No.	Speed M.P.H.	MEAN DEFLECTIONS							SEMI-AMPLITUDES						MAXIMUM DEFLECTIONS					
		Elec. Instr. East Gir.	Mech. Instr. West Gir.	Aver. East and West	Speed Effect Deflection	Speed Effect Per Cent	Roll Effect Deflection	Roll Effect Per Cent	East Girder Track Effect Deflection	East Girder Track Effect Per Cent	West Girder Track Effect Deflection	West Girder Track Effect Per Cent	Average Both Girders Track Effect Deflection	Average Both Girders Track Effect Per Cent	Elec. Instr. East Gir.	Mech. Instr. West Gir.	East Girder Total Impact Deflection	East Girder Total Impact Per Cent	West Girder Total Impact Deflection	West Girder Total Impact Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
155	4.4	0.630	0.675	0.652	0	0	0	0	0	0	0	0	0	0	0.630	0.675	0	0	0	0
156	9.8	0.635	0.665	0.650	-0.002	-0.3	0.008 E	1.2 E	0	0	0	0	0	0	0.635	0.665	0.005	0.8	-0.010	-1.5
228	10.3	0.570	0.695	0.632	-0.020	-3.1	0.040 W	6.1 W	0	0	0	0	0	0	0.570	0.695	-0.060	-9.5	0.020	3.0
157	12.7	0.620	0.665	0.642	-0.010	1.5	0	0	0	0	0	0	0	0	0.620	0.665	-0.010	-1.6	-0.010	-1.5
158	15.6	0.630	0.685	0.658	0.006	0.9	0.003 W	0.5 W	0.010	1.6	0.010	1.5	0.010	1.5	0.640	0.695	0.010	1.6	0.020	3.0
159	18.5	0.610	0.685	0.648	-0.004	-0.6	0.013 W	2.0 W	0.010	1.6	0.005	0.7	0.008	1.2	0.620	0.690	-0.010	-1.6	0.015	2.2
160	25.0	0.620	0.685	0.652	0	0	0.010 W	1.5 W	0.010	1.6	0	0	0.005	0.8	0.630	0.685	0	0	0.010	1.5
161	28.7	0.640	0.675	0.658	0.006	0.9	0.007 E	1.1 E	0.010	1.6	0.010	1.5	0.010	1.5	0.650	0.685	0.020	3.2	0.010	1.5
165	35.2	0.650	0.675	0.662	0.010	1.5	0.011 E	1.7 E	0.010	1.6	0.010	1.5	0.010	1.5	0.660	0.685	0.030	4.8	0.010	1.5
162	35.7	0.640	0.685	0.662	0.010	1.5	0.001 E	0.2 E	0.010	1.6	0.010	1.5	0.010	1.5	0.650	0.695	0.020	3.2	0.020	3.0
227	39.7	0.595	0.675	0.635	-0.017	-2.6	0.018 W	2.8 W	0.005	0.8	0.020	3.0	0.012	1.8	0.600	0.695	-0.030	-4.8	0.020	3.0
163	39.8	0.640	0.675	0.658	0.006	0.9	0.007 E	1.1 E	0.010	1.6	0.010	1.5	0.010	1.5	0.650	0.685	0.020	3.2	0.010	1.5
164	44.7	0.640	0.680	0.660	0.008	1.2	0.003 E	0.5 E	0.010	1.6	0.015	2.2	0.012	1.8	0.650	0.695	0.020	3.2	0.020	3.0
166	50.1	0.640	0.705	0.672	0.020	3.1	0.009 W	1.4 W	0.010	1.6	0.010	1.5	0.010	1.5	0.650	0.715	0.020	3.2	0.040	5.9
226	51.1	0.580	0.695	0.638	-0.014	-2.1	0.034 W	5.2 W	0.010	1.6	0	0	0.005	0.8	0.590	0.695	-0.040	-6.3	0.020	3.0
178	54.8	0.665	0.700	0.682	0.030	4.6	0.006 E	0.9 E	0.005	0.8	0.005	0.7	0.005	0.8	0.670	0.705	0.040	6.3	0.030	4.4
225	57.0	0.585	0.715	0.650	-0.002	-0.3	0.042 W	6.4 W	0.005	0.8	0.010	1.5	0.008	1.2	0.590	0.725	-0.040	-6.3	0.050	7.4
177	59.8	0.655	0.725	0.690	0.038	5.8	0.010 W	1.5 W	0.005	0.8	0.005	0.7	0.005	0.8	0.660	0.730	0.030	4.8	0.055	8.1
179	60.9	0.645	0.725	0.685	0.033	5.1	0.016 W	2.5 W	0.005	0.8	0.010	1.5	0.008	1.2	0.650	0.735	0.020	3.2	0.060	8.9
176	64.6	0.645	0.745	0.695	0.043	6.6	0.026 W	4.0 W	0.005	0.8	0	0	0.002	0.4	0.650	0.745	0.020	3.2	0.070	10.4
224	69.4	0.530							0.010	1.6					0.540		-0.090	-14.3		
175	71.6	0.655	0.765	0.710	0.058	8.9	0.030 W	4.6 W	0.005	0.8	0	0	0.002	0.4	0.660	0.765	0.030	4.8	0.090	13.3
174	73.0	0.635	0.725	0.680	0.028	4.3	0.021 W	3.2 W	0.005	0.8	0	0	0.002	0.4	0.640	0.725	0.010	1.6	0.050	7.4
223	73.0	0.545	0.735	0.640	-0.012	-1.8	0.073 W	11.2 W	0.005	0.8	0	0	0.002	0.4	0.550	0.735	-0.080	-12.7	0.060	8.9
221	78.7	0.545	0.725	0.635	-0.017	-2.6	0.068 W	10.4 W	0.005	0.8	0	0	0.002	0.4	0.550	0.725	-0.080	-12.7	0.050	7.4
171	79.5	0.635	0.715	0.675	0.023	3.5	0.017 W	2.6 W	0.005	0.8	0.010	1.5	0.008	1.2	0.640	0.725	0.010	1.6	0.050	7.4
222	80.6	0.545	0.715	0.630	-0.022	-3.4	0.063 W	9.7 W	0.005	0.8	0.010	1.5	0.008	1.2	0.550	0.725	-0.080	-12.7	0.050	7.4
167	82.1	0.625	0.735	0.680	0.028	4.3	0.031 W	4.8 W	0.005	0.8	0.010	1.5	0.008	1.2	0.630	0.745	0	0	0.070	10.4
216	83.5	0.595	0.755	0.675	0.023	3.5	0.056 W	8.6 W	0.005	0.8	0	0	0.002	0.4	0.600	0.755	-0.030	-4.8	0.080	11.8
168	84.0	0.615	0.755	0.685	0.033	5.1	0.046 W	7.1 W	0.005	0.8	0.010	1.5	0.008	1.2	0.620	0.765	-0.010	-1.6	0.090	13.3
217	86.0	0.595	0.765	0.680	0.028	4.3	0.061 W	9.4 W	0.005	0.8	0	0	0.002	0.4	0.600	0.765	-0.030	-4.8	0.090	13.3
215	86.9	0.590	0.765	0.678	0.026	4.0	0.063 W	9.7 W	0	0	0.010	1.5	0.005	0.8	0.590	0.775	-0.040	-6.3	0.100	14.8
169	90.4	0.600	0.785	0.692	0.040	6.1	0.069 W	10.6 W	0.010	1.6	0.010	1.5	0.010	1.5	0.610	0.795	-0.020	3.2	0.120	17.8
218	92.9	0.590	0.800	0.695	0.043	6.6	0.081 W	12.4 W	0.010	1.6	0	0	0.005	0.8	0.600	0.800	-0.030	-4.8	0.125	18.5
170	95.9	0.630	0.795	0.712	0.060	9.2	0.059 W	9.1 W	0.010	1.6	0.010	1.5	0.010	1.5	0.640	0.805	0.010	1.6	0.130	19.3
220	97.0	0.540	0.795	0.668	0.016	2.5	0.103 W	15.8 W	0.010	1.6	0.010	1.5	0.010	1.5	0.550	0.805	-0.080	-12.7	0.130	19.3
173	98.5	0.655	0.755	0.705	0.053	8.1	0.025 W	3.8 W	0.005	0.8	0.005	0.7	0.005	0.8	0.660	0.760	0.030	4.8	0.085	12.6
219	100.8	0.585	0.780	0.682	0.030	4.6	0.074 W	11.4 W	0.005	0.8	0.005	0.7	0.005	0.8	0.590	0.785	-0.040	-6.3	0.110	16.3
172	105.0	0.705	0.755	0.730	0.078	12.0	0.001 E	0.2 E	0.005	0.8	0.005	0.7	0.005	0.8	0.710	0.760	0.080	12.7	0.085	12.6

NOTE: (a) All deflections shown in Columns 3, 4, 10, 12, 16 and 17 are taken from Table 8.
(b) All deflections shown are in inches.
(c) The mean deflections for the first run are considered as the "static deflections" in the east and west girders and their comparisons with the theoretical deflections are as follows:

MEASURED STATIC DEFLECTIONS

East Girder	= 0.630
West Girder	= 0.675
Average	= 0.652
Eccentricity	= +3.50 Per Cent

THEORETICAL STATIC DEFLECTIONS
(Based on gross moment of inertia at center)

East Girder	= 0.588
West Girder	= 0.608
Average	= 0.598
Eccentricity	= +1.60 Per Cent

DEFLECTION FACTORS
(Measured/Theoretical)

East Girder	= 1.071
West Girder	= 1.101
Average	= 1.086

(d) The loaded frequency "n", based on a measured static deflection of 0.652 inch, is 3.56 vibrations per second

TABLE 29

ANALYSIS OF VERTICAL DEFLECTOMETER READINGS
(VERTICAL DEFLECTION AT CENTER OF SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS K4-S (STEAM)

Run No.	Speed M.P.H.	Speed R.P.S.	Dimension "X" Feet	Theoretical Loaded Frequency "n" V.P.S.	MEAN DEFLECTIONS: Elec. Instr. East Girder	Mech. Instr. West Girder	Average East and West	Speed Effect Deflection	Speed Effect Per Cent	Roll Effect Deflection	Roll Effect Per Cent	SEMI-AMPLITUDES: East Girder Track and Hammer Blow Effect Deflection	$D_H N^2$	Dynamic Magnifier	West Girder Track and Hammer Blow Effect Deflection	$D_H N^2$	Dynamic Magnifier	Average - Both Girders Track and Hammer Blow Effect Deflection	$D_H N^2$	Dynamic Magnifier	MAXIMUM DEFLECTIONS: Elec. Instr. East Girder	Mech. Instr. West Girder	East Girder Total Impact Deflection	East Girder Total Impact Per Cent	West Girder Total Impact Deflection	West Girder Total Impact Per Cent
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
132	5.2	0.37		3.54	0.621	0.705	0.663	0	0	0	0	0			0			0			0.621	0.705	0	0	0	0
128	18.9	1.34		3.54	0.623	0.703	0.663	0	0	0.002 E	0.3 E	0.020			0.020			0.020			0.643	0.723	0.022	3.5	0.018	2.6
127	26.2	1.89		3.54	0.633	0.693	0.663	0	0	0.012 E	1.8 E	0.020	0.008	2.50	0.020	0.010	2.00	0.020	0.009	2.22	0.653	0.713	0.032	5.2	0.008	1.1
126	30.1	2.13		3.53	0.632	0.712	0.672	0.009	1.4	0.002 E	0.3 E	0.020	0.010	2.00	0.035	0.013	2.70	0.028	0.011	2.54	0.652	0.747	0.031	5.0	0.042	6.0
125	35.4	2.52		3.52	0.627	0.722	0.674	0.011	1.7	0.006 W	0.9 W	0.025	0.014	1.78	0.045	0.018	2.50	0.035	0.016	2.19	0.652	0.767	0.031	5.0	0.062	8.8
124	40.2	2.84			0.600							0.020	0.018	1.11							0.620	0.680	-0.001	-0.2	-0.025	-3.5
130	40.2	2.85		3.51	0.653	0.708	0.681	0.018	2.7	0.017 E	2.6 E	0.035	0.018	1.95	0.040	0.023	1.74	0.038	0.021	1.81	0.688	0.748	0.067	10.8	0.043	6.1
131	41.7	2.96		3.53	0.638	0.703	0.671	0.008	1.2	0.010 E	1.5 E	0.030	0.019	1.54	0.050	0.025	2.00	0.040	0.022	1.82	0.668	0.753	0.047	7.6	0.048	6.8
129	42.6	3.02		3.56	0.631	0.683	0.657	-0.006	-0.9	0.016 E	2.4 E	0.040	0.020	2.00	0.050	0.026	1.92	0.045	0.023	1.96	0.671	0.733	0.050	8.0	0.028	4.0
123	44.2	3.13		3.52	0.647	0.707	0.677	0.014	2.1	0.013 E	2.0 E	0.040	0.022	1.82	0.045	0.027	1.67	0.043	0.025	1.74	0.687	0.752	0.066	10.6	0.047	6.7
214	45.8	3.25		3.51	0.668	0.693	0.681	0.018	2.7	0.032 E	4.8 E	0.045	0.024	1.88	0.070	0.030	2.33	0.058	0.027	2.18	0.713	0.763	0.092	14.8	0.058	8.2
122	52.3	3.70	3.5 S	3.50	0.658	0.708	0.683	0.020	3.0	0.018 E	2.7 E	0.050	0.031	1.62	0.075	0.038	1.97	0.063	0.035	1.83	0.708	0.783	0.087	14.0	0.078	11.1
121	55.5	3.93	6.0 S	3.48	0.664	0.724	0.694	0.031	4.7	0.013 E	2.0 E	0.045	0.034	1.32	0.060	0.043	1.40	0.058	0.039	1.49	0.709	0.784	0.088	14.2	0.079	11.2
208	57.5	4.07	0.8 N	3.42	0.699	0.759	0.729	0.066	9.9	0.016 E	2.4 E	0.070	0.037	1.89	0.090	0.046	1.96	0.080	0.042	1.91	0.739	0.849	0.118	19.0	0.144	20.4
195	59.3	4.21	6.8 S	3.37	0.696	0.831	0.764	0.101	15.2	0.019 W	2.9 W	0.055	0.040	1.28	0.070	0.050	1.40	0.063	0.045	1.41	0.751	0.901	0.130	20.9	0.196	27.0
209	60.0	4.25	4.6 N	3.46	0.677	0.737	0.707	0.044	6.6	0.014 E	2.1 E	0.040	0.040	1.00	0.085	0.051	1.67	0.063	0.046	1.38	0.717	0.822	0.096	15.4	0.117	16.6
196	60.3	4.28	2.8 S		0.689							0.050	0.041	1.22							0.734		0.113	18.2		
119	62.2	4.41	6.9 N	3.50	0.626	0.741	0.684	0.021	3.2	0.014 W	2.1 W	0.050	0.043	1.16	0.070	0.054	1.30	0.060	0.049	1.22	0.676	0.811	0.055	8.9	0.106	15.0
210	63.3	4.49	6.7 N	3.45	0.666	0.761	0.714	0.051	7.7	0.003 W	0.5 W	0.040	0.045	0.89	0.070	0.056	1.25	0.055	0.051	1.08	0.706	0.831	0.085	13.7	0.126	17.9
197	[illegible].9	4.53	4.7 N	3.44	0.667	0.772	0.720	0.057	8.6	0.007 W	1.1 W	0.030	0.046	0.65	0.055	0.057	0.96	0.043	0.052	0.83	0.697	0.827	0.076	12.2	0.122	17.3
211	[illegible].5	4.64	7.9 S	3.46	0.666	0.746	0.706	0.043	6.5	0.005 E	0.8 E	0.040	0.048	0.83	0.070	0.060	1.17	0.055	0.054	1.01	0.706	0.816	0.085	13.7	0.111	15.7
120	67.0	4.75	8.6 S	3.52	0.620	0.735	0.678	0.015	2.3	0.014 W	2.1 W	0.025	0.050	0.50	0.050	0.063	0.79	0.038	0.057	0.67	0.645	0.785	0.024	3.9	0.080	11.3
198	67.7	4.80	8.8 S	3.42	0.665	0.810	0.738	0.075	11.3	0.025 W	3.8 W	0.040	0.051	0.78	0.045	0.064	0.70	0.043	0.058	0.74	0.705	0.855	0.084	13.5	0.150	21.3
212	68.4	4.85	3.7 S	3.47	0.650	0.755	0.703	0.040	6.0	0.008 W	1.2 W	0.035	0.052	0.67	0.060	0.066	0.90	0.048	0.059	0.81	0.685	0.815	0.064	10.3	0.110	15.6
199	69.0	4.89	7.9 S	3.45	0.661	0.766	0.714	0.051	7.7	0.008 W	1.2 W	0.035	0.053	0.66	0.065	0.067	0.97	0.050	0.060	0.83	0.696	0.831	0.075	12.1	0.126	17.9
213	70.6	5.00		3.48	0.629	0.764	0.697	0.034	5.1	0.022 W	3.3 W	0.035	0.056	0.63	0.060	0.070	0.86	0.048	0.063	0.76	0.664	0.824	0.043	6.9	0.119	16.9
118	71.0	5.04	1.3 N	3.50	0.595	0.780	0.688	0.025	3.8	0.048 W	7.2 W	0.040	0.057	0.70	0.055	0.071	0.78	0.048	0.064	0.75	0.635	0.835	0.014	2.2	0.130	18.4
200	72.1	5.12	2.6 N	3.48	0.622	0.772	0.697	0.034	5.1	0.030 W	4.5 W	0.040	0.058	0.69	0.065	0.073	0.89	0.053	0.066	0.80	0.662	0.837	0.041	6.6	0.132	18.7
117	76.3	5.40	4.1 S	3.47	0.619	0.784	0.702	0.039	5.9	0.038 W	5.7 W	0.035	0.065	0.54	0.065	0.082	0.79	0.050	0.074	0.68	0.654	0.849	0.033	5.3	0.144	20.4
201	77.3	5.48	2.5 N	3.45	0.642	0.782	0.712	0.049	7.4	0.025 W	3.8 W	0.045	0.067	0.67	0.060	0.084	0.71	0.053	0.076	0.70	0.687	0.842	0.066	10.6	0.137	19.4
202	79.4	5.64	7.1 N	3.45	0.626	0.796	0.711	0.048	7.3	0.040 W	6.0 W	0.045	0.071	0.63	0.080	0.089	0.90	0.063	0.080	0.79	0.671	0.876	0.050	8.0	0.171	24.2
116	80.2	5.73	6.4 N	3.45	0.639	0.794	0.717	0.054	8.2	0.032 W	4.8 W	0.050	0.073	0.68	0.065	0.092	0.71	0.058	0.083	0.70	0.689	0.859	0.068	10.9	0.154	21.8
203	82.2	5.83	9.8 N	3.48	0.629	0.759	0.694	0.031	4.7	0.022 W	3.3 W	0.065	0.076	0.86	0.110	0.095	1.16	0.088	0.086	1.03	0.694	0.869	0.073	11.8	0.164	23.3
113	84.0	5.95	1.8 S	3.37	0.706	0.831	0.769	0.106	16.0	0.014 W	2.1 W	0.090	0.079	1.14	0.085	0.099	0.86	0.088	0.089	0.99	0.796	0.916	0.175	28.2	0.211	30.0
204	85.0	6.03	5.6 S	3.43	0.675	0.780	0.728	0.065	9.8	0.006 W	0.9 W	0.055	0.081	0.68	0.115	0.102	1.13	0.085	0.092	0.93	0.730	0.895	0.109	17.5	0.190	26.9
114	85.0	6.03	4.5 S	3.37	0.720	0.810	0.765	0.102	15.4	0.004 E	0.6 E	0.090	0.081	1.11	0.105	0.102	1.03	0.098	0.092	1.07	0.810	0.915	0.189	30.4	0.210	29.8
115	87.0	6.17	1.9 S	3.39	0.700	0.805	0.753	0.090	13.6	0.004 W	0.6 W	0.070	0.085	0.82	0.085	0.107	0.79	0.078	0.097	0.81	0.770	0.890	0.149	24.0	0.185	26.2
207	88.0	6.20	0.6 S	3.42	0.711	0.746	0.729	0.066	9.9	0.028 E	4.2 E	0.070	0.087	0.80	0.100	0.109	0.92	0.085	0.098	0.87	0.781	0.846	0.160	25.8	0.141	20.0
206	88.3	6.26	7.7 N	3.44	0.671	0.766	0.719	0.056	8.5	0.002 W	0.3 W	0.045	0.087	0.52	0.090	0.110	0.82	0.068	0.099	0.69	0.716	0.856	0.095	15.3	0.151	21.4
205	89.4	6.34	1.8 N	3.47	0.665	0.735	0.700	0.037	5.6	0.010 E	1.5 E	0.050	0.090	0.55	0.140	0.112	1.25	0.095	0.101	0.94	0.715	0.875	0.094	15.1	0.170	24.1

NOTE: (a) All deflections shown in columns 6, 7, 13, 16, 22, and 23 are taken from Table 9.
(b) All deflections are in inches.
(c) Dimension "X" in column 4 is the distance, either north or south, from the center of the span to the main driver at the time the pins are in position for maximum hammer blow effect on the span. Locomotive headed south.
(d) The mean deflections for the first run are considered as the "static deflections" in the east and west girders and their comparisons with the theoretical deflections are as follows:

Measured Static Deflections

East Girder	=	0.621
West Girder	=	0.705
Average	=	0.663
Eccentricity	=	+6.30 per cent

Theoretical Static Deflections
(Based on gross moment of inertia at center)

East Girder	=	0.620
West Girder	=	0.642
Average	=	0.631
Eccentricity	=	+1.60 per cent

Deflection Factors
(Measured/Theoretical)

East Girder	=	1.001
West Girder	=	1.101
Average	=	1.051

(e) The "hammer blow deflections" at one revolution per second are as follows:

East Girder	=	0.00222	x	1.001	=	0.00223
West Girder	=	0.00254	x	1.101	=	0.00280
Average					=	0.00252

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on this span, is 38.80, or, the increase due to speed is found to be 14.8 percent. From the measured stresses (see Table 11, column 7) the increase is found to be 19.8 percent.

In the upper portion of Tables 19 to 22, the ordinates of the theoretical stress influence curve, and the actual measured ordinates for some one run have been plotted. The increase in area is apparent and it may be interesting to note that actually there is not a measurable stress until the front axle of the locomotive has traveled an appreciable distance along the span. This distance simply represents a lapse in time, and seems to vary from 0.042 to 0.077 sec. If we consider for a moment that these measured ordinates

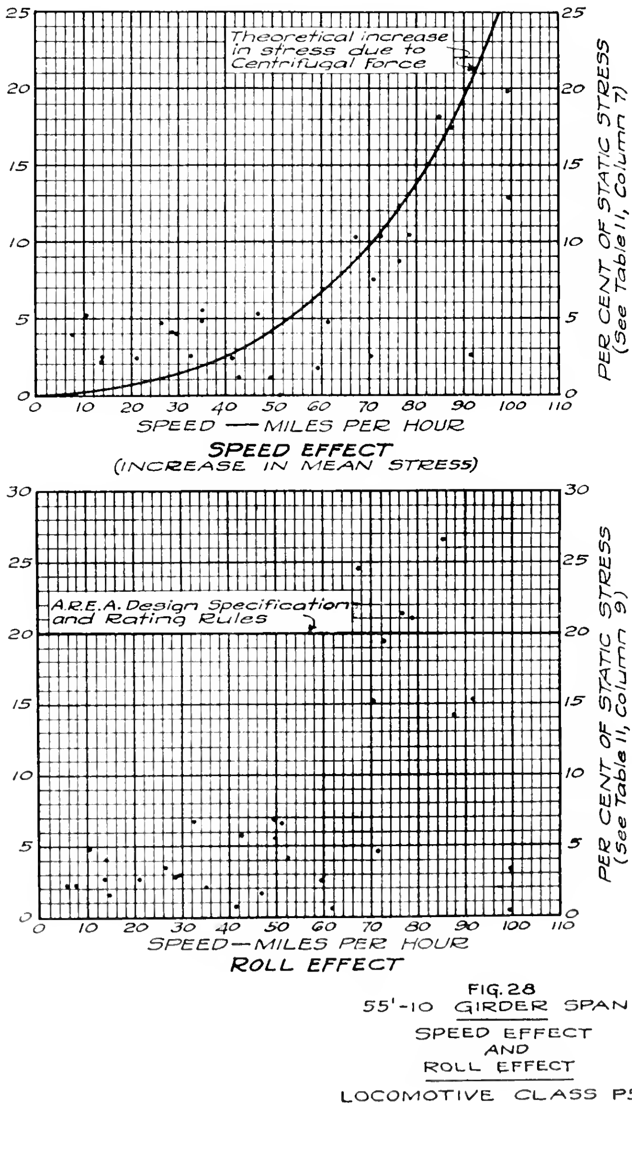


FIG. 28
55'-10 GIRDER SPAN
SPEED EFFECT AND ROLL EFFECT
LOCOMOTIVE CLASS P5-A

represent deflections at the center instead of stresses, it will perhaps be better understood as something to be expected, as it would require a force approaching infinity in magnitude, to deflect the span in zero time.

Roll Effect

As the springborne weight of the locomotive, in motion, oscillates about a horizontal axis, it has the effect of increasing the pressure on one rail and decreasing it on the other rail a like amount. This rolling action is probably set up, not only by track

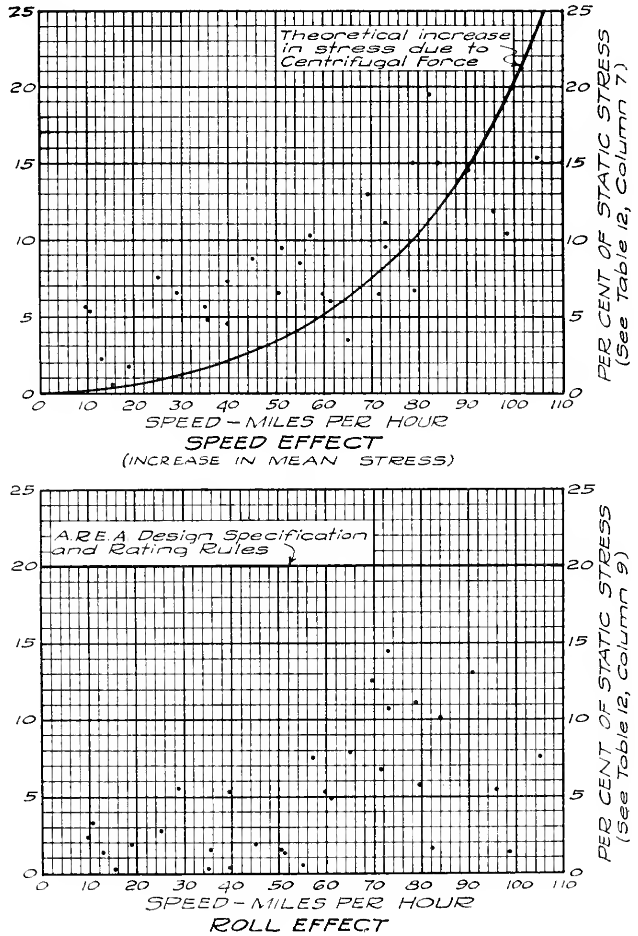


FIG. 29
55'-10 GIRDER SPAN
SPEED EFFECT
AND
ROLL EFFECT
LOCOMOTIVE CLASS GG-1

inequalities, but also by the locomotive weaving or nosing from side to side. The period of this roll is presumably sinusoidal in time, but the spans tested were too short to obtain any idea as to its frequency from the stress influence curves.

When the track is centrally located with respect to the span, the magnitude of the increase of pressure on one rail can be found by subtracting average stress or deflection of both girders from the maximum stress or deflection found in either girder. It has been pointed out however that the track, on both spans, was somewhat off center, so this eccentricity must be taken into account in arriving at the actual roll effect.

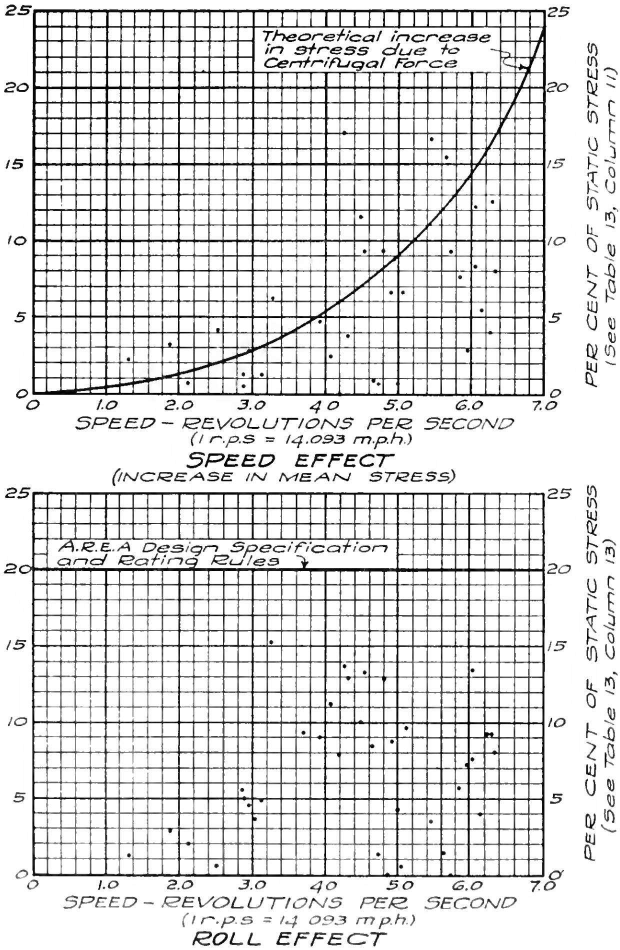


FIG. 30
55'-10 GIRDER SPAN
SPEED EFFECT
AND
ROLL EFFECT
LOCOMOTIVE CLASS K4-S

At the bottom of Table 11, the average static or crawl stress is given as 7.28 kips per sq. in. in the east girder and 7.86 in the west girder, with an average of 7.57. The stress in the west girder is 0.29 kips per sq. in. greater than the average, which indicates an eccentricity in static loading of 3.8 percent. For run 244 at a speed of 85.4 m.p.h. in this same table, we find the stresses to be 6.66 in the east girder and 11.23 in the west, with an average of 8.94. To eliminate the influence of eccentricity, the average stress of 8.94 must be increased by 3.8 percent which would give a stress of 9.22 in the west girder if there were no roll. The stress due to roll is then the difference between 9.22

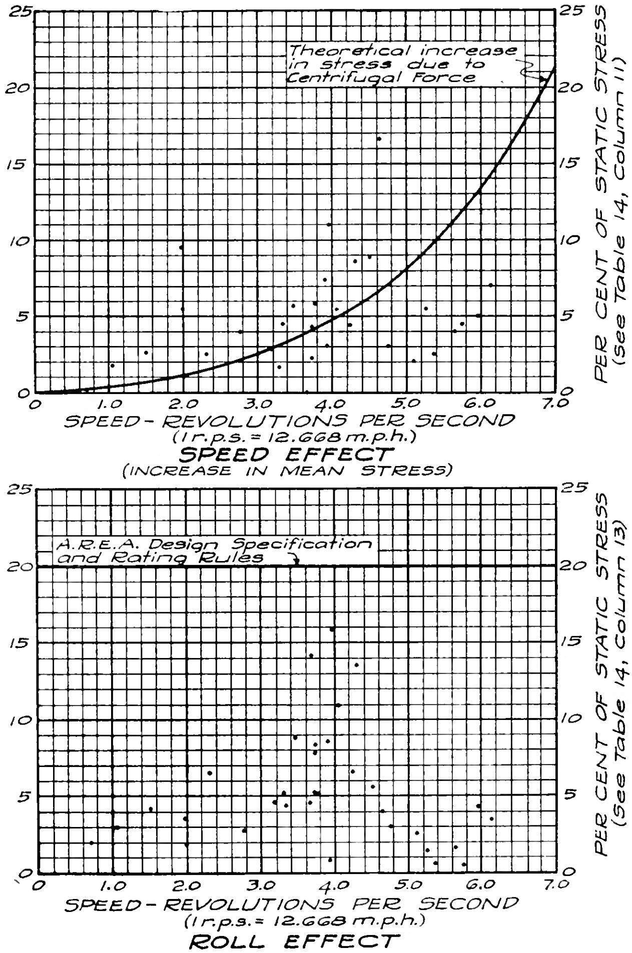


FIG. 31
55'-10 GIRDER SPAN
SPEED EFFECT
AND
ROLL EFFECT
LOCOMOTIVE CLASS M1-A

and the recorded stress of 11.23 or 2.01 kips per sq. in. which is 26.6 percent of the average static stress.

The effect of roll, shown in percent of static load, is given for both spans as determined from stresses in Tables 11 to 18, inclusive, and for the 122-ft. span, as determined by deflections, in Tables 27 to 30. Roll to the west or east is marked "W" or "E" as the case may be. The preponderance of westerly roll was probably due to some track condition or the westerly track eccentricity or both.

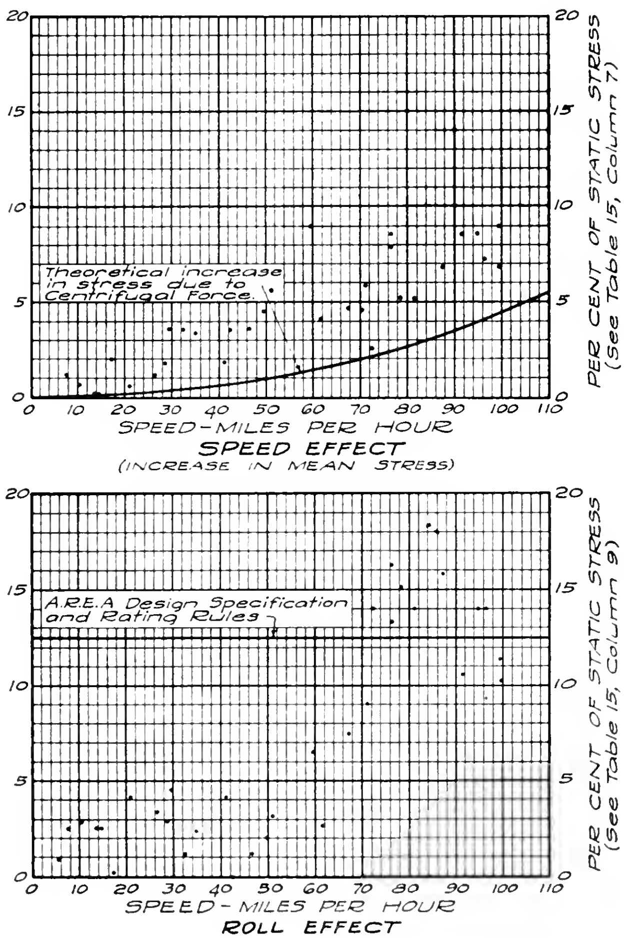


FIG. 32
122'-0 GIRDER SPAN
SPEED EFFECT
AND
ROLL EFFECT
LOCOMOTIVE CLASS P5-A

This roll, in percentage, has been plotted in the lower diagrams of Figures 28 to 35. It will be noted that, with the exception of the P5–A electric locomotive on both spans, the values are well below those provided for in both the AREA design specification and AREA rating rules for steel bridges. It is interesting to note that for all locomotives on both spans, the maximum roll does not occur at the maximum speed, but at speeds from 70 to 80 m.p.h. or even lower with the class M1–A engine, and at speeds of less than 40 or 50 m.p.h. it is not an important factor. It should be remembered that the girders of the 55-ft.-10 in. span are only 5 ft. apart and this accounts for the much greater effect of roll in this span than in the 122-ft. span, of which the girders are 8 ft. apart.

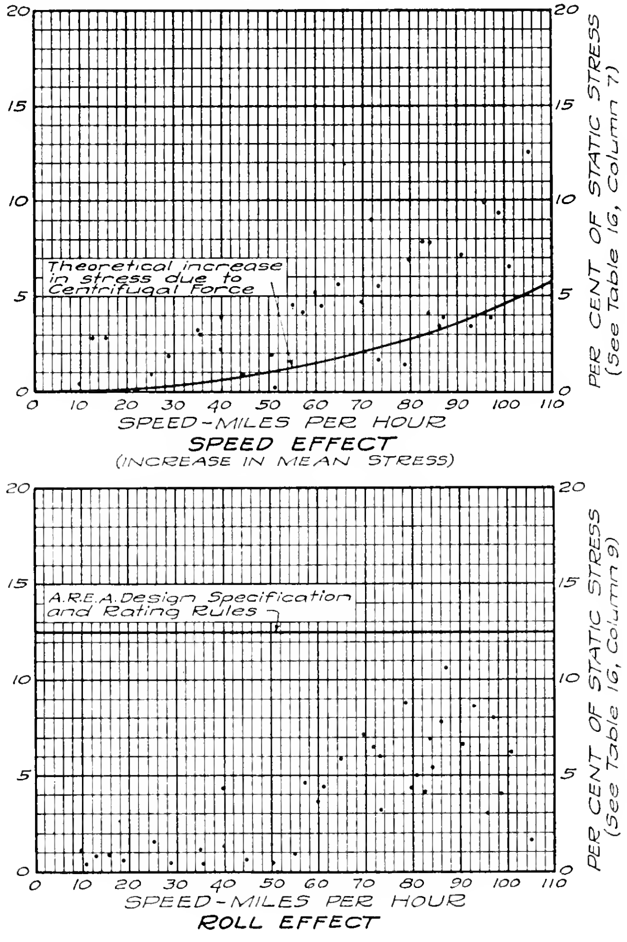


FIG. 33
122'-0 GIRDER SPAN
SPEED EFFECT
AND
ROLL EFFECT
LOCOMOTIVE CLASS GG-1

Track Effect—Electric Locomotives

In impact tests made heretofore, steam locomotives with unbalanced weights in the driving wheels have been used and it has been impossible to apportion the total dynamic effect of such engines between the disturbing force set up by the revolving overbalance in the counterweight of the drivers and that caused by track or wheel irregularities. Here, however, the use of electric locomotives, with no unbalanced weights, afforded an opportunity to determine more definitely the effect of track irregularities such as joints and uneven surfaces and wheel irregularities which might be due to flat spots, eccentric mount-

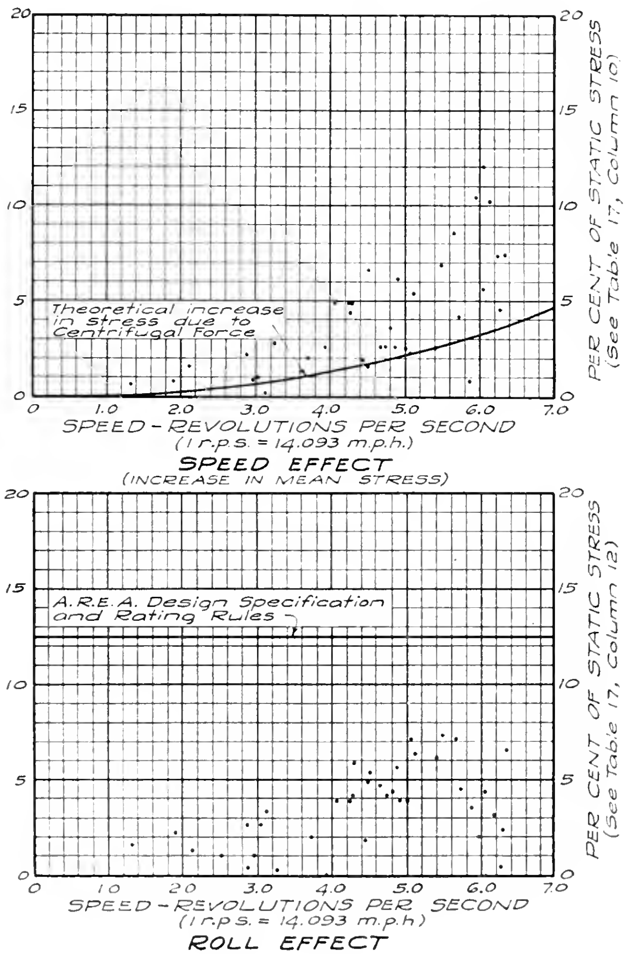


FIG. 34
122'-0 GIRDER SPAN
SPEED EFFECT
AND
ROLL EFFECT
LOCOMOTIVE CLASS K4-S

ing or an out-of-round perimeter. Perfect wheels on a perfect track surface could be considered as smoothly rolling loads, and yet could set up free oscillations in the span if the wheel spacing and speed were such that the time of application of the successive wheel loads synchronized with the natural period of such free oscillations.

Where the axle spacing is not uniform, as was the case with the electric locomotives used in these tests, the time of the application of the successive axle loads would vary, getting out of step with the free vibrations and causing the oscillations to decrease in magnitude. The oscillograph records, a sample of which is shown in Figures 25 and 27,

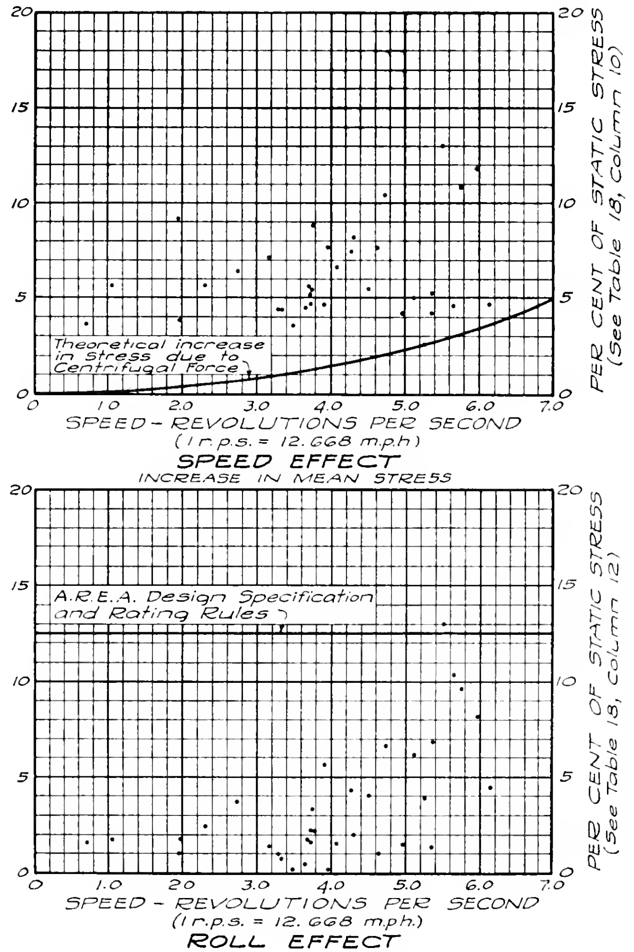


FIG. 35
122'-0 GIRDER SPAN
SPEED EFFECT AND ROLL EFFECT
LOCOMOTIVE CLASS M1-A

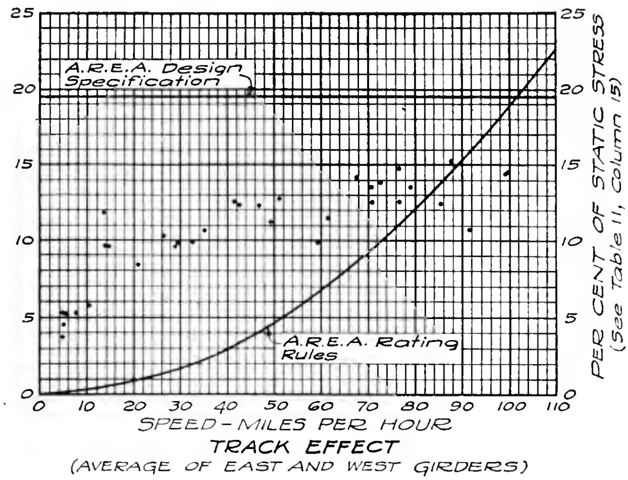


FIG. 36
55'-10 GIRDER SPAN
TRACK EFFECT
LOCOMOTIVE CLASS P5-A

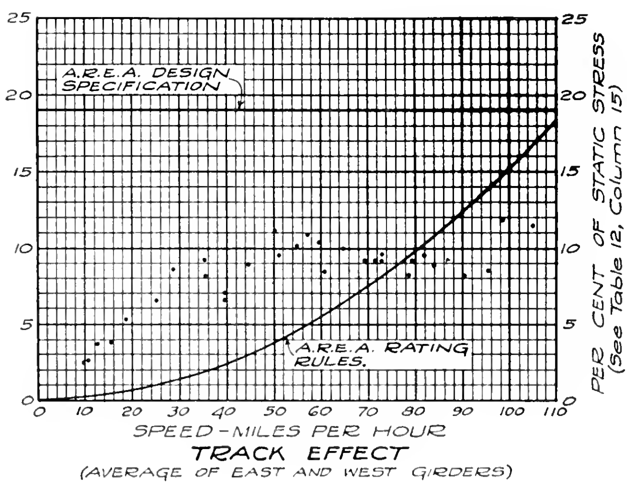


FIG. 37
55'-10 GIRDER SPAN
TRACK EFFECT
LOCOMOTIVE CLASS GG-1

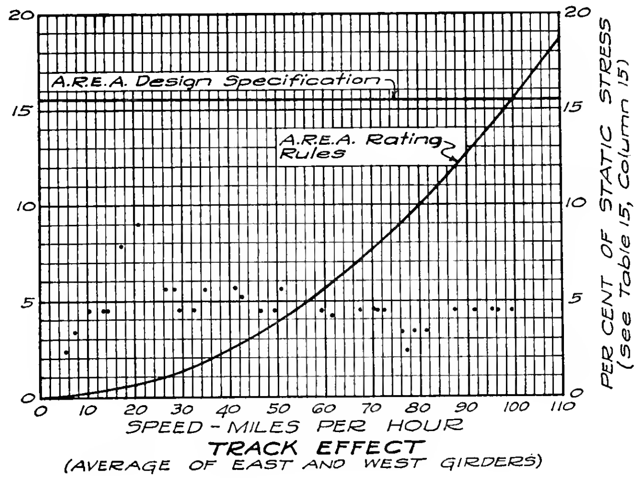


FIG. 38
122'-0 GIRDER SPAN
TRACK EFFECT
LOCOMOTIVE CLASS P5-A

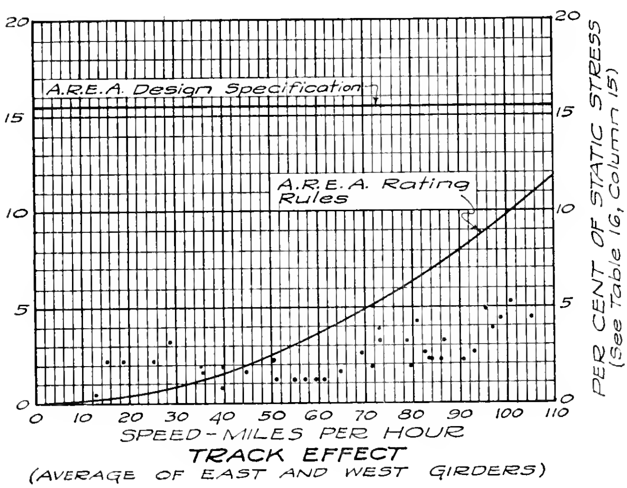


FIG. 39
122'-0 GIRDER SPAN
TRACK EFFECT
LOCOMOTIVE CLASS GG-1

could be interpreted as indicating this very condition, but on the other hand, the departure from the smooth mean stress curve might be considered as due to the successive wheels passing over a joint or irregularity in rail surface due to uneven tie support. Regardless of the cause, these electric locomotives produced dynamic forces, and until more is known about them, they must be ascribed in this report to a track or wheel condition or both and given the term "track effect".

This track effect, both in magnitude of stress and percentage of the mean static stress is given in columns 14 and 15 of Tables 11 and 12 for the 55-ft. 10-in. span, and in Tables 15 and 16 for the 122-ft. span. This same information, as obtained from deflections, is given for the east girder of the short span in Tables 23 and 24, and for both girders of the long span in Tables 27 and 28.

The various values of this track effect, in percentage of the mean static stress as found from the tests, have been plotted in Figures 36 to 39. It will be seen that the measured values are considerably lower than those provided for in the AREA design specification, but at lower speeds exceed the amount provided for in the AREA rating rules. There seems to be but a very small increase in the 55-ft. 10-in. span after a speed of 50 or 60 m.p.h. is attained, and with the P5–A locomotive on the 122-ft. span, the maximum effect occurred at a speed of about 20 m.p.h.

As was to be expected, the effect was greater on the short span, amounting to from 12 to 15 percent, while on the 122-ft. girder it was slightly more than 5 percent for the GG–1 locomotive and 9 percent for the P5–A. It is hoped that at some future time tests can be made with similar locomotives on spans on which the rail is continuous or in which the joints are welded, to determine more conclusively whether these oscillations are natural vibrations set up by the rolling load or are simply an increase in stress due to the track condition.

Combined Track and Hammer Blow Effect—Steam Locomotives

An important source of vertical oscillations in a railroad bridge is the periodic disturbing force of the counterweights of the steam locomotive. This disturbing force, or hammer blow, is due to the centrifugal force of the unbalanced weights on the revolving driving wheels. In these tests, as well as in the impact tests reported in the AREA Proceedings for 1936, Vol. 37, the recorded dynamic effects are due to both track effect and hammer blow effect. It is quite possible that in some cases the condition of the track would tend to counteract the oscillations due to the hammer blow. On the other hand, the oscillations due to the track conditions might be additive to the oscillations caused by the hammer blow. Since for these tests, there is no way to determine the separate effects, the only alternative is to report their combined effect.

The combined track and hammer blow stresses and the dynamic magnifiers for the east girder, west girder and average of both girders are shown under the heading of Semi-Amplitudes in Tables 13, 14, 17 and 18 for the two steam locomotives on both the 55-ft. 10-in. girder span and the 122-ft. girder span. The deflections and dynamic magnifiers for the east girder of the 55-ft. 10-in. span are shown for the electrical deflectometer, the mechanical deflectometer and the average of the two instruments in Tables 25 and 26. The deflections and dynamic magnifiers for the east girder, west girder, and average of both girders are shown in Tables 29 and 30 for the 122-ft. span.

The theory of vibrations as pertaining to impact in railway bridges has been fully discussed in the AREA Proceedings for 1936, Vol. 37, page 761, and this theory has been followed in determining the dynamic magnifiers for the steam locomotives on these two test spans. The method used in determining the dynamic magnifiers will now be explained, using the steam locomotive Class K4–S on the 55-ft. 10-in. span as a typical example. According to Table 13, columns 14 to 22, inclusive, the semi-amplitude stress for run 205 at a speed of 89.4 m.p.h. is 2.87 kips per sq. in. for the west girder; see column 17. The values of $D_H N^2$ in column 18 are the stress semi-amplitudes due to the hammer blow forces when considered as acting statically, that is without magnification, on the span in the position for maximum moment. The theoretical hammer blow stress at one revolution per second in the west girder is 0.055 kips per sq. in. and by correcting this theoretical stress by the stress factor of 0.979, as found in note (d) at the bottom of Table 14, the actual hammer blow stress at one r.p.s. is 0.054 as shown in note (e), Table 14. For run 205, the speed of the locomotive drivers "N" was 6.33 r.p.s. The value of $D_H N^2$ for this run therefore becomes equal to $0.054 \times 6.33^2 = 2.16$ kips per sq. in. The dynamic magnifier, or the ratio of the measured semi-amplitudes to the stress in the span due to the hammer blow when considered as acting statically at the center, is then equal to $2.87 \div 2.16 = 1.33$.

It should be pointed out that the static or unmagnified hammer blow stresses and deflections, or $D_H N^2$, are computed for the hammer blow as found by the dynamic method of analysis, whereas the hammer blow deflections as reported in the impact tests in the AREA Proceedings, Vol. 37, are based upon the static method of analysis. The difference in the hammer blow stresses or deflections resulting from the two methods of computing the hammer blow, as shown in Figures 18 and 19, is very small for these two locomotives. Since certain refinements had been made in the dynamic method of analysis, it was felt that the hammer blow as computed by the dynamic method of analysis should be used in analyzing these data as well as all future data.

The average semi-amplitudes and dynamic magnifiers, as found for the two locomotives on each span, have been plotted and are shown in Figures 40 to 43. The theoretical values which might be expected and which are based on damping factors as recommended in the AREA Rating Rules for Steel Bridges, are expressed by the curves. It will be seen that for the 55-ft. 10-in. span the actual values, in the range of critical or synchronous speed, are well below the theoretical. At other speeds, while the actual values somewhat exceed the theoretical values, the difference is not serious and it must be remembered that some portion of these semi-amplitudes represent track effect.

For the 122-ft. span, the measured values, are well below the theoretical values. It is quite evident that the damping qualities of the span were greater than that assumed in the rating rules for a span of similar length. It would also seem that locomotive spring friction had been overcome, and that additional damping was contributed from this action. There is also shown a theoretical value of the oscillations and magnifiers, based on the assumption that spring damping was present, and the agreement is about as close as can be expected, in view of the large number of unknown factors entering into the problem.

Total Impacts

The total impact stresses and percentages shown under the heading of "Maximum Stresses" in the Tables 11 to 18, inclusive, and the total impact deflections and percentages in the Tables 23 to 30, inclusive, are the maximum increases in stresses or deflections, for that particular run, over the stresses or deflections obtained at a speed of approximately 5 m.p.h. or the measured static stresses or deflections. These total impacts as given are the combination of (1) speed effect, (2) roll effect, (3) track effect for the electric locomotives and (4) track and hammer blow effect for the steam locomotives, as found for that particular run, although it would be only by chance that the maximum for all effects would occur simultaneously.

The total maximum impacts, in percentage of the crawl stress, for the four locomotives on the 55-ft. 10-in. span have been plotted in Figures 44 to 47 and in Figures 48 to 51 on the 122-ft. span. These diagrams show the amount of impact fixed by the AREA design specification and the AREA rating rules for steel bridges for the particular locomotives and spans used in these tests.

It will be seen that for the P5–A locomotive on the short span, Fig. 44, both the design and rating impacts are exceeded, and with this same locomotive on the long span, the impact percentages as found are below those provided for in the design specifications, but exceed, by a small amount, the rating impacts as shown in Fig. 48. The GG–1

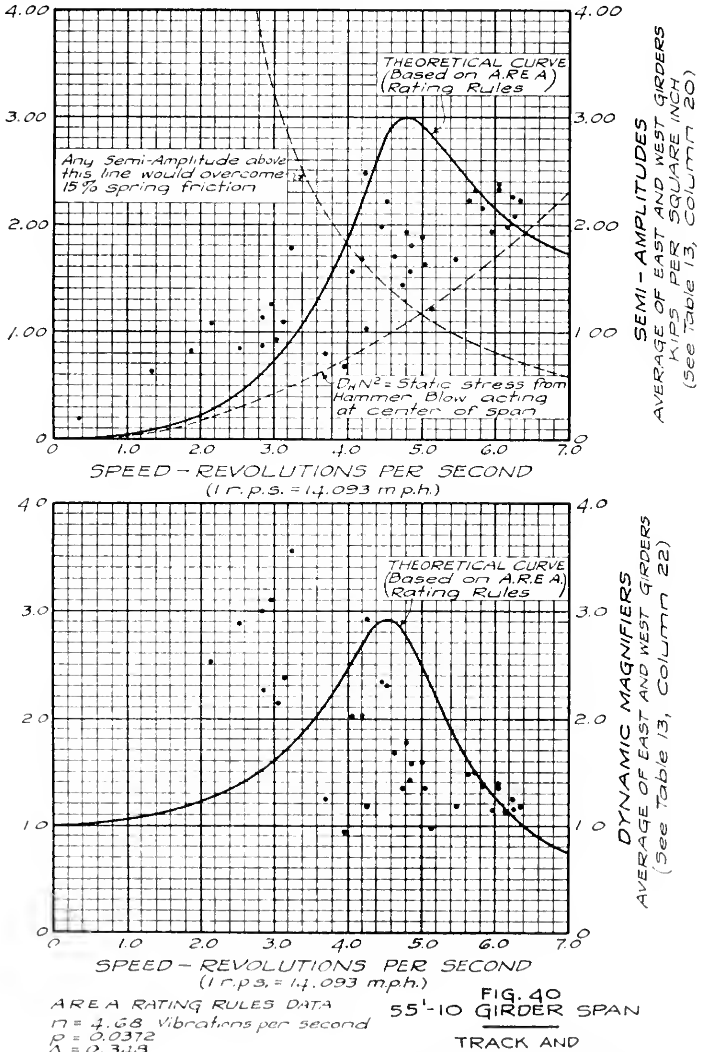


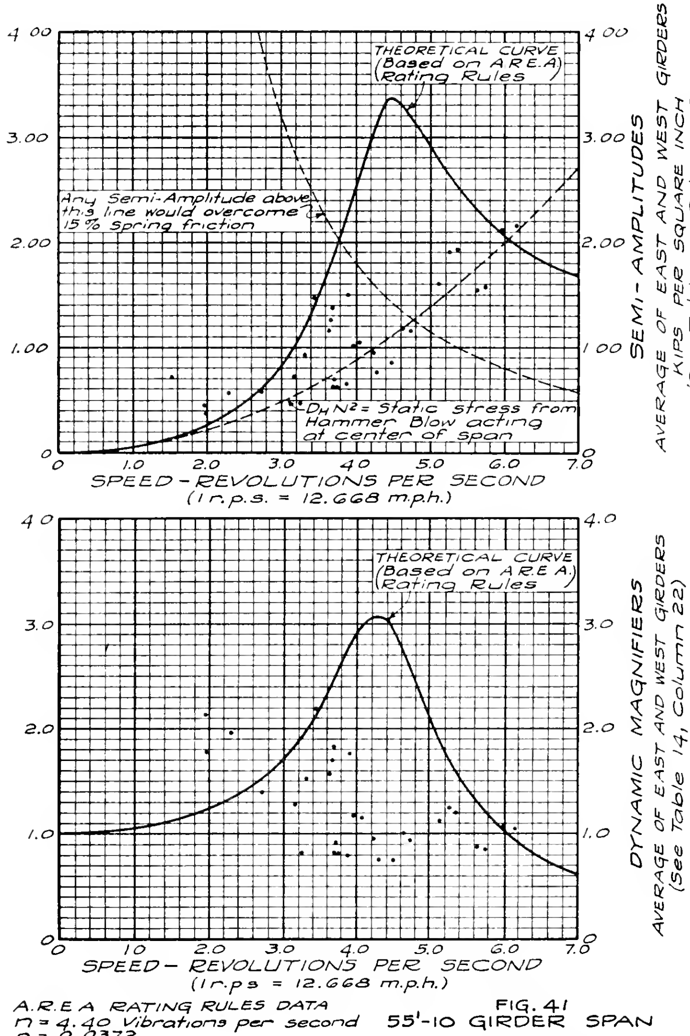
FIG. 40
55'-10 GIRDER SPAN

TRACK AND HAMMER BLOW EFFECT

LOCOMOTIVE CLASS K4-S

electric locomotive produced impacts on the short span well below the design allowances but are somewhat higher than those fixed by the rating rules, as shown in Fig. 45, while on the long span the impacts as measured were well within the requirements fixed by either design or rating rules; see Fig. 49. The total impact produced by the steam locomotives on both spans was less than that called for by either the design or rating rules (Figs. 46, 47, 50 and 51).

The excess in any case can be ascribed to the speed effect which is not now provided for in the specifications for design or the rating rules. It will also be found that,



A.R.E.A RATING RULES DATA
n = 4.40 Vibrations per second
ρ = 0.0372
Δ = 0.327

FIG. 41
55'-10 GIRDER SPAN

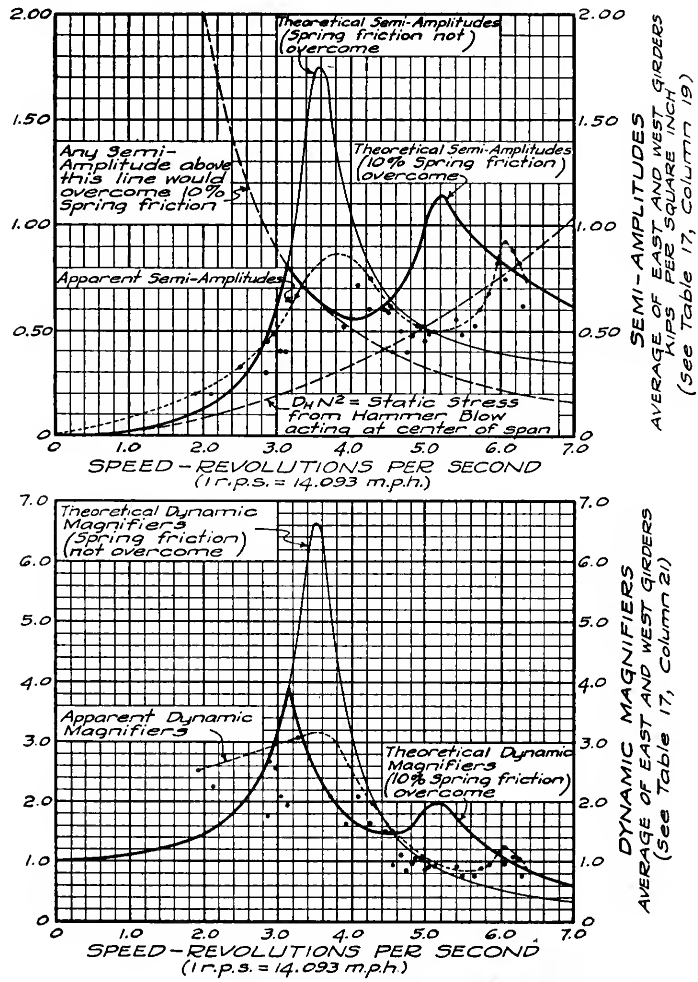
TRACK AND HAMMER BLOW EFFECTS

LOCOMOTIVE CLASS M1-A

in most instances, the excess occurred in the west girder, which, as has been pointed out, was more heavily loaded due to track eccentricity, and this would tend to increase the roll in that direction and consequently increase the total impact in that girder.

Lateral Forces

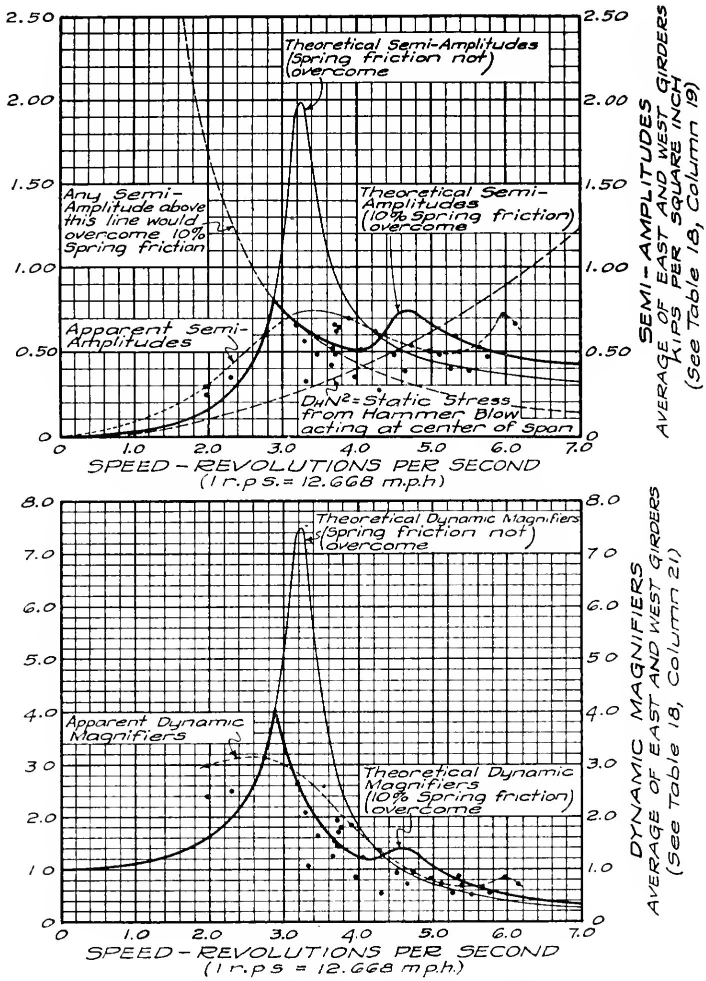
Little has been known as to the magnitude of the lateral forces acting on bridge spans but in these tests, lateral deflections were measured from which it was hoped that some idea as to such forces might be obtained.



A.R.E.A. RATING RULES DATA
n = 3.54 Vib. per Sec.
n_1 = 4.32 Vib. per Sec.
f = 5.10 Vib. per Sec.
p = 0.0211

FIG. 42
122'-0 GIRDER SPAN
TRACK AND
HAMMER BLOW EFFECTS
LOCOMOTIVE CLASS K4-S

These deflections, as measured at the bottom flange, are given in Tables 31 to 38. While the deflections are generally found to increase with speed up to a certain point, the maximum does not occur at the highest speed, and even at low speeds they are in some instances quite high. Neither does the position of the locomotive on the span, at the time of maximum deflection, seem to be a controlling factor as shown by the distances "Z" in these tables. *(Text continued on page 482)*



A.R.E.A RATING RULES DATA

n = 3.23 Vib. per sec
n_1 = 3.72 Vib. per sec
f = 4.51 Vib. per sec
p = 0.0211

FIG 43
122'-0 GIRDER SPAN

TRACK AND HAMMER BLOW EFFECT

LOCOMOTIVE CLASS M1-A

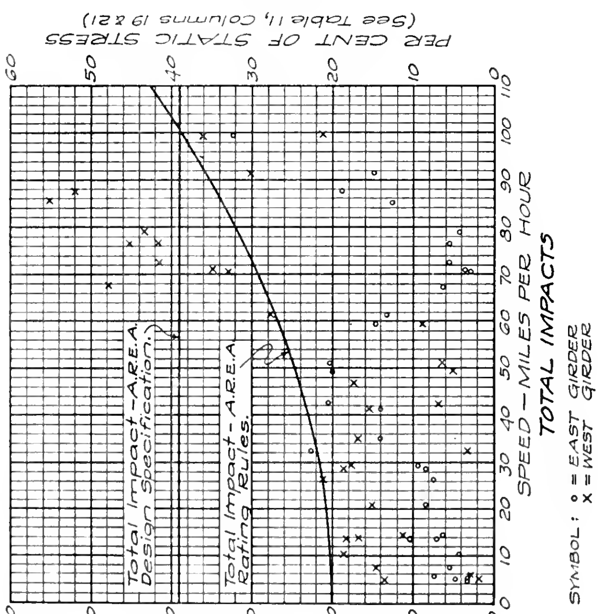


FIG. 44
55'-10 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS
WITH
DESIGN AND RATING RULES IMPACT
LOCOMOTIVE CLASS P5-A

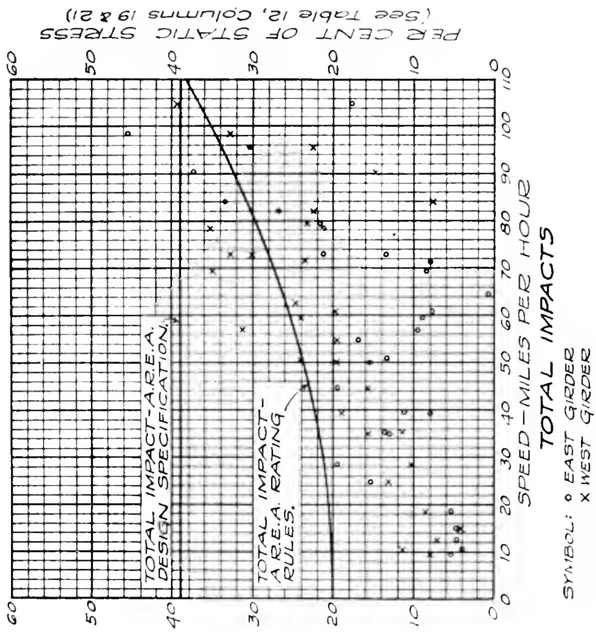


FIG. 45
55'-10 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS
WITH
DESIGN AND RATING RULES IMPACTS
LOCOMOTIVE CLASS GG-1

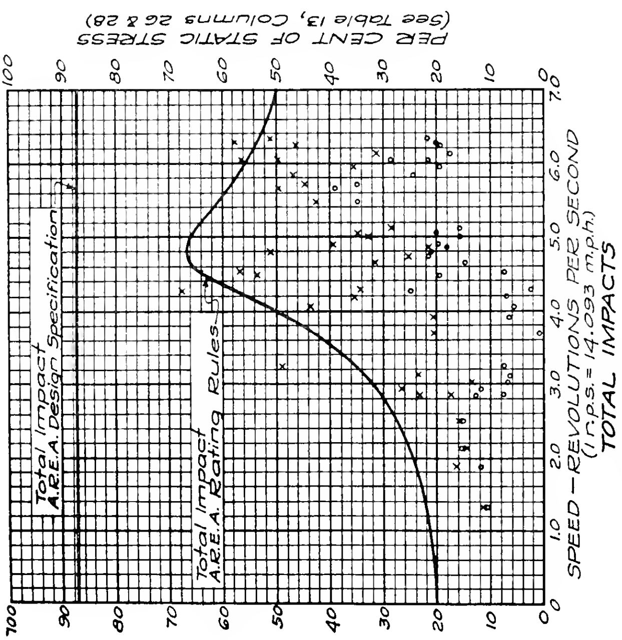


FIG. 46
55'-10 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS
WITH
DESIGN AND RATING RULES IMPACTS
LOCOMOTIVE CLASS K4-S

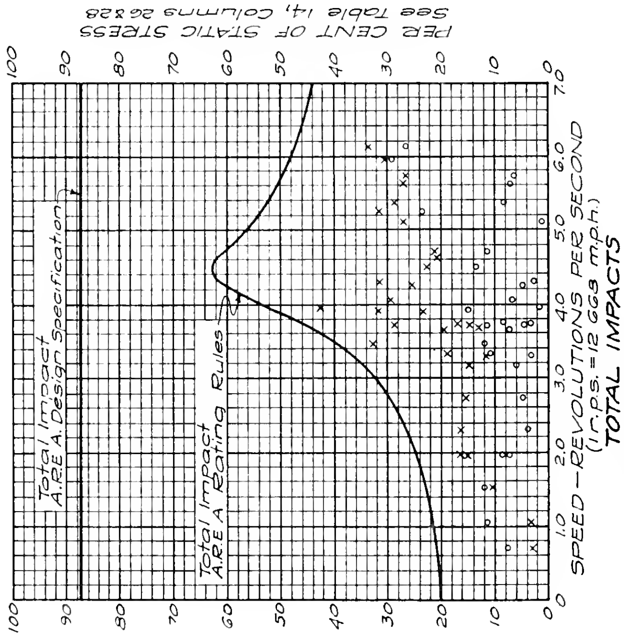


FIG. 47
55'-10 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS
WITH
DESIGN AND RATING RULES IMPACTS
LOCOMOTIVE CLASS M1-A

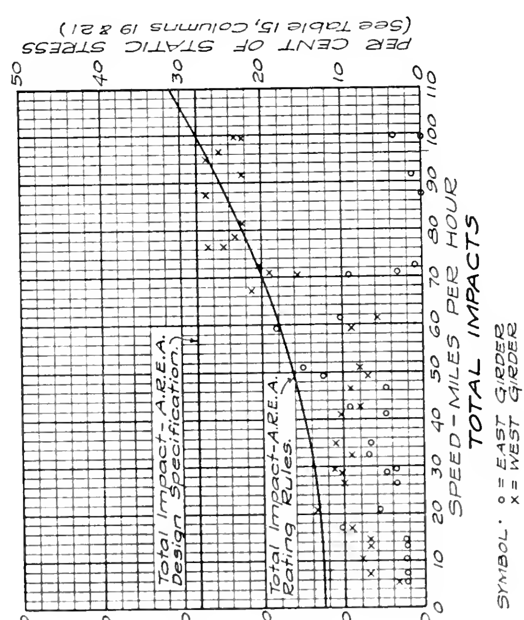


FIG. 48
122'-0 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS WITH DESIGN AND RATING RULES IMPACTS
LOCOMOTIVE CLASS P5-A

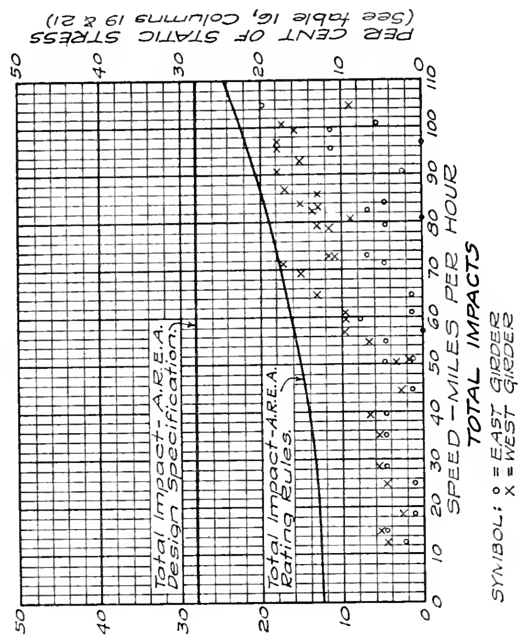


FIG. 49
122'-0 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS WITH DESIGN AND RATING RULES IMPACTS
LOCOMOTIVE CLASS GG-1

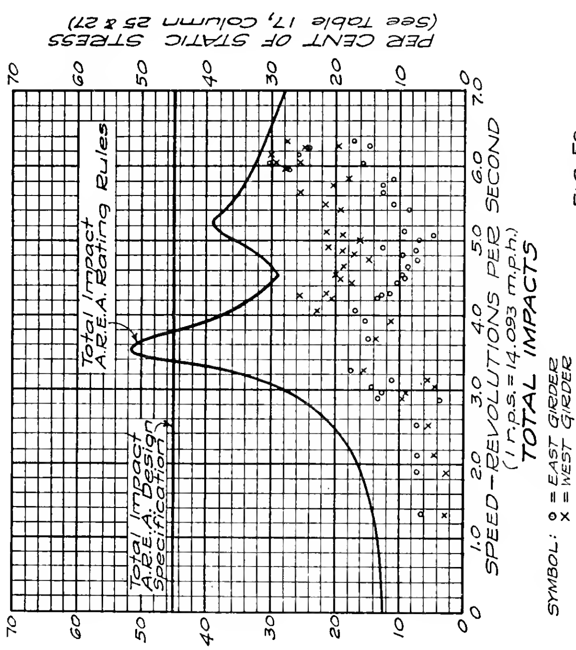


FIG. 50
122'-0 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS WITH DESIGN AND RATING RULES IMPACTS
LOCOMOTIVE CLASS K4-S

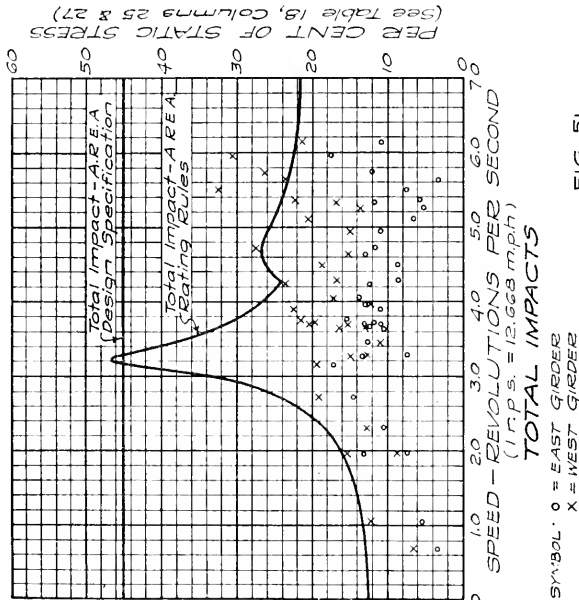
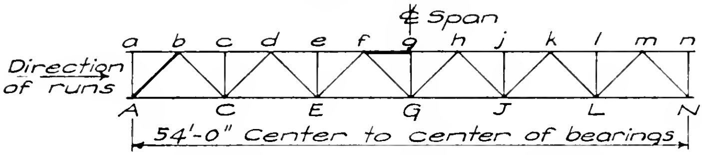


FIG. 51
122'-0 GIRDER SPAN
COMPARISON OF ACTUAL IMPACTS WITH DESIGN AND RATING RULES IMPACTS
LOCOMOTIVE CLASS M1-A

TABLE 31

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)



PLAN OF LATERAL BRACING

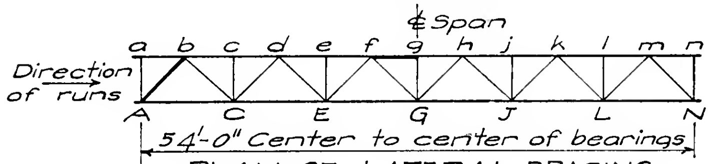
Run No.	Speed M.P.H.	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections: Single Load At "G"	Equal Loads At "E, G & J"	Equal Loads At "C, E, G, J & L"	Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads: Single Load At "G" A-b	Single Load At "G" f-g	Equal Loads At "E, G & J" A-b	Equal Loads At "E, G & J" f-g	Equal Loads At "C, E, G, J & L" A-b	Equal Loads At "C, E, G, J & L" f-g
Col.1	2	3	4	5	6	7	8	9	10	11	12	13
100	4.3	0.02	-9.0	3.20	1.30	1.00	0.72	0.09	0.88	0.08	1.10	0.08
229	4.6	0.03	+7.0	4.80	2.00	1.50	1.10	0.14	1.35	0.13	1.70	0.14
101	4.9	0.01		1.60	0.67	0.50	0.36	0.05	0.44	0.04	0.56	0.04
102	5.6	0.02		3.20	1.30	1.00	0.72	0.09	0.88	0.08	1.10	0.08
230	7.5	0.04	+14.0	6.30	2.70	2.00	1.40	0.18	1.80	0.18	2.20	0.17
232	10.2	0.08	+7.0	13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
231	13.4	0.07	+29.0	11.00	4.70	3.50	2.50	0.31	3.20	0.31	3.90	0.30
233	13.8	0.08	+13.0	13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
253	14.2	0.11		17.00	7.30	5.50	3.90	0.48	4.90	0.48	6.20	0.46
234	20.8	0.07	+2.0	11.00	4.70	3.50	2.50	0.31	3.20	0.31	3.90	0.30
235	26.1	0.09	+2.0	14.00	6.00	4.50	3.20	0.39	4.10	0.39	5.00	0.38
236	28.7	0.12	+2.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
237	29.3	0.10		16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
104	32.3	0.08	+11.0	13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
252	34.9	0.09		14.00	6.00	4.50	3.20	0.39	4.10	0.39	5.00	0.38
251	41.3	0.10		16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
105	42.3	0.08	+43.0	13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
238	46.5	0.10		16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
107	49.5	0.09	+48.0	14.00	6.00	4.50	3.20	0.39	4.10	0.39	5.00	0.38
106	51.1	0.09	+48.0	14.00	6.00	4.50	3.20	0.39	4.10	0.39	5.00	0.38
108	59.5	0.12	+10.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
239	61.5	0.08		13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
246	67.6	0.12	-21.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
109	70.4	0.16		25.00	11.00	8.00	5.70	0.70	7.40	0.72	9.00	0.68
240	71.0	0.12	-22.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
241	72.4	0.13	-23.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
243	76.5	0.11	-21.0	17.00	7.30	5.50	3.90	0.48	4.90	0.48	6.20	0.46
249	76.5	0.12		19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
242	78.8	0.11	-22.0	17.00	7.30	5.50	3.90	0.48	4.90	0.48	6.20	0.46
244	85.4	0.07	-23.0	11.00	4.70	3.50	2.50	0.31	3.20	0.31	3.90	0.30
245	87.8	0.10		16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
111	91.8	0.14	-23.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
248	99.5	0.10	-20.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
112	99.7	0.13	+34.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked "-" indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked "+" indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

TABLE 32

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)



PLAN OF LATERAL BRACING

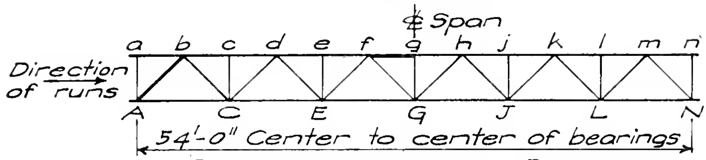
Run No.	Speed M.P.H.	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections: Single Load At "G"	Equal Loads At "E, G & J"	Equal Loads At "C, E, G, J & L"	Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads: Single Load At "G" A-b	Single Load At "G" f-g	Equal Loads At "E, G & J" A-b	Equal Loads At "E, G & J" f-g	Equal Loads At "C, E, G, J & L" A-b	Equal Loads At "C, E, G, J & L" f-g
Col.1	2	3	4	5	6	7	8	9	10	11	12	13
155	4.4	0.02		3.20	1.30	1.00	0.72	0.09	0.88	0.08	1.10	0.08
156	9.8	0.01		1.60	0.67	0.50	0.36	0.04	0.44	0.04	0.56	0.04
228	10.3	0.02		3.20	1.30	1.00	0.72	0.09	0.88	0.08	1.10	0.08
157	12.7	0.02		3.20	1.30	1.00	0.72	0.09	0.88	0.08	1.10	0.08
158	15.6	0.03	+21.0	4.80	2.00	1.50	1.10	0.14	1.40	0.13	1.70	0.13
159	18.5	0.02		3.20	1.30	1.00	0.72	0.09	0.88	0.08	1.10	0.08
160	25.0	0.02		3.20	1.30	1.00	0.72	0.09	0.88	0.08	1.10	0.08
161	28.7	0.03	+27.0	4.80	2.00	1.50	1.10	0.14	1.40	0.13	1.70	0.13
165	35.2	0.03	+33.0	4.80	2.00	1.50	1.10	0.14	1.40	0.13	1.70	0.13
162	35.7	0.04	+27.0	6.30	2.70	2.00	1.40	0.18	1.80	0.18	2.20	0.17
227	39.7	0.05	- 7.0	7.90	3.30	2.50	1.80	0.22	2.20	0.22	2.80	0.21
163	39.8	0.03	+ 9.0	4.80	2.00	1.50	1.10	0.14	1.40	0.13	1.70	0.13
164	44.7	0.04	+57.0	6.30	2.70	2.00	1.40	0.18	1.80	0.18	2.20	0.17
166	50.1	0.04	+40.0	6.30	2.70	2.00	1.40	0.18	1.80	0.18	2.20	0.17
226	51.1	0.06	+12.0	9.50	4.00	3.00	2.20	0.27	2.70	0.26	3.40	0.25
178	54.8	0.10		16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
225	57.0	0.06		9.50	4.00	3.00	2.20	0.27	2.70	0.26	3.40	0.25
177	59.8	0.10	+36.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
179	60.9	0.10	+28.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
176	64.6	0.09	+28.0	14.00	6.00	4.50	3.20	0.39	4.10	0.39	5.00	0.38
224	69.4	0.08		13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
175	71.6	0.12	+32.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
174	73.0	0.11	+40.0	17.00	7.30	5.50	3.90	0.48	4.90	0.48	6.20	0.46
223	73.0	0.08	+20.0	13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
221	78.7	0.09		14.00	6.00	4.50	3.20	0.39	4.10	0.39	5.00	0.38
171	79.5	0.12	+38.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
222	80.6	0.08		13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
167	82.1	0.08	+61.0	13.00	5.30	4.00	2.90	0.36	3.60	0.35	4.50	0.34
216	83.5	0.11	-21.0	17.00	7.30	5.50	3.90	0.48	4.90	0.48	6.20	0.46
168	84.0	0.11	+65.0	17.00	7.30	5.50	3.90	0.48	4.90	0.48	6.20	0.46
217	86.0	0.14	-22.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
215	86.9	0.12	-22.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
169	90.4	0.12	+84.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
218	92.9	0.12	-21.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
170	95.9	0.12	+80.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
220	97.0	0.06	-22.0	9.50	4.00	3.00	2.20	0.27	2.70	0.26	3.40	0.25
173	98.5	0.11	+21.0	17.00	7.30	5.50	3.90	0.48	4.90	0.48	6.20	0.46
172	105.0	0.14	+19.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked " - " indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked " + " indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

TABLE 33

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS K4-S (STEAM)



PLAN OF LATERAL BRACING

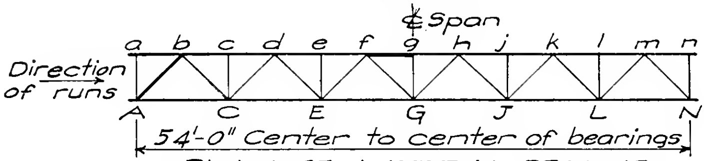
Run No.	Speed M.P.H.	Speed R.P.S.	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections: Single Load At "G"	Equal Loads At "E, G & J"	Equal Loads At "C, E, G, J & L"	Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads: Single Load At "G" A-b	Single Load At "G" f-g	Equal Loads At "E, G & J" A-b	Equal Loads At "E, G & J" f-g	Equal Loads At "C, E, G, J & L" A-b	Equal Loads At "C, E, G, J & L" f-g
Col. 1	2	3	4	5	6	7	8	9	10	11	12	13	14
132	5.2	0.37	0.04	+19.0	6.30	2.70	2.00	1.43	0.18	1.80	0.18	2.25	0.17
128	18.9	1.34	0.12	+34.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.74	0.51
127	26.6	1.88	0.13	+22.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
126	30.1	2.13	0.15	- 4.0	24.00	10.00	7.50	5.40	0.67	6.80	0.66	8.40	0.63
125	35.6	2.52	0.15	+21.0	24.00	10.00	7.50	5.40	0.67	6.80	0.66	8.40	0.63
124	40.0	2.84	0.16	-11.0	25.00	10.70	8.00	5.70	0.70	7.20	0.70	9.00	0.68
130	40.2	2.85	0.16	+28.0	25.00	10.70	8.00	5.70	0.70	7.20	0.70	9.00	0.68
131	41.7	2.96	0.14	+21.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
129	42.6	3.02	0.14	- 4.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
123	44.2	3.13	0.14	- 2.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
214	45.8	3.25	0.10	+ 2.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
122	52.3	3.70	0.16	+14.0	25.00	10.70	8.00	5.70	0.70	7.20	0.70	9.00	0.67
121	55.5	3.93	0.14	-13.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
208	57.5	4.07	0.10	- 6.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
195	59.3	4.20	0.10	- 5.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
209	60.0	4.25	0.13	+ 3.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
196	60.3	4.28	0.13	-23.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
210	63.3	4.48	0.13	+21.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
197	63.9	4.53	0.11	-22.0	17.00	7.30	5.50	3.80	0.48	4.90	0.48	6.20	0.46
211	65.5	4.64	0.11	- 5.0	17.00	7.30	5.50	3.80	0.48	4.90	0.48	6.20	0.46
120	67.0	4.75	0.14	+32.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
198	67.7	4.80	0.12	-20.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.74	0.51
212	68.4	4.85	0.14	+30.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
199	69.0	4.89	0.10	-21.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
213	70.6	5.00	0.11	-11.0	17.00	7.30	5.50	3.80	0.48	4.90	0.48	6.20	0.46
118	71.0	5.04	0.13	-10.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
200	72.1	5.12	0.09	-21.0	14.00	6.00	4.50	3.20	0.39	4.10	0.39	5.05	0.38
201	77.3	5.47	0.12		19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.74	0.51
202	79.4	5.63	0.12	-21.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.74	0.51
116	80.8	5.72	0.15	-12.0	24.00	10.00	7.50	5.40	0.67	6.80	0.66	8.40	0.63
203	82.2	5.82	0.10	-21.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
113	84.0	5.96	0.16	-16.0	25.00	10.70	8.00	5.70	0.70	7.20	0.70	9.00	0.68
114	85.0	6.03	0.15	+19.0	24.00	10.00	7.50	5.40	0.67	6.80	0.66	8.40	0.63
204	85.0	6.03	0.16	+15.0	25.00	10.70	8.00	5.70	0.70	7.20	0.70	9.00	0.68
115	87.0	6.16	0.16	-17.0	25.00	10.70	8.00	5.70	0.70	7.20	0.70	9.00	0.68
207	88.0	6.23	0.14		22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
206	88.3	6.26	0.11	-21.0	17.00	7.30	5.50	3.80	0.48	4.90	0.48	6.20	0.46
205	89.4	6.33	0.12		19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.74	0.51

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked " - " indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked " + " indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

TABLE 34

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

55' - 10" GIRDER SPAN
LOCOMOTIVE CLASS M1-A (STEAM)



PLAN OF LATERAL BRACING

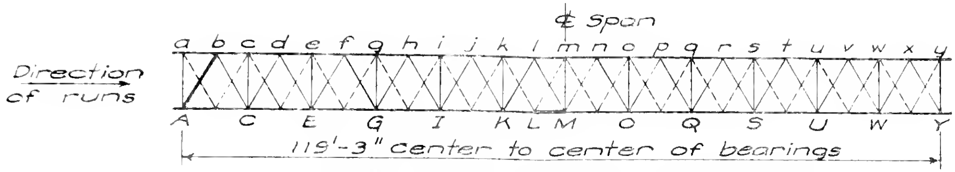
Run No.	Speed M.P.H.	Speed R.P.S.	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections: Single Load At "G"	Equal Loads At "E, G & J"	Equal Loads At "C, E, G, J & L"	Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads: Single Load At "G" A-b	Single Load At "G" f-g	Equal Loads At "E, G & J" A-b	Equal Loads At "E, G & J" f-g	Equal Loads At "C, E, G, J & L" A-b	Equal Loads At "C, E, G, J & L" f-g
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14
133	4.8	0.38	0.03	+19.0	4.80	2.00	1.50	1.10	0.13	1.40	0.13	1.70	0.13
134	9.0	0.71	0.07	+31.0	11.00	4.70	3.50	2.50	0.31	3.20	0.31	3.90	0.30
135	13.3	1.05	0.10	+69.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
136	19.5	1.54	0.12		19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
137	25.0	1.98	0.13		21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
150	25.2	1.99	0.12		19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
149	29.4	2.32	0.13	+35.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
148	34.8	2.75	0.17	+37.0	27.00	11.00	8.50	6.10	0.76	7.40	0.72	9.50	0.72
147	40.3	3.18	0.14	+ 1.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
153	41.5	3.28	0.14	+ 5.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
193	42.0	3.32	0.14		22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
189	43.9	3.47	0.12		19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
154	46.2	3.65	0.13	+28.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
188	46.5	3.67	0.10		16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
146	47.0	3.71	0.14	+60.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
187	47.0	3.71	0.11	- 4.0	17.00	7.30	7.30	3.80	0.48	4.90	0.48	6.20	0.46
152	47.2	3.72	0.12	+55.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
151	47.4	3.74	0.14	+21.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
191	49.5	3.91	0.10	-10.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
194	49.7	3.92	0.10	+ 2.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
143	50.2	3.96	0.18	+25.0	29.00	12.00	9.00	6.60	0.82	8.10	0.79	10.00	0.76
192	51.4	4.06	0.10	- 3.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
190	53.8	4.25	0.10	0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
145	54.3	4.29	0.16	+20.0	25.00	11.00	8.00	5.70	0.70	7.40	0.72	9.00	0.68
141	57.0	4.50	0.12	- 4.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
140	58.5	4.62	0.12	+20.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
185	60.0	4.74	0.11	+13.0	17.00	7.30	5.50	3.80	0.48	4.90	0.48	6.20	0.46
186	62.8	4.96	0.10	+24.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
144	64.8	5.12	0.13	+19.0	21.00	8.70	6.50	4.80	0.59	5.90	0.57	7.30	0.55
139	66.5	5.25	0.16	+28.0	25.00	11.00	8.00	5.70	0.70	7.40	0.72	9.00	0.68
184	67.7	5.34	0.12		19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
182	68.1	5.38	0.18	+32.0	29.00	12.00	9.00	6.60	0.82	8.10	0.79	10.00	0.76
183	69.9	5.52	0.10	- 3.0	16.00	6.70	5.00	3.60	0.45	4.50	0.44	5.60	0.42
138	71.2	5.62	0.14	-20.0	22.00	9.30	7.00	5.00	0.62	6.30	0.61	7.90	0.59
181	72.8	5.75	0.12	+36.0	19.00	8.00	6.00	4.30	0.53	5.40	0.52	6.70	0.51
180	75.7	5.98	0.16		25.00	11.00	8.00	5.70	0.70	7.40	0.72	9.00	0.68
142	77.9	6.15	0.15	- 3.0	24.00	10.00	7.50	5.40	0.67	6.80	0.66	8.40	0.63

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked "-" indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked " + " indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

TABLE 35

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS P5-A (ELECTRIC)



PLAN OF LATERAL BRACING

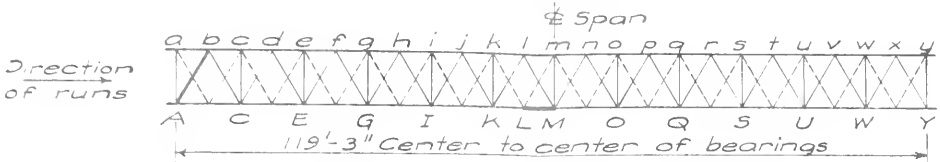
				Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections					Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads									
Run No.	Speed M.P.H.	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Single Load At "M"	Equal Loads At "K,M,O"	Equal Loads At "I,K,M,O,Q"	Equal Loads At "G,I,K,M,O,Q,S"	Equal Loads At "C,E,G,I,K,M,O,Q,S,U,W"	Single Load At "M" A-b	L-M	Equal Loads At "K,M,O" A-b	L-M	Equal Loads At "I,K,M,O,Q" A-b	L-M	Equal Loads At "G,I,K,M,O,Q,S" A-b	L-M	Equal Loads At "C,E,G,I,K,M,O,Q,S,U,W" A-b	L-M
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
100	4.3	0																
229	4.6	0																
101	4.9	0																
102	5.6	0.01	+26.0	1.50	0.54	0.36	0.28	0.23	0.14	0.02	0.15	0.02	0.17	0.02	0.19	0.02	0.24	0.02
230	7.5	0.05	- 9.0	7.40	2.70	1.80	1.40	1.10	0.70	0.10	0.77	0.10	0.86	0.10	0.94	0.10	1.20	0.09
232	10.2	0.06	+12.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
231	13.4	0.06	+68.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
233	13.8	0.07	+24.0	10.00	3.80	2.50	2.00	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
253	14.2	0.06		8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
103	17.2	0.04	+30.0	5.90	2.20	1.40	1.10	0.91	0.56	0.08	0.63	0.08	0.67	0.08	0.73	0.08	0.95	0.08
234	20.8	0.07	+ 6.0	10.00	3.80	2.50	[illegible]	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
235	26.1	0.07	-20.0	10.00	3.80	2.50	[illegible]	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
236	28.7	0.07	+11.0	10.00	3.80	2.50	2.00	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
237	29.3	0.07	+46.0	10.00	3.80	2.50	[illegible]	1.60	0.95	0.14	1.20	0.14	1.20	0.14	1.30	0.14	1.70	0.14
104	32.3	0.03		4.40	1.60	1.10	[illegible]	0.68	0.42	0.06	0.46	0.06	0.57	0.06	0.57	0.06	0.63	0.05
252	34.9	0.07		10.00	3.80	2.50	[illegible]	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
251	41.3	0.08		12.00	4.40	2.90	[illegible]	1.80	1.10	0.16	1.30	0.16	1.40	0.16	1.50	0.16	1.90	0.15
105	42.3	0.04	+61.0	5.90	2.20	1.40	[illegible]	0.91	[illegible]	0.08	0.63	0.08	0.67	0.08	0.73	0.08	0.95	0.08
238	46.5	0.07	+21.0	10.00	3.80	2.50	2.00	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
107	49.5	0.04	+49.0	5.90	2.20	1.40	1.10	0.91	0.56	0.08	0.63	0.08	0.67	0.08	0.73	0.08	0.95	0.08
106	51.1	0.06	+32.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
108	59.5	0.06	+78.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
239	61.5	0.11	+33.0	16.00	6.00	3.90	3.10	2.50	1.50	0.22	1.70	0.22	1.90	0.22	1.60	0.16	1.90	0.15
246	67.6	0.24	+58.0	35.00	13.00	8.60	6.80	5.40	3.30	0.48	3.70	0.47	4.10	0.48	4.70	0.48	5.70	0.46
109	70.4	0.14	+65.0	21.00	7.60	5.00	3.90	3.20	2.00	0.29	2.20	0.27	2.40	0.38	2.50	0.28	3.40	0.27
240	71.0	0.22	+65.0	32.00	12.00	7.90	6.20	5.00	3.00	0.44	3.40	0.43	3.80	0.45	4.20	0.44	5.20	0.42
241	72.4	0.22	+56.0	32.00	12.00	7.90	6.20	5.00	3.00	0.44	3.40	0.43	3.80	0.45	4.20	0.44	5.20	0.42
249	76.5	0.25		37.00	14.00	8.90	7.00	5.70	3.50	0.51	4.00	0.50	4.30	0.50	4.70	0.50	6.00	0.48
243	76.5	0.30	+56.0	44.00	16.00	11.00	8.40	6.80	4.20	0.60	4.60	0.58	5.30	0.62	5.60	0.59	7.10	0.57
242	78.8	0.20	+52.0	29.00	11.00	7.10	5.60	4.50	2.80	0.40	3.10	0.40	3.40	0.40	3.70	0.40	4.70	0.38
110	81.6	0.22		32.00	12.00	7.90	6.20	5.00	3.00	0.44	3.40	0.43	3.80	0.45	4.20	0.44	5.20	0.42
245	87.8	0.31	+77.0	46.00	17.00	11.00	8.70	7.00	4.40	0.63	4.90	0.61	5.30	0.62	5.80	0.62	7.30	0.59
111	91.8	0.30	+84.0	44.00	16.00	11.00	8.40	6.80	4.20	0.60	4.60	0.58	5.30	0.62	5.60	0.59	7.10	0.57
247	95.2	0.24	+91.0	35.00	13.00	8.60	6.80	5.40	3.30	0.48	3.70	0.47	4.10	0.48	4.70	0.48	5.70	0.46
250	96.3	0.27		40.00	15.00	9.60	7.60	6.10	3.80	0.55	4.30	0.54	4.60	0.54	5.10	0.54	6.40	0.52
248	99.5	0.23	+89.0	34.00	12.00	8.20	6.50	5.20	3.20	0.46	3.40	0.43	3.80	0.46	4.40	0.46	5.40	0.44
112	99.7	0.18	+89.0	27.00	9.80	6.40	5.10	4.10	2.60	0.37	2.80	0.35	3.10	0.36	3.40	0.36	4.30	0.35

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked " - " indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked " + " indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

TABLE 36

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS GG-1 (ELECTRIC)



PLAN OF LATERAL BRACING

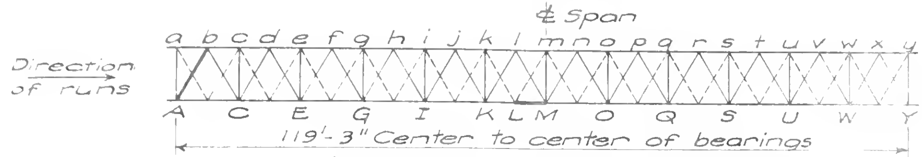
Run No.	Speed M.P.H.	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections: Single Load At "M"	Equal Loads At "K,M,O"	Equal Loads At "I,K,M,O,Q"	Equal Loads At "G,I,K,M,O,Q,S"	Equal Loads At "C,E,G,I,K,M,O,Q,S,U,W"	Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads: Single Load At "M" A-b	Single Load At "M" L-M	Equal Loads At "K,M,O" A-b	Equal Loads At "K,M,O" L-M	Equal Loads At "I,K,M,O,Q" A-b	Equal Loads At "I,K,M,O,Q" L-M	Equal Loads At "G,I,K,M,O,Q,S" A-b	Equal Loads At "G,I,K,M,O,Q,S" L-M	Equal Loads At "C,E,G,I,K,M,O,Q,S,U,W" A-b	Equal Loads At "C,E,G,I,K,M,O,Q,S,U,W" L-M
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
155	4.4	0.01	+52.0	1.50	0.54	0.36	0.28	0.23	0.14	0.02	0.15	0.02	0.17	0.02	0.19	0.02	0.24	0.02
156	9.8	0.01	+46.0	1.50	0.54	0.36	0.28	0.23	0.14	0.02	0.15	0.02	0.17	0.02	0.19	0.02	0.24	0.02
157	12.7	0.03	+20.0	4.40	1.60	1.10	0.85	0.68	0.42	0.06	0.46	0.06	0.53	0.06	0.57	0.06	0.63	0.05
158	15.6	0.02		2.90	1.10	0.71	0.56	0.45	0.28	0.04	0.31	0.04	0.34	0.04	0.37	0.04	0.47	0.04
159	18.5	0.02		2.90	1.10	0.71	0.56	0.45	0.28	0.04	0.31	0.04	0.34	0.04	0.37	0.04	0.47	0.04
160	25.0	0.04	+12.0	5.90	2.20	1.40	1.10	0.91	0.56	0.08	0.63	0.08	0.67	0.08	0.73	0.08	0.95	0.08
161	28.7	0.04	+14.0	5.90	2.20	1.40	1.10	0.91	0.56	0.08	0.63	0.08	0.67	0.08	0.73	0.08	0.95	0.08
162	35.7	0.02		2.90	1.10	0.71	0.56	0.45	0.28	0.04	0.31	0.04	0.34	0.04	0.37	0.04	0.47	0.04
227	39.7	0.06	+24.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
163	39.8	0.04	+20.0	5.90	2.20	1.40	1.10	0.91	0.56	0.08	0.63	0.08	0.67	0.08	0.73	0.08	0.95	0.08
164	44.7	0.04	+77.0	5.90	2.20	1.40	1.10	0.91	0.56	0.08	0.63	0.08	0.67	0.08	0.73	0.08	0.95	0.08
166	50.1	0.02	+12.0	2.90	1.10	0.71	0.56	0.45	0.28	0.04	0.31	0.04	0.34	0.04	0.37	0.04	0.47	0.04
226	51.1	0.07	+22.0	10.00	3.80	2.50	2.00	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
178	54.8	0.06	+55.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
225	57.0	0.06	+55.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
177	59.8	0.05	+65.0	7.40	2.70	1.80	1.40	1.10	0.70	0.10	0.77	0.10	0.86	0.10	0.94	0.10	1.20	0.09
179	60.9	0.05	+66.0	7.40	2.70	1.80	1.40	1.10	0.70	0.10	0.77	0.10	0.86	0.10	0.94	0.10	1.20	0.09
176	64.5	0.07	+66.0	10.00	3.80	2.50	2.00	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
224	69.4	0.06	+71.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
175	71.6	0.06	+19.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
174	73.0	0.08	+14.0	12.00	4.40	2.90	2.30	1.80	1.10	0.16	1.30	0.16	1.40	0.16	1.50	0.16	1.90	0.15
223	73.0	0.08	+19.0	12.00	4.40	2.90	2.30	1.80	1.10	0.16	1.30	0.16	1.40	0.16	1.50	0.16	1.90	0.15
221	78.7	0.10	+35.0	15.00	5.40	3.60	2.80	2.30	1.40	0.21	1.50	0.19	1.70	0.20	1.90	0.20	2.40	0.19
171	79.5	0.13	+64.0	19.00	7.10	4.60	3.70	3.00	1.80	0.26	2.00	0.27	2.20	0.26	2.50	0.26	3.10	0.25
222	80.6	0.15	+35.0	22.00	8.20	5.40	4.20	3.40	2.10	0.30	2.30	0.31	2.60	0.30	2.80	0.30	3.60	0.29
167	82.1	0.10	+22.0	15.00	5.40	3.60	2.80	2.30	1.40	0.21	1.50	0.19	1.70	0.20	1.90	0.20	2.40	0.19
216	83.5	0.09	+23.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
168	84.0	0.13	+87.0	19.00	7.10	4.60	3.70	3.00	1.80	0.26	2.00	0.27	2.20	0.26	2.50	0.26	3.10	0.25
217	86.0	0.32	+86.0	47.00	17.00	11.00	9.00	7.30	4.50	0.64	4.80	0.64	5.30	0.62	6.00	0.64	7.70	0.62
215	86.9	0.44	+90.0	65.00	24.00	16.00	12.00	10.00	6.20	0.89	6.80	0.90	7.60	0.90	8.00	0.85	10.50	0.84
169	90.4	0.09	+48.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
218	92.9	0.37	+82.0	54.00	20.00	13.00	10.00	8.40	5.10	0.74	5.70	0.75	6.20	0.74	6.70	0.71	8.80	0.71
170	95.9	0.22	+52.0	32.00	12.00	7.90	6.20	5.00	3.00	0.44	3.40	0.43	3.80	0.44	4.20	0.44	5.20	0.42
220	97.0	0.36	+97.0	53.00	20.00	13.00	10.00	8.20	5.00	0.72	5.70	0.75	6.20	0.74	6.70	0.71	8.60	0.69
173	98.5	0.32	+101.0	47.00	17.00	11.00	9.00	7.30	4.50	0.64	4.80	0.64	5.30	0.62	6.00	0.64	7.70	0.62
219	100.8	0.24	+127.0	35.00	13.00	8.60	6.80	5.40	3.30	0.48	3.70	0.47	4.10	0.48	4.50	0.48	5.70	0.46
172	105.0	0.27	+124.0	40.00	15.00	9.60	7.60	6.10	3.80	0.55	4.30	0.54	4.60	0.54	5.10	0.54	6.40	0.52

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked " - " indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked " - " indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

TABLE 37

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS K4-S (STEAM)



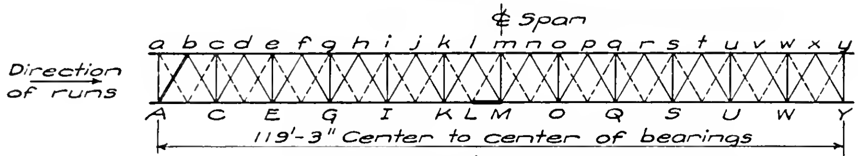
PLAN OF LATERAL BRACING

Run No.	Speed M.P.H	Speed R.P.S	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections: Single Load At "M"	Equal Loads At "K,M,O"	Equal Loads At "I,K,M O,Q"	Equal Loads At "G,I,K,M O,Q,S"	Equal Loads At "C,E,G,I,K,M O,Q,S,U,W"	Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads: Single Load At "M" A-b	L-M	Equal Loads At "K,M,O" A-b	L-M	Equal Loads At "I,K,M,O,Q" A-b	L-M	Equal Loads At "G,I,K,M,O,Q,S" A-b	L-M	Equal Loads At "C,E,G,I,K,M O,Q,S,U,W" A-b	L-M
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	19	20	21
132	5.2	0.37	0																
128	18.9	1.34	0.02	+41.0	2.90	1.10	0.71	0.56	0.45	0.27	0.04	0.31	0.04	0.34	0.04	0.37	0.04	0.47	0.04
127	26.6	1.99	0.09	+ 1.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
126	30.1	2.13	0.06	+44.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
125	35.6	2.52	0.12	+ 8.0	18.00	6.50	4.30	3.40	2.70	1.70	0.25	1.90	0.24	2.10	0.24	2.30	0.24	2.80	0.23
124	40.0	2.84	0.09	+16.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
130	40.2	2.85	0.06	+65.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
131	41.7	2.96	0.10	+21.0	15.00	5.40	3.60	2.80	2.30	1.40	0.20	1.50	0.21	1.70	0.20	1.90	0.20	2.40	0.19
129	42.6	3.02	0.15	+52.0	22.00	8.20	5.40	4.20	3.40	2.10	0.30	2.30	0.31	2.60	0.30	2.80	0.30	3.60	0.29
123	44.2	3.13	0.06	+52.0	8.80	3.30	2.10	1.70	1.40	0.84	0.12	0.94	0.12	1.00	0.12	1.10	0.12	1.50	0.12
214	45.8	3.25	0.07	+21.0	10.00	3.80	2.50	2.00	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
122	52.3	3.70	0.04	+11.0	5.90	2.20	1.40	1.10	0.91	0.56	0.08	0.63	0.08	0.67	0.08	0.74	0.08	0.95	0.08
121	55.5	3.93	0.09	+13.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
208	57.5	4.07	0.11	+27.0	16.00	6.00	3.90	3.10	2.50	1.50	0.22	1.70	0.23	1.90	0.22	2.10	0.22	2.60	0.21
195	59.3	4.21	0.10	+36.0	15.00	5.40	3.60	2.80	2.30	1.40	0.20	1.50	0.21	1.70	0.20	1.90	0.20	2.40	0.19
209	60.0	4.25	0.10	+41.0	15.00	5.40	3.60	2.80	2.30	1.40	0.20	1.50	0.21	1.70	0.20	1.90	0.20	2.40	0.19
196	60.3	4.28	0.10	+32.0	15.00	5.40	3.60	2.80	2.30	1.40	0.20	1.50	0.21	1.70	0.20	1.90	0.20	2.40	0.19
119	62.2	4.41	0.08	+24.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
210	63.3	4.49	0.10	+41.0	15.00	5.40	3.60	2.80	2.30	1.40	0.20	1.50	0.21	1.70	0.20	1.90	0.20	2.40	0.19
197	63.9	4.53	0.11	+46.0	16.00	6.00	3.90	3.10	2.50	1.50	0.22	1.70	0.23	1.90	0.22	2.10	0.22	2.60	0.21
211	65.5	4.64	0.11	+39.0	16.00	6.00	3.90	3.10	2.50	1.50	0.22	1.70	0.23	1.90	0.22	2.10	0.22	2.60	0.21
120	67.0	4.75	0.12	- 4.0	18.00	6.50	4.30	3.40	2.70	1.70	0.25	1.90	0.24	2.10	0.24	2.30	0.24	2.80	0.23
198	67.7	4.80	0.12	+40.0	18.00	6.50	4.30	3.40	2.70	1.70	0.25	1.90	0.24	2.10	0.24	2.30	0.24	2.80	0.23
212	68.4	4.85	0.11	+50.0	16.00	6.00	3.90	3.10	2.50	1.50	0.22	1.70	0.23	1.90	0.22	2.10	0.22	2.60	0.21
199	69.0	4.89	0.10	+11.0	15.00	5.40	3.60	2.80	2.30	1.40	0.20	1.50	0.21	1.70	0.20	1.90	0.20	2.40	0.19
213	70.6	5.00	0.13	+47.0	19.00	7.10	4.60	3.70	3.00	1.80	0.26	2.00	0.27	2.20	0.26	2.50	0.26	3.10	0.25
118	71.0	5.04	0.07	+24.0	10.00	3.80	2.50	2.00	1.60	0.95	0.14	1.10	0.14	1.20	0.14	1.30	0.14	1.70	0.14
200	72.1	5.12	0.14	+51.0	21.00	7.60	5.00	3.90	3.20	2.00	0.29	2.20	0.29	2.40	0.28	2.60	0.28	3.40	0.27
117	76.3	5.40	0.15	+106.0	22.00	8.20	5.40	4.20	3.40	2.10	0.30	2.30	0.31	2.60	0.30	2.80	0.30	3.60	0.29
201	77.3	5.48	0.18	+ 50.0	26.00	9.80	6.40	5.10	4.10	2.50	0.36	2.80	0.37	3.00	0.36	3.40	0.36	4.30	0.35
202	79.4	5.64	0.14	+ 44.0	21.00	7.60	5.00	3.90	3.20	2.00	0.29	2.20	0.29	2.40	0.28	2.60	0.28	3.40	0.27
116	80.8	5.73	0.12	+23.0	18.00	6.50	4.30	3.40	2.70	1.70	0.25	1.90	0.24	2.10	0.24	2.30	0.24	2.80	0.23
203	82.2	5.83	0.15	+77.0	22.00	8.20	5.40	4.20	3.40	2.10	0.30	2.30	0.31	2.60	0.30	2.80	0.30	3.60	0.29
113	84.0	5.95	0.14	+53.0	21.00	7.60	5.00	3.90	3.20	2.00	0.29	2.20	0.29	2.40	0.28	2.60	0.28	3.40	0.27
204	85.0	6.03	0.18	+75.0	26.00	9.80	6.40	5.10	4.10	2.50	0.36	2.80	0.37	3.00	0.36	3.40	0.36	4.30	0.35
114	85.0	6.03	0.24	+64.0	35.00	13.00	8.60	6.80	5.50	3.30	0.48	3.70	0.49	4.10	0.99	4.50	0.48	5.80	0.46
115	87.0	6.17	0.18	+53.0	26.00	9.80	6.40	5.10	4.10	2.50	0.36	2.80	0.37	3.00	0.36	3.40	0.36	4.30	0.35
207	88.0	6.24	0.30	+90.0	44.00	16.00	11.00	8.40	6.80	4.20	0.60	4.60	0.60	5.20	0.62	5.60	0.59	7.10	0.58
206	88.3	6.26	0.10	+97.0	15.00	5.40	3.60	2.80	2.30	1.40	0.20	1.50	0.21	1.70	0.20	1.90	0.20	2.40	0.19
205	89.4	6.34	0.14	+85.0	21.00	7.60	5.00	3.90	3.20	2.00	0.29	2.20	0.29	2.40	0.28	2.60	0.28	3.40	0.27

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked "-" indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked "+" indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

ANALYSIS OF LATERAL DEFLECTOMETER READINGS
(LATERAL DEFLECTIONS AT CENTER OF SPAN)

122' - 0" GIRDER SPAN
LOCOMOTIVE CLASS M1-A (STEAM)



PLAN OF LATERAL BRACING

Run No.	Speed M.P.H.	Speed R.P.S.	Maximum Lateral Deflection Inches	Dimension "Z" Feet	Concentrated Panel Point Loads in Kips Required to Produce Actual Lateral Deflections: Single Load At "M"	Equal Loads At "K,M,O"	Equal Loads At "I,K,M" O,Q"	Equal Loads At "G,I,K,M" O,Q,S"	Equal Loads At "C,E,G,I,K,M" O,Q,S,U,W"	Stresses in Members in Kips Per Square Inch Due to Concentrated Panel Point Loads: Single Load At "M" A-b	Single Load At "M" L-M	Equal Loads At "K,M,O" A-b	Equal Loads At "K,M,O" L-M	Equal Loads At "I,K,M,O,Q" A-b	Equal Loads At "I,K,M,O,Q" L-M	Equal Loads At "G,I,K,M,O,Q,S" A-b	Equal Loads At "G,I,K,M,O,Q,S" L-M	Equal Loads At "C,E,G,I,K,M O,Q,S,U,W" A-b	Equal Loads At "C,E,G,I,K,M O,Q,S,U,W" L-M
Col.1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
133	4.75	0.38	0																
134	9.02	0.71	0.05	+94.0	7.40	2.70	1.80	1.40	1.10	0.70	0.10	0.77	0.10	0.86	0.10	0.93	0.10	1.20	
135	13.3	1.05	0.09	-12.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
137	25.0	1.98	0.11		16.00	6.00	3.90	3.10	2.50	1.50	0.22	1.70	0.22	1.90	0.22	2.10	0.22	2.60	0.21
150	25.2	1.99	0.20		29.00	11.00	7.10	5.60	4.60	2.80	0.40	3.10	0.41	3.40	0.40	3.70	0.40	4.80	0.39
149	29.4	2.32	0.17	+12.0	25.00	9.20	6.10	4.80	3.90	2.40	0.34	2.60	0.34	2.90	0.34	3.20	0.34	4.10	0.33
148	34.8	2.75	0.29	+19.0	43.00	16.00	10.00	8.20	6.60	4.10	0.59	4.60	0.60	4.80	0.56	5.50	0.58	6.90	0.56
147	40.3	3.18	0.12	+32.0	18.00	6.50	4.30	3.40	2.70	1.70	0.25	1.90	0.24	2.10	0.24	2.30	0.24	2.80	0.23
153	41.5	3.28	0.10	- 1.0	15.00	5.40	3.60	2.80	2.30	1.40	0.21	1.50	0.20	1.70	0.20	1.90	0.20	2.40	0.19
193	42.0	3.32	0.08	+43.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
189	43.9	3.47	0.09	+27.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
154	46.2	3.65	0.13	+39.0	19.00	7.00	4.60	3.70	3.00	1.80	0.26	2.00	0.26	2.20	0.26	2.50	0.26	3.10	0.25
188	46.5	3.67	0.08	+31.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
187	47.0	3.71	0.08	+30.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
146	47.0	3.71	0.08	-15.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
152	47.2	3.72	0.08	+ 4.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
151	47.4	3.74	0.09	+23.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
191	49.5	3.91	0.11	+40.0	16.00	6.00	3.90	3.10	2.50	1.50	0.22	1.70	0.22	1.90	0.22	2.10	0.22	2.60	0.21
143	50.2	3.96	0.10	+13.0	15.00	5.40	3.60	2.80	2.30	1.40	0.21	1.50	0.20	1.70	0.20	1.90	0.20	2.40	0.19
192	51.4	4.06	0.08	+19.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
190	53.8	4.25	0.09	+39.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
145	54.3	4.29	0.09	+81.0	13.00	4.90	3.20	2.50	2.00	1.20	0.18	1.40	0.18	1.50	0.18	1.70	0.18	2.10	0.17
141	57.0	4.50	0.16	+86.0	24.00	8.70	5.70	4.50	3.60	2.30	0.33	2.50	0.33	2.70	0.32	3.00	0.32	3.80	0.30
140	58.5	4.62	0.14	+45.0	21.00	7.60	5.00	3.90	3.20	2.00	0.29	2.20	0.29	2.40	0.28	3.60	0.28	3.40	0.27
185	60.0	4.74	0.08	+44.0	12.00	4.30	2.90	2.30	1.80	1.10	0.16	1.20	0.16	1.40	0.16	1.50	0.16	1.90	0.15
186	62.8	4.96	0.10	+55.0	15.00	5.40	3.60	2.80	2.30	1.40	0.21	1.50	0.20	1.70	0.20	1.90	0.20	2.40	0.19
144	64.8	5.12	0.12	+49.0	18.00	6.50	4.30	3.40	2.70	1.70	0.25	1.90	0.24	2.10	0.24	2.30	0.24	2.80	0.23
139	66.5	5.25	0.18	+52.0	27.00	9.70	6.40	5.10	4.10	2.60	0.37	2.80	0.36	3.10	0.36	3.40	0.36	4.30	0.35
184	67.7	5.34	0.22	+81.0	32.00	12.00	7.80	6.20	5.00	3.00	0.41	3.40	0.45	3.70	0.44	4.10	0.44	5.20	0.42
182	68.1	5.38	0.15	+56.0	22.00	8.10	5.40	4.20	3.40	2.10	0.30	2.30	0.30	2.60	0.30	3.80	0.30	3.60	0.29
183	69.9	5.52	0.13	+51.0	19.00	7.00	4.60	3.70	3.00	1.80	0.26	2.00	0.26	2.20	0.26	2.50	0.26	3.10	0.25
138	71.2	5.62	0.10	+42.0	15.00	5.40	3.60	2.80	2.30	1.40	0.21	1.50	0.20	1.70	0.20	1.90	0.20	2.40	0.19
181	72.8	5.75	0.19	+61.0	28.00	10.00	6.80	5.40	4.30	2.70	0.38	2.80	0.38	3.20	0.38	3.60	0.38	4.50	0.36
180	75.7	5.98	0.12	+62.0	18.00	6.50	4.30	3.40	2.70	1.70	0.25	1.90	0.24	2.10	0.24	2.30	0.24	2.80	0.23
142	77.9	6.15	0.14	+16.0	21.00	7.60	5.00	3.90	3.20	2.00	0.29	2.20	0.29	2.40	0.28	2.60	0.27	3.40	0.27

NOTE: Dimension "Z" in column 4 is the distance that wheel number 1 is from the center of the span at the time of maximum lateral deflection. Distances marked " - " indicate that the maximum lateral deflection occurred before wheel number 1 had reached the center of the span. Distances marked " + " indicate that the maximum lateral deflection occurred after wheel number 1 had passed the center of the span.

In order to arrive at the lateral force present, the span was considered as a horizontal truss and the force, acting at the center, or at other panel points, which would produce the measured deflection, was computed. For the 55-ft. 10-in. span, the central force was found to be as high as 25,000 lb. for the P5–A electric locomotive and K4–S steam locomotive, and 29,000 lb. for the M1–A locomotive. On the 122-ft. span a central force of 65,000 lb. was found for the GG–1, and from 43,000 to 46,000 lb. for the other locomotives. Had these deflections been measured at the top flange, where the force was applied, they should have been somewhat larger than those recorded, with a consequent increase in the magnitude of the force necessary to produce them.

The force causing this lateral deflection is largely due to the nosing of the locomotive, caused by the oscillations about its vertical axis. Considering the force as applied at a panel point, it does not produce particularly high stresses in the girders or bracing, as shown in the tables. If however it represents the lateral pressure of one wheel, and that force were applied to the girder betwen panel points, quite high local bending stresses might be found in the top flange.

10. Conclusions

These tests afforded an opportunity to measure and compare the dynamic effects on the same spans, of electric and steam locomotives running over a wide range of speeds, up to the probable maximum speeds to be expected from either class. The instruments used were of such number and type that it was possible to obtain simultaneous readings in several parts of the same span, providing certain information not heretofore available.

A great deal of interesting and valuable data was obtained but it must be remembered that these tests represent but two spans, and while there is evidence that certain factors are more important than had been generally realized, it is recommended that, until they can be verified by other tests, there be no revision of the impact allowances as now provided for by the AREA design specification or rating rules.

The analysis of these data was particularly helpful in that it resulted in a clearer conception as to the desirability of investigating certain factors in future tests.

From the data, as found from these tests, it seems logical to conclude that:

(1) With the possible exception of speed effect and lateral forces, the impact allowances, as now provided for in the section on design of the AREA Specifications for Steel Railway Bridges, and Rules for Rating Existing Iron and Steel Bridges, are ample.

(2) In these two spans, at least, there was an increase in the vertical force due to speed. These forces are of such magnitude that they require further investigation, and if it is found that they occur in other spans, it will be necessary to include some allowances for them. While there has been evidence of such forces in other tests, they were not so apparent, due to the fact that runs were not made at such high speeds and the instruments used were not suitable for their exact measurement.

(3) Further investigation should be made as to lateral or nosing forces. While this is not so important in the design of new structures, definite information as to their magnitude is necessary for determining the capacity of old structures. The forces as computed from the measured lateral deflections as found in these tests, are somewhat greater than those provided for in the rating rules.

(4) In these tests it was found that the track effect did not increase with the square of the speed as provided for in the rating rules, and the measured values, in all cases, were less than those called for in the design specification.

(5) The determination of impact by the measurements of stresses, when suitable instruments are used, is more satisfactory than determination by measuring deflections. This is especially true for short spans.

11. Acknowledgment

The Committee on Impact and the American Railway Engineering Association are deeply indebted to the Pennsylvania Railroad for the use of the most complete data covering these tests. They throw much needed light on several aspects of the impact problem.

Report of Committee 3—Ties

John Foley, *Chairman,*	S. B. Clement	W. D. Simpson, *Vice-Chairman,*
R. S. Belcher	R. L. Cook	J. E. Lockhart
W. C. Bolin	H. R. Duncan	A. F. Maischaider
W. H. Brameld	C. F. Ford*	E. F. Salisbury
H. F. Brown	W. E. Gardner	Raymond Swenk
W. J. Burton	W. R. Gillam	Sverre Thorvaldson
R. E. Butler	B. D. Howe	C. D. Turley
F. G. Campbell	C. T. Jackson	A. W. White

Committee

* Died June 9, 1940.

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

No report.

2. Extent of adherence to specifications.

Report of observations made during 1940, submitted as information below.

3. Substitutes for wood ties.

No report.

4. Tie averages and costs per maintained mile.

Progress report, presented as information .... page 486

5. Investigate and report on the dimensions of ties, and bring up to date the information presented in the 1924 and 1932 Proceedings.

Progress report, presented as information .... page 487

6. Cause and control of splitting in railroad ties.

No report.

The Committee on Ties,
John Foley, *Chairman.*

Report on Assignment 2

Extent of Adherence to Specifications

W. D. Simpson (chairman, subcommittee), R. S. Belcher, W. C. Bolin, W. H. Brameld, H. F. Brown, W. J. Burton, F. G. Campbell, R. L. Cook, H. R. Duncan, W. E. Gardner, W. R. Gillam, B. D. Howe, C. T. Jackson, J. E. Lockhart, E. F. Salisbury, Raymond Swenk, Sverre Thorvaldson, A. W. White.

The following statements regarding the ties and their surroundings observed during 1940, are submitted as information.

The committee as a whole examined in June and in November, 1940, the seasoning and creosoted stocks of six railroads at the yards of six wood preserving-plants in the Mississippi valley, five west and one east of the river.

Bulletin 423, February, 1941.

Four of the railroads represented procured their ties in the territories traversed by their lines. All six railroads obtained their supplies in Arkansas, Louisiana, Missouri, Oklahoma and Texas.

The majority of the 3,000,000 ties observed were oak, with gum and pine next in number. All of them had been purchased under AREA specifications and marked to designate AREA standard sizes. Their inspection as a whole left little to be desired, except in the case of one railroad, some of whose ties had been accepted when decayed, were undersize, and were not well manufactured. Since these ties came from the same localities as the other, better ones observed, only laxity in the maintenance of standards can account for their poorer quality.

The sanitary condition of only one seasoning yard was unsatisfactory, though none of the commercial yards equalled in cleanliness and orderliness the railroad owned and operated yard among those visited. In the substandard yard referred to the vegetation constituted a fire hazard and decayed ties sunk into the ground are not suitable sills for seasoning stacks. In general the stacking of ties had been well done, but in one yard the number of misplaced stringers and of ties touching each other in the layers reflected disregard for probable decay.

Two of the railroads had their ties stacked eight to a layer of Sizes 4 and 5 and nine to a layer of Sizes 1, 2, and 3; the other roads' ties were spaced nine and ten to a layer, respectively. The wider spacing did not result in more split ties than prevailed with the closer spacing, which corresponds with observations elsewhere in the past, and refutes the contention that accelerated splitting from wide spacing is more of a problem than decay from spacing too close to permit sufficient seasoning.

All the locations visited in 1940 were under observation several years ago, and the improvement in the ties and their care is so marked in most cases as to reflect considerable credit on those responsible for it. The change for the better demonstrates that "where there's a will, there's a way."

Report on Assignment 4

Tie Averages and Costs per Maintained Mile

John Foley (chairman, subcommittee), W. J. Burton, S. B. Clement, H. R. Duncan, A. F. Maischaider.

The statistics of tie renewals appearing on the folded inserts (Tables A and B for 1939, and Table C for the last five years and averages of them) comprise the data reported to the Interstate Commerce Commission by railroads in the United States and to this Association by Canadian railroads. They were given advance publication in Bulletin 418, June–July, 1940.

Comparisons between railroads are practically only when allowance is made for variations in practice which would influence the costs in columns 3 and 5 of Table A and column 6 of Table B. The different prices at which ties are charged out are due not only to the factors listed on page 309 of the 1929 Proceedings, but are affected by whether or not these costs include expenses for adzing, boring, incising or ironing any or all ties, for freight on preservative and ties to the treating plant, for inspection, etc.

TABLE A

CROSS TIES LAID IN REPLACEMENT - CLASS I STEAM ROADS, UNITED STATES AND LARGER CANADIAN ROADS

Sheet 1 of 2 sheets

TABLE A

CROSS TIES LAID IN REPLACEMENT - CLASS I STEAM ROADS, UNITED STATES AND LARGE CANADIAN ROADS

Calendar year ended December 31, 1939

Road	New wooden ties untreated (U) Number	New wooden ties untreated (U) Average cost	New wooden ties treated (T) Number	New wooden ties treated (T) Average cost	Ties other than wood(S) and secondhand reapplied ties	Total ties applied	Miles of maintained tracks (item 24)	Estimated total cross ties in all maintained tracks (item 25)	Total equated gross ton-miles (thousands)
1	2	3	4	5	6	7	8	9	10
NEW ENGLAND REGION:									
Bangor & Aroostook	150 009	$0.65	-	-	-	150 009	830.14	2 376 656	45 024
Boston & Maine	32 361	0.90	181 428	$1.56	-	213 789	3 093.00	9 100 000	72 606
Canadian Nat. Lines in New Eng.	16 994	0.64	28 498	1.23	-	45 492	249.30	766 456	537 508
Canadian Pacific (lines in Me.)	-	-	11 707	1.48	-	11 707	212.50	652 377	1 230 633
Canadian Pacific (lines in Vt.)	985	0.46	6 351	1.43	-	7 336	132.02	420 146	543 143
Central Vermont	790	0.54	51 938	1.28	-	52 728	497.31	1 427 383	2 183 040
Maine Central	184 225	0.76	39 586	1.71	-	223 811	1 240.30	3 761 100	3 249 904
New York Connecting	-	-	8 926	1.73	-	8 926	25.90	81 641	344 260
New York, New Haven & Hartford	-	-	329 309	0.92	-	329 309	4 018.74	12 190 928	19 882 121
Rutland	-	-	23 277	1.29	*322	23 599	499.86	1 550 800	1 531 441
GREAT LAKES REGION:									
Ann Arbor	-	-	35 231	1.48	-	35 231	405.15	1 222 681	1 473 445
Cambria & Indiana	5 930	0.90	12 399	1.94	-	18 329	59.28	161 000	147 906
Delaware & Hudson	762	1.30	170 782	2.17	(S) 6 605	178 149	1 457.42	4 450 961	8 619 920
Delaware, Lackawanna & Western	-	-	81 592	1.62	*14 494	96 086	2 339.51	6 784 579	16 219 592
Detroit & Mackinac	21 481	0.48	11 482	0.70	-	32 963	293.51	879 873	250 378
Detroit & Toledo Shore Line	-	-	19 796	1.84	*768	20 564	151.58	456 698	665 973
Erie (Inc. Chgo. & Erie)	491	0.43	429 719	1.43	-	430 210	4 845.19	14 177 769	31 822 259
Grand Trunk Western	-	-	327 132	1.53	-	327 132	1 945.70	6 151 004	7 882 445
Lehigh & Hudson River	-	-	13 509	2.02	*715	14 224	118.00	317 000	592 035
Lehigh & New England	-	-	18 013	1.62	-	18 013	266.82	804 888	865 815
Lehigh Valley	-	-	142 093	1.82	-	142 093	2 719.52	8 056 596	14 952 863
Monongahela	-	-	43 223	1.67	-	43 223	241.70	704 606	895 450
Montour	2 448	0.72	5 171	2.03	-	7 619	71.37	205 555	273 227
New York Central	392	1.74	2 030 776	1.53	*16 454	2 047 622	21 719.42	68 127 027	145 296 679
New York, Chicago & St. Louis	-	-	293 980	1.45	(S) 50	294 030	2 522.19	7 944 892	17 250 587
New York, Ontario & Western	-	-	-	-	*28 541	28 541	872.84	2 498 911	2 204 313
New York, Susquehanna & Western	-	-	16 705	1.31	-	16 705	228.04	662 577	386 736
Pere Marquette	-	-	471 487	1.58	-	471 487	2 820.41	6 532 100	10 410 560
Pittsburgh & Lake Erie	1 495	0.99	63 476	1.95	-	64 971	925.99	2 773 997	4 025 062
Pittsburg & Shawmut	8 479	0.98	16 960	1.70	*379	25 818	124.49	346 381	161 551
Pittsburgh & West Virginia	1 142	1.04	32 463	1.91	-	33 605	198.26	576 410	876 107
Pittsburg, Shawmut & Northern	40 107	1.02	-	-	-	40 107	221.24	650 143	242 955
Wabash	-	-	514 721	1.51	-	514 721	3 186.50	9 904 763	19 377 680
CENTRAL EASTERN REGION:									
Akron, Canton & Youngstown	13 384	1.19	4 782	1.41	*26 115	44 281	213.35	636 633	461 952
Baltimore & Ohio	1 122	0.78	1 672.083	1.47	-	1 673 205	10 611.60	30 189 651	63 659 318
Bessemer & Lake Erie	195	0.79	94 185	2.16	(S) 1	94 381	490.48	1 507 551	3 445 085
Central R.R. of New Jersey	-	-	104 044	1.79	-	104 044	1 486.51	4 177 788	8 257 013
Chicago & Eastern Illinois	-	-	155 472	1.17	-	155 472	1 469.05	4 256 605	6 000 338
Chicago & Illinois Midland	-	-	11 557	1.73	-	11 557	164.66	507 656	945 181
Chicago, Indpls. & Louisville	4	0.75	119 811	1.17	*2 898	122 713	807.18	2 481 764	3 453 988
Detroit, Toledo & Ironton	2 659	0.57	57 780	1.42	-	60 439	611.57	1 761 322	1 516 874
Elgin, Joliet & Eastern	-	-	179 885	1.63	*2 691	182 576	871.12	2 691 048	2 805 242
Illinois Terminal	915	0.89	53 475	1.28	*7 439	61 829	634.65	1 903 950	968 923
Long Island	-	-	53 500	1.80	-	53 500	817.96	2 425 291	3 952 426
Missouri-Illinois	64 506	0.68	7 655	1.26	-	72 161	238.97	747 562	316 845
Pennsylvania	-	-	1 648 926	1.57	† 761	1 649 687	21 323.15	59 700 640	159 861 916
Penna.-Reading Seashore Lines	-	-	58 627	1.85	-	58 627	661.88	1 811 846	1 770 923
Reading Co.	-	-	134 634	1.79	-	134 634	3 027.59	8 353 005	15 087 023
Staten Island Rapid Transit	-	-	1 865	1.41	-	1 865	80.21	220 252	142 348
Western Maryland	46 329	1.02	176 431	1.60	-	222 760	1 167.47	3 281 061	5 670 879
Wheeling & Lake Erie	-	-	132 318	1.32	*657	132 975	844.79	2 532 658	3 633 155
POCAHONTAS REGION:									
Chesapeake & Ohio	-	-	420 287	1.21	-	420 287	5 069.05	15 603 537	47 676 923
Norfolk & Western	-	-	160 221	1.29	*6 048	166 269	4 228.23	13 107 513	36 642 161
Richmond, Fred. & Potomac	-	-	99 756	1.61	-	99 756	371.63	1 061 800	3 946 875
Virginian	154	0.25	150 884	1.43	*1 565	152 603	872.84	2 718 024	7 692 123
SOUTHERN REGION:									
Alabama Great Southern	2 912	1.28	60 361	1.70	-	63 273	548.13	1 711 348	2 958 504
Atlanta & West Point	24 460	1.13	341	1.20	-	24 801	141.54	434 036	655 729
Western Ry. of Alabama	29 272	1.13	616	1.63	-	29 888	182.22	553 342	701 644
Atlanta, Birmingham & Coast	82 923	0.76	36 138	1.15	-	119 061	794.22	2 298 864	1 826 312
Atlantic Coast Line	297 780	0.79	560 858	1.24	-	858 638	6 832.77	19 887 642	23 164 158
Central of Georgia	14 616	0.98	350 047	0.90	-	364 663	2 343.97	6 891 000	7 196 742
Charleston & Western Carolina	58 130	1.07	-	-	-	58 130	427.80	1 235 342	853 476
Cincinnati, New Orleans & Tex. Pac.	-	-	63 181	1.74	-	63 181	772.17	2 407 275	7 203 878
Clinchfield	50 827	0.71	39 412	1.40	-	90 239	395.81	1 203 262	2 733 950
Columbus & Greenville	12 890	0.63	31 211	1.30	-	44 101	203.91	645 987	352 857
Florida East Coast	260 949	0.93	-	-	-	260 949	1 344.46	3 858 827	4 749 404
Georgia R.R.	68 878	1.05	3 944	1.95	-	72 822	433.11	1 326 053	1 466 985
Georgia & Florida	90 819	0.64	-	-	-	90 819	451.95	1 220 265	448 678
Georgia, Southern & Florida	49 163	0.97	-	-	-	49 163	469.75	1 477 454	1 419 234
Gulf & Ship Island	-	-	70 389	1.02	*229	70 618	309.52	954 715	428 643
Gulf, Mobile & Northern	70 040	0.60	188 201	1.09	*436	258 677	931.38	2 950 608	2 048 536
Illinois Central	41 453	0.81	1 283 639	1.12	*263	1 325 355	7 743.10	23 595 046	41 715 481
Yazoo & Miss. Valley	185 668	0.75	226 528	1.09	-	412 196	2 114.01	6 463 256	5 627 922
Louisville & Nashville	49 710	1.07	758 887	1.46	-	808 597	6 873.85	19 621 290	36 291 696
Mississippi Central	2 287	0.47	54 567	1.03	-	56 854	168.18	532 458	224 889
Mobile & Ohio	157 515	0.67	255 705	1.10	-	413 220	1 196.07	3 789 142	4 899 033
Nashville, Chatt. & St. Louis	-	-	160 715	1.37	* 69	160 784	1 522.42	4 140 982	6 136 670
New Orleans & Northeastern	-	-	27 573	1.56	-	27 573	281.38	876 188	1 287 256
Norfolk Southern	312 158	0.62	-	-	-	312 158	932.54	2 574 716	1 393 971
Northern Alabama	20 918	0.64	23 114	1.90	-	44 032	119.89	374 765	258 637
Seaboard Air Line	375 805	0.91	615 385	1.18	-	991 190	5 368.14	16 258 343	19 957 540
Southern Ry.	515 863	1.10	1 210 067	1.59	-	1 725 930	8 706.05	27 237 987	41 219 673
Tennessee Central	75 960	0.72	218	1.31	-	76 178	336.21	1 018 029	749 473

TABLE A

TABLE A

CROSS TIES LAID IN REPLACEMENT - CLASS I STEAM ROADS, UNITED STATES AND LARGE CANADIAN ROADS

Calendar year ended December 31, 1939

Road	New wooden ties untreated (U)		New wooden ties treated (T)		Ties other than wood(S) and secondhand reapplied ties	Total ties applied	Miles of maintained tracks (item 24)	Estimated total cross ties in all maintained tracks (item 25)	Total equated gross ton-miles a (thousands)
	Number	Average cost	Number	Average cost					
1	2	3	4	5	6	7	8	9	10
NORTHWESTERN REGION:									
Chicago & North Western	43 689	$0.58	1 639 606	$1.05	-	1 683 295	12 040.24	35 670 702	35 940 2[illegible]
Chicago Great Western	122 672	0.87	174 848	1.39	-	297 520	1 896.11	5 594 052	8 865 12[illegible]
Chicago, Milwaukee, St. Paul & Pac.	551 749	0.57	1 892 913	1.29	-	2 444 662	13 825.32	42 435 787	46 635 871
Chicago, St. Paul, Minpls. & Omaha	44 272	0.57	347 100	1.28	-	391 372	2 223.37	6 586 504	6 952 780
Duluth, Missabe & Iron Range	27 853	0.82	69 641	1.63	-	97 494	1 166.00	3 293 826	3 374 473
Duluth, South Shore & Atlantic	90 130	0.59	1 426	1.18	-	91 556	513.48	1 462 388	738 947
Duluth, Winnipeg & Pacific	50 433	0.54	11 000	1.51	-	61 433	209.78	629 340	493 508
Great Northern	14 511	0.44	1 289 943	1.30	*47 123	1 351 577	9 898.17	30 627 965	36 059 048
Green Bay & Western	78 623	0.77	15 355	1.54	-	93 978	282.50	817 459	479 161
Lake Superior & Ishpeming	32 401	0.61	2 357	1.73	-	34 758	235.52	706 560	187 986
Minneapolis & St. Louis	259 881	0.74	108 744	1.25	-	368 625	1 669.25	5 063 028	2 387 384
Minneapolis, St. Paul & S.S. Marie	406 928	0.57	254 235	1.26	-	661 163	4 957.39	14 591 675	10 828 240
Northern Pacific	20 284	0.52	1 210 603	1.19	-	1 230 887	9 058.30	26 302 459	28 735 536
Spokane International	63 449	0.46	-	-	-	63 449	180.54	512 195	230 438
Spokane, Portland & Seattle	54 341	0.58	144 880	1.29	-	199 221	1 088.45	3 156 027	3 527 7[illegible]
CENTRAL WESTERN REGION:									
Alton R.R.	200 971	1.06	178 191	1.80	*10 575	389 737	1 508.12	4 557 025	6 943 181
Atchison, Topeka & Santa Fe	160	1.01	1 947 642	1.18	-	1 947 802	19 375.01	58 941 905	80 527 806
Chicago, Burlington & Quincy	-	-	1 916 233	1.30	*103 270	2 019 503	12 383.52	38 240 310	45 718 40[illegible]
Chgo., R.I. & Pac. (Inc. CRI&G)	-	-	1 173 978	1.00	*12 488	1 186 466	9 814.70	29 263 858	36 948 195
Colorado & Southern	10 187	0.61	67 890	1.27	*13 812	91 889	899.78	2 699 340	2 691 945
Denver & Rio Grande Western	13 436	0.53	236 791	1.10	*62 914	313 141	3 285.89	10 257 148	11 770 625
Denver & Salt Lake	31	0.68	54 463	1.35	-	54 494	313.50	957 429	747 352
Fort Worth & Denver City	-	-	99 555	1.16	*5 989	105 544	953.14	2 869 786	2 795 575
Nevada Northern	33 074	0.83	-	-	-	33 074	190.69	547 390	148 098
Northwestern Pacific	81 173	0.78	-	-	-	81 173	459.70	1 338 484	857 706
Southern Pacific	146 680	0.72	1 022 559	1.20	-	1 169 239	12 313.67	37 277 328	73 199 545
Toledo, Peoria & Western	351	0.45	61 958	1.40	-	62 309	276.45	875 794	730 472
Union Pacific	19 693	0.55	2 015 335	1.16	-	2 035 028	13 147.04	37 112 796	80 777 640
Utah Ry.	328	0.70	5 501	2.27	*1 742	7 571	73.60	209 024	216 126
Western Pacific	192 492	0.84	273 468	1.42	-	465 960	1 486.41	4 411 937	8 408 769
SOUTHWESTERN REGION:									
Burlington-Rock Island	-	-	18 398	0.87	-	18 398	212.49	665 094	442 440
Gulf Coast Lines:									
Beaumont, Sour Lake & Western	610	0.57	13 586	1.04	-	14 196	139.73	416 000	896 670
New Orleans, Texas & Mexico	5 374	0.55	42 143	1.04	-	47 517	225.39	689 400	747 735
St. Louis, Brownsville & Mexico	-	-	91 135	1.00	* 52	91 187	750.67	2 271 100	2 501 478
San Antonio, Uvalde & Gulf	-	-	52 796	1.02	-	52 796	360.19	1 038 500	490 479
International-Great Northern	-	-	172 530	0.99	-	172 530	1 482.75	4 442 700	5 297 506
Kansas City Southern	68	0.54	179 573	1.05	-	179 641	1 257.98	3 986 138	4 932 946
Kansas, Oklahoma & Gulf	150	0.20	45 249	1.07	-	45 399	354.40	1 049 024	844 235
Louisiana & Arkansas (Inc. LA&T)	63 263	0.54	139 114	0.87	-	202 377	934.63	3 030 430	2 396 706
Midland Valley	223	0.20	32 617	1.07	-	32 840	382.40	1 133 740	376 871
Missouri & Arkansas	125 443	0.45	-	-	-	125 443	357.81	1 115 064	375 801
Missouri-Kansas-Texas Lines	13 829	0.71	462 142	1.02	-	475 971	4 089.36	12 877 700	13 412 750
Missouri Pacific	129 152	0.55	1 562 356	1.08	-	1 691 508	8 975.83	27 787 756	40 666 607
Oklahoma City-Ada-Atoka	25 638	0.54	8 815	0.49	-	34 453	142.71	410 700	68 098
St. Louis-San Francisco	71 322	0.64	849 428	1.08	-	920 750	6 461.74	20 333 872	20 488 962
St. Louis, San Fran. & Texas	2 308	0.64	36 512	1.03	-	38 820	234.09	786 430	442 770
St. Louis Southwestern Lines	-	-	336 725	1.16	*11 328	348 053	1 908.94	6 047 538	7 998 384
Texas & New Orleans	-	-	763 913	0.93	-	763 913	5 655.47	15 389 303	17 932 988
Texas & Pacific	55	0.31	256 870	1.00	-	256 925	2 475.95	7 233 100	11 602 976
Texas Mexican	480	0.25	22 416	1.14	-	22 896	205.57	651 246	161 002
CANADIAN ROADS:									
Canadian National									
Canadian Pacific	1 857 436	0.52	1 471 024	1.15	-	3 328 460	21 377	61 031 931	58 535 095
Temiskaming & Northern Ontario	137 028	0.69	272	1.89	-	137 300	545.10	1 548 900	1 543 086

* Secondhand ties.

t Tunnel ties.

a Gross ton-miles of cars and contents, plus two times gross ton-miles of locomotives and tenders in freight service, plus three times gross ton-miles of locomotives and tenders in passenger service.

Note: "Average cost", as shown in columns 3 and 5, represent storekeepers' average cost of ties charged out and used. They are not the actual costs or the prices paid for ties purchased during the period.

Note: Compiled from annual reports of Class I railways to the Interstate Commerce Commission.

Compiled by
Association of American Railroads
Bureau of Railway Economics
Washington, D.C.

TABLE B

NEW WOODEN CROSS TIES LAID IN REPLACEMENT (TREATED & UNTREATED) ON LEADING RAILROADS IN THE UNITED STATES AND CANADA

TABLE B

NEW WOODEN CROSS TIES LAID IN REPLACEMENT (TREATED & UNTREATED) ON LEADING RAILROADS IN THE UNITED STATES AND CANADA

Calendar year ended December 31, 1939

Note: All figures are exclusive of bridge & switch ties

Road	Miles of maintained track occupied by cross ties (Col.8-Table A)	Average number of cross ties per mile of maintained track	Total number of new wooden cross ties laid in replacement 1939	Number of new wooden cross ties laid in replacement per mile of maintained track	Weighted average cost per new wooden cross tie	Cost of new wooden cross tie renewals per mile of maintained track	Per cent new wooden cross tie renewals to all ties in tracks	Equated gross ton-miles per mile of maintained track	Cost of new wooden cross tie renewals per thousand equated gross ton-miles
1	2	3	4	5	6	7	8	9	10
NEW ENGLAND REGION:									(cents)
Bangor & Aroostook	830.14	2 863	150 009	181	$0.65	$118	6.3	1 499 776	7.99
Boston & Maine	3 093.00	2 942	213 789	69	1.46	101	2.3	4 161 851	2.43
Canadian Nat.Lines in New Eng.	249.30	3 074	45 492	182	1.01	184	5.9	2 156 069	8.52
Canadian Pacific (lines in Me.)	212.50	3 070	11 707	55	1.48	81	1.8	5 791 238	1.41
Canadian Pacific (lines in Vt.)	132.02	3 182	7 336	56	1.30	72	1.7	4 114 096	1.81
Central Vermont	497.31	2 870	52 728	106	1.27	134	3.7	4 389 697	3.06
Maine Central	1 240.30	3 032	223 811	180	0.93	168	6.0	2 620 256	6.41
New York Connecting	25.90	3 152	8 926	345	1.73	597	10.9	13 291 892	4.49
New York,New Haven & Hartford	4 018.74	3 034	329 309	82	0.92	75	2.7	4 947 352	1.52
Rutland	499.86	3 102	23 277	47	1.29	60	1.5	3 063 740	1.96
GREAT LAKES REGION:									
Ann Arbor	405.15	3 018	35 231	87	1.48	129	2.9	3 636 759	3.53
Cambria & Indiana	59.28	2 716	18 329	309	1.61	496	11.4	2 495 040	19.90
Delaware & Hudson	1 457.42	3 054	171 544	118	2.17	255	3.9	6 051 735	4.21
Delaware,Lackawanna & Western	2 339.51	2 900	81 592	35	1.62	56	1.2	6 932 901	0.81
Detroit & Mackinac	293.51	2 998	32 963	112	0.56	62	3.7	853 048	7.31
Detroit & Toledo Shore Line	151.58	3 013	19 796	131	1.84	241	4.3	4 393 541	5.48
Erie (Inc.Chgo.& Erie)	4 845.19	2 926	430 210	89	1.43	127	3.0	6 567 804	1.94
Grand Trunk Western	1 945.70	3 161	327 132	168	1.53	257	5.3	4 052 213	6.35
Lehigh & Hudson River	118.00	2 686	13 509	114	2.02	231	4.3	5 017 246	4.61
Lehigh & New England	266.82	3 017	18 013	68	1.62	110	2.2	3 244 940	3.38
Lehigh Valley	2 719.52	2 963	142 093	52	1.82	95	1.8	5 498 346	1.73
Monongahela	241.70	2 915	43 223	179	1.67	299	6.1	3 704 799	8.07
Montour	71.37	2 880	7 619	107	1.61	172	3.7	3 626 317	4.74
New York Central	21 719.42	3 137	2 031 168	94	1.53	143	3.0	6 689 713	2.13
New York,Chicago & St.Louis	2 522.19	3 150	293 980	117	1.45	169	3.7	6 839 527	2.47
New York,Ontario & Western	872.84	2 863	-	-	-	-	-	2 525 449	-
New York,Susquehanna & Western	228.04	2 906	16 705	73	1.31	96	2.5	1 695 913	5.64
Pere Marquette	2 820.41	3 025	471 487	167	1.58	264	5.5	3 691 293	7.14
Pittsburgh & Lake Erie	925.99	2 996	64 971	70	1.93	135	2.3	4 346 766	3.11
Pittsburg & Shawmut	124.49	2 782	25 439	204	1.46	298	7.3	1 297 703	22.94
Pittsburgh & West Virginia	198.26	2 907	33 605	169	1.88	318	5.8	4 418 980	7.20
Pittsburg,Shawmut & Northern	221.24	2 939	40 107	181	1.02	184	6.2	1 098 151	16.77
Wabash	3 186.50	3 108	514 721	162	1.51	244	5.2	6 081 180	4.01
CENTRAL EASTERN REGION:									
Akron.Canton & Youngstown	213.35	2 984	18 166	85	1.25	106	2.9	2 165 231	4.90
Baltimore & Ohio	10 611.60	2 845	1 673 205	158	1.47	232	5.5	5 999 031	3.86
Bessemer & Lake Erie	490.48	3 074	94 380	192	2.16	416	6.3	7 023 905	5.92
Central R.R.of New Jersey	1 486.51	2 810	104 044	70	1.79	125	2.5	5 554 630	2.25
Chicago & Eastern Illinois	1 469.05	2 898	155 472	106	1.17	124	3.7	4 084 502	3.04
Chicago & Illinois Midland	164.66	3 083	11 557	70	1.73	121	2.3	5 740 198	2.11
Chicago,Indpls.& Louisville	807.18	3 075	119 815	148	1.17	173	4.8	4 279 080	4.04
Detroit,Toledo & Ironton	611.57	2 880	60 439	99	1.39	137	3.4	2 480 295	5.53
Elgin,Joliet & Eastern	871.12	3 089	179 885	206	1.63	337	6.7	3 220 270	10.46
Illinois Terminal	634.65	3 000	54 390	86	1.27	109	2.9	1 526 704	7.13
Long Island	817.96	2 965	53 500	65	1.80	118	2.2	4 832 053	2.44
Missouri-Illinois	238.97	3 128	72 161	302	0.74	224	9.7	1 325 878	16.91
Pennsylvania	21 323.15	2 800	1 648 926	77	1.57	121	2.8	7 497 106	1.62
Penna.-Reading Seashore Lines	661.88	2 737	58 627	89	1.85	164	3.2	2 675 595	6.12
Reading Co.	3 027.59	2 759	134 634	44	1.79	80	1.6	4 983 179	1.60
Staten Island Rapid Transit	80.21	2 746	1 865	23	1.41	33	0.8	1 774 691	1.85
Western Maryland	1 167.47	2 810	222 760	191	1.48	282	6.8	4 857 409	5.81
Wheeling & Lake Erie	844.79	2 998	132 318	157	1.32	207	5.2	4 300 661	4.82
POCAHONTAS REGION:									
Chesapeake & Ohio	5 069.05	3 078	420 287	83	1.21	100	2.7	9 405 495	1.06
Norfolk & Western	4 228.23	3 100	160 221	38	1.29	49	1.2	8 666 076	0.57
Richmond,Fred.& Potomac	371.63	2 857	99 756	268	1.61	433	9.4	10 620 442	4.08
Virginian	872.84	3 114	151 038	173	1.43	248	5.6	8 812 753	2.81
SOUTHERN REGION:									
Alabama Great Southern	548.13	3 122	63 273	115	1.68	194	3.7	5 397 450	3.60
Atlanta & West Point	141.54	3 067	24 801	175	1.13	199	5.7	4 632 818	4.29
Western Ry.of Alabama	182.22	3 037	29 888	164	1.14	187	5.4	3 850 532	4.86
Atlanta,Birmingham & Coast	794.22	2 894	119 061	150	0.88	132	5.2	2 299 504	5.76
Atlantic Coast Line	6 832.77	2 911	858 638	126	1.09	137	4.3	3 390 156	4.03
Central of Georgia	2 343.97	2 940	364 663	156	0.90	140	5.3	3 070 322	4.56
Charleston & Western Carolina	427.80	2 888	58 130	136	1.07	146	4.7	1 995 035	7.30
Cincinnati,New Orleans & Tex.Pac.	772.17	3 118	63 181	82	1.74	143	2.6	9 329 394	1.53
Clinchfield	395.81	3 040	90 239	228	1.01	230	7.5	6 907 228	3.33
Columbus & Greenville	203.91	3 168	44 101	216	1.11	240	6.8	1 730 455	13.85
Florida East Coast	1 344.46	2 870	260 949	194	0.92	180	6.8	3 532 574	5.08
Georgia R.R.	433.11	3 062	72 822	168	1.10	185	5.5	3 387 096	5.45
Georgia & Florida	451.95	2 700	90 819	201	0.64	129	7.4	992 760	12.99
Georgia,Southern & Florida	469.75	3 145	49 163	105	0.97	101	3.3	3 021 254	3.36
Gulf & Ship Island	309.52	3 085	70 389	227	1.02	232	7.4	1 384 864	16.79
Gulf,Mobile & Northern	931.38	3 168	258 241	277	0.96	265	8.8	2 199 463	12.04
Illinois Central	7 743.10	3 047	1 325 092	171	1.11	190	5.6	5 387 439	3.52
Yazoo & Miss. Valley	2 114.01	3 057	412 196	195	0.94	183	6.4	2 662 202	6.87
Louisville & Nashville	6 873.85	2 854	808 597	118	1.44	169	4.1	5 279 675	3.21
Mississippi Central	168.18	3 166	56 854	338	1.01	340	10.7	1 337 192	25.42
Mobile & Ohio	1 196.07	3 168	413 220	345	0.94	323	10.9	4 095 942	7.89
Nashville,Chatt.& St.Louis	1 522.42	2 720	160 715	106	1.37	144	3.9	4 030 865	3.58
New Orleans & Northeastern	281.38	3 124	27 573	98	1.56	153	3.1	4 574 796	3.35
Norfolk Southern	932.54	2 761	312 158	335	0.62	208	12.1	1 494 811	13.88
Northern Alabama	119.89	3 126	44 032	367	1.31	483	11.7	1 157 286	22.38
Seaboard Air Line	5 368.14	3 029	991 190	185	1.08	199	6.1	3 717 776	5.35
Southern Ry.	8 706.05	3 129	1 725 930	198	1.45	287	6.3	4 734 601	6.05
Tennessee Central	336.21	3 028	76 178	227	0.72	164	7.5	2 229 181	7.35

Sheet 2 of 2 sheets.

TABLE B

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TABLE B

NEW WOODEN CROSS TIES LAID IN REPLACEMENT (TREATED & UNTREATED) ON LEADING RAILROADS IN THE UNITED STATES AND CANADA

Calendar year ended December 31, 1939

Note: All figures are exclusive of bridge & switch ties

Road	Miles of maintained track occupied by cross ties (Col.8-Table A)	Average number of cross ties per mile of maintained track	Total number of new wooden cross ties laid in replacement 1939	Number of new wooden cross ties laid in replacement per mile of maintained track	Weighted average cost per new wooden cross tie	Cost of new wooden cross tie renewals per mile of maintained track	Per cent new wooden cross tie renewals to all ties in tracks	Equated gross ton-miles per mile of maintained track	Cost of new wooden cross tie renewals per thousand equated gross ton-miles
1	2	3	4	5	6	7	8	9	10
NORTHWESTERN REGION:									(cents)
Chicago & North Western	12 040.24	2 963	1 683 295	140	$1.04	$145	4.7	2 985 011	4.86
Chicago Great Western	1 896.11	2 950	297 520	157	1.18	184	5.3	4 675 427	3.94
Chicago, Milwaukee, St. Paul & Pac.	13 825.32	3 069	2 444 662	177	1.13	200	5.8	3 373 222	5.93
Chicago, St. Paul, Minpls. & Omaha	2 223.37	2 962	391 372	176	1.20	211	5.9	3 127 136	6.74
Duluth, Missabe & Iron Range	1 166.00	2 825	97 494	84	1.40	117	3.0	2 894 059	4.03
Duluth, South Shore & Atlantic	513.48	2 848	91 556	178	0.60	106	6.3	1 439 096	7.39
Duluth, Winnipeg & Pacific	209.78	3 000	61 433	293	0.72	209	9.8	2 352 503	8.90
Great Northern	9 898.17	3 094	1 304 454	132	1.29	170	4.3	3 643 001	4.67
Green Bay & Western	282.50	2 894	93 978	333	0.90	298	11.5	1 696 145	17.58
Lake Superior & Ishpeming	235.52	3 000	34 758	148	0.68	101	4.9	798 174	12.67
Minneapolis & St. Louis	1 669.25	3 033	368 625	221	0.89	197	7.3	1 729 749	11.39
Minneapolis, St. Paul & S.S. Marie	4 957.39	2 943	661 163	133	0.83	111	4.5	2 184 262	5.10
Northern Pacific	9 058.30	2 904	1 230 887	136	1.17	160	4.7	3 172 288	5.03
Spokane International	180.54	2 837	63 449	351	0.46	160	12.4	1 276 382	12.56
Spokane, Portland & Seattle	1 088.45	2 900	199 221	183	1.09	200	6.3	3 241 058	6.18
CENTRAL WESTERN REGION:									
Alton	1 508.12	3 022	379 162	251	1.41	354	8.3	4 603 865	7.68
Atchison, Topeka & Santa Fe	19 375.01	3 037	1 947 802	101	1.18	118	3.3	4 156 272	2.85
Chicago, Burlington & Quincy	12 383.52	3 088	1 916 233	155	1.30	201	5.0	3 691 875	5.45
Chgo., R.I. & Pac. (Inc. CRI&G)	9 814.70	2 982	1 173 978	120	1.00	119	4.0	3 764 577	3.17
Colorado & Southern	899.78	3 000	78 077	87	1.18	103	2.9	2 991 781	3.44
Denver & Rio Grande Western	3 285.89	3 122	250 227	76	1.07	81	2.4	3 582 173	2.27
Denver & Salt Lake	313.50	3 054	54 494	174	1.35	234	5.7	2 383 898	9.81
Fort Worth & Denver City	953.14	3 011	99 555	104	1.16	121	3.5	2 933 016	4.12
Nevada Northern	190.69	2 871	33 074	173	0.83	144	6.0	776 643	18.49
Northwestern Pacific	459.70	2 912	81 173	177	0.78	138	6.1	1 865 795	7.39
Southern Pacific	12 313.67	3 027	1 169 239	95	1.14	108	3.1	5 944 576	1.82
Toledo, Peoria & Western	276.45	3 168	62 309	225	1.39	313	7.1	2 642 330	11.85
Union Pacific	13 147.04	2 823	2 035 028	155	1.15	178	5.5	6 144 169	2.90
Utah	73.60	2 840	5 829	79	2.18	173	2.8	2 936 495	5.88
Western Pacific	1 486.41	2 968	465 960	313	1.18	371	10.6	5 657 099	6.55
SOUTHWESTERN REGION:									
Burlington-Rock Island	212.49	3 130	18 398	87	0.87	75	2.8	2 082 169	3.61
Gulf Coast Lines:									
Beaumont, Sour Lake & Western	139.73	2 977	14 196	102	1.02	104	3.4	6 417 162	1.62
New Orleans, Texas & Mexico	225.39	3 059	47 517	211	0.99	208	6.9	3 317 516	6.27
St. Louis, Brownsville & Mexico	750.67	3 025	91 135	121	1.00	121	4.0	3 332 327	3.64
San Antonio, Uvalde & Gulf	360.19	2 883	52 796	147	1.02	150	5.1	1 361 723	11.00
International-Great Northern	1 482.75	2 996	172 530	116	0.99	115	3.9	3 572 961	3.21
Kansas City Southern	1 257.98	3 169	179 641	143	1.05	150	4.5	3 921 323	3.82
Kansas, Oklahoma & Gulf	354.40	2 960	45 399	128	1.06	136	4.3	2 382 153	5.71
Louisiana & Arkansas (Inc. LA&T)	934.63	3 242	202 377	217	0.77	166	6.7	2 564 337	6.46
Midland Valley	382.40	2 965	32 840	86	1.06	91	2.9	985 541	9.24
Missouri & Arkansas	357.81	3 116	125 443	351	0.45	156	11.2	1 050 281	14.89
Missouri-Kansas-Texas Lines	4 089.36	3 149	475 971	116	1.01	118	3.7	3 279 914	3.60
Missouri Pacific	8 975.83	3 096	1 691 508	188	1.04	196	6.1	4 530 679	4.32
Oklahoma City-Ada-Atoka	142.71	2 878	34 453	241	0.53	128	8.4	477 177	26.79
St. Louis-San Francisco	6 461.74	3 147	920 750	142	1.05	150	4.5	3 170 812	4.72
St. Louis, San Fran. & Texas	234.09	3 360	38 820	166	1.00	166	4.9	1 891 452	8.79
St. Louis Southwestern Lines	1 908.94	3 168	336 725	176	1.16	205	5.6	4 189 961	4.88
Texas & New Orleans	5 655.47	2 721	763 913	135	0.93	126	5.0	3 170 910	3.96
Texas & Pacific	2 475.95	2 921	256 925	104	1.00	104	3.6	4 686 272	2.22
Texas Mexican	205.57	3 168	22 896	111	1.12	124	3.5	783 198	15.89
CANADIAN ROADS:									
Canadian National									
Canadian Pacific	21 377	2 855	3 328 460	156	0.80	124	5.5	2 738 228	5.00
Temiskaming & Northern Ontario	545.10	2 900	137 300	257	0.69	179	8.9	2 889 132	6.20

Col.3 derived by dividing Col.9 Table A, by Col.8 of same table.
Col.4 is total of Cols. 2 and 4 of Table A.
Col.5 derived by dividing total of Cols. 2 and 4 Table A, by Col.8 of same table.
Col.6 is weighted average of costs shown in Cols. 3 and 5 of Table A.

Note: Compiled from annual reports of Class I railways to the Interstate Commerce Commission.

Compiled by
Association of American Railroads
Bureau of Railway Economics
Washington, D.C.

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TABLE C

NUMBER AND AGGREGATE COST OF NEW WOODEN CROSS TIE RENEWALS PER MILE OF MAINTAINED TRACK AND RATIO OF NEW WOODEN CROSS TIE RENEWALS TO TOTAL CROSS TIES IN MAINTAINED TRACK

Class I roads in the United States and large Canadian roads, by years, and for the average of the five years 1935 to 1939, inclusive

Note: All figures are exclusive of bridge and switch ties.

Road	Number of new wooden cross tie renewals per mile of maintained track						Aggregate cost of new wooden cross tie renewals per mile of maintained track						Per cent new wooden cross tie renewals to all ties in tracks					
	1935	1936	1937	1938	1939	5 year average	1935	1936	1937	1938	1939	5 year average	1935	1936	1937	1938	1939	5 year average
NEW ENGLAND REGION:																		
Bangor & Aroostook	190	188	198	190	181	189	$106	$102	$109	$109	$118	$109	6.7	6.6	6.9	6.6	6.3	6.6
Boston & Maine	64	71	103	73	69	76	94	99	155	105	101	111	2.2	2.4	3.5	2.5	2.3	2.6
Canadian Nat. Lines in New Eng.	92	135	111	130	182	130	137	163	122	139	184	147	3.0	4.4	3.6	4.2	5.9	4.2
Canadian Pacific (lines in Me.)	153	148	139	107	55	120	186	181	175	154	81	155	5.3	5.1	4.8	3.7	1.8	4.1
Canadian Pacific (lines in Vt.)	53	42	46	55	56	50	66	53	48	70	72	62	1.5	1.3	1.4	1.8	1.7	1.5
Central Vermont	153	137	113	100	106	122	213	195	166	150	134	172	5.0	4.5	3.7	3.5	3.7	4.1
Maine Central	187	219	230	202	180	204	204	254	271	245	168	228	6.2	7.2	7.6	6.7	6.3	6.7
New York Connecting	213	317	226	297	345	280	330	469	332	453	597	436	6.7	9.9	7.1	9.3	10.9	8.8
New York, New Haven & Hartford	71	86	78	70	82	77	93	107	93	90	75	92	2.3	2.8	2.6	2.3	2.7	2.5
Rutland	109	88	74	57	47	75	129	111	94	77	60	94	3.5	2.8	2.4	1.9	1.5	2.4
GREAT LAKES REGION:																		
Ann Arbor	106	110	101	90	87	99	142	142	133	127	129	135	3.6	3.7	3.4	3.0	2.9	3.3
Cambria & Indiana	237	285	338	342	309	302	211	277	437	475	496	379	8.8	10.3	12.9	13.1	11.4	11.4
Delaware & Hudson	106	93	108	73	118	100	223	199	230	154	255	212	3.5	3.1	3.5	2.4	3.9	3.3
Delaware, Lackawanna & Western	92	127	70	57	35	76	128	161	97	95	56	107	3.2	4.4	2.4	2.0	1.2	2.6
Detroit & Mackinac	132	119	127	156	112	129	70	67	72	76	62	70	4.4	4.0	4.2	5.2	3.7	4.3
Detroit & Toledo Shore Line	134	129	111	82	131	117	235	224	196	147	241	209	4.4	4.2	3.6	2.7	4.3	3.3
Erie (Incl. C&E)	90	88	90	82	89	88	131	124	132	124	127	128	3.1	3.0	3.1	2.8	3.0	3.0
Grand Trunk Western	153	160	150	144	168	155	206	223	217	230	257	227	4.8	5.1	4.8	4.6	5.3	4.9
Lehigh & Hudson River	46	57	91	90	114	80	77	103	184	206	231	160	1.8	2.2	3.4	3.4	4.3	3.0
Lehigh & New England	69	64	59	59	68	64	93	90	82	93	110	94	2.3	2.1	2.0	2.0	2.2	2.1
Lehigh Valley	74	38	22	46	52	46	100	52	32	63	95	68	2.5	1.3	0.8	1.6	1.8	1.6
Monongahela	157	188	182	104	179	162	260	338	343	179	299	234	5.4	6.5	6.3	3.6	6.1	5.6
Montour	103	94	101	88	107	99	194	177	222	179	172	189	3.7	3.4	3.6	3.2	3.7	3.5
New York Central R.R.Co.	71	82	97	83	94	85	96	118	132	125	143	123	2.3	2.7	3.1	2.7	3.0	2.8
New York, Chicago & St. Louis	88	94	111	94	117	101	141	135	167	147	169	152	2.8	3.0	3.5	3.0	3.7	3.2
New York, Ontario & Western	83	51	55	43	-	46	122	67	72	63	-	65	2.9	1.8	1.9	1.5	-	1.6
New York, Susquehanna & Western	99	92	85	73	73	84	129	111	112	104	96	110	3.4	3.1	2.9	2.5	2.5	2.9
Pere Marquette	127	142	172	153	167	152	182	214	281	259	264	240	4.2	4.7	5.7	5.1	5.5	5.0
Pittsburgh & Lake Erie	29	51	71	32	70	51	59	102	124	63	135	97	1.0	1.7	2.4	1.1	2.3	1.7
Pittsburg & Shawmut	261	301	348	224	204	268	309	283	476	320	298	337	10.3	10.8	12.5	8.0	7.3	9.8
Pittsburgh & West Virginia	170	308	318	265	169	246	175	267	524	488	318	354	5.9	10.6	10.9	9.1	5.8	8.5
Pittsburg, Shawmut & Northern	174	150	157	113	181	161	157	164	155	112	184	154	5.9	6.1	5.4	3.8	6.2	5.5
Wabash	139	146	151	153	162	150	205	204	229	216	244	220	4.5	4.7	4.9	4.9	5.2	4.8
CENTRAL EASTERN REGION:																		
Akron, Canton & Youngstown	339	194	173	165	85	191	366	240	226	179	136	223	11.8	6.7	6.0	5.7	2.9	6.6
Baltimore & Ohio	91	109	118	65	158	108	128	146	168	103	232	155	3.2	3.8	4.2	2.3	5.5	3.8
Bessemer & Lake Erie	239	260	270	212	192	235	507	554	585	467	416	506	7.7	8.4	8.7	6.9	6.3	7.6
Central R.R. of New Jersey	49	60	62	40	70	56	80	98	106	68	125	95	1.8	2.1	2.2	1.4	2.5	2.0
Chicago & Eastern Illinois	100	79	97	111	106	99	107	91	109	134	124	113	3.2	2.6	3.1	3.6	3.7	3.2
Chicago & Illinois Midland	147	99	85	76	70	95	193	151	135	134	121	147	4.8	3.2	2.7	2.5	2.3	3.1
Chicago, Indpls. & Louisville	97	79	96	183	148	121	101	82	101	206	173	133	3.2	2.6	3.1	6.0	4.8	3.9
Detroit, Toledo & Ironton	155	134	130	110	99	126	193	152	159	143	137	157	5.4	4.6	4.5	3.8	3.4	4.3
Elgin, Joliet & Eastern	176	211	216	98	206	181	242	300	331	164	337	275	5.7	6.8	6.8	3.1	6.7	5.8
Illinois Terminal	85	88	96	84	86	88	88	98	114	95	109	101	2.8	2.9	3.2	2.8	2.9	2.9
Long Island	58	58	85	60	65	65	73	84	131	113	118	104	2.0	2.0	2.9	2.0	2.2	2.2
Missouri-Illinois	421	384	339	279	302	345	381	260	272	280	224	283	13.4	12.3	10.9	8.9	9.7	11.0
Pennsylvania R.R.	57	79	105	60	77	76	89	114	168	93	121	117	2.0	2.8	3.7	2.2	2.8	2.7
Penna.-Reading Seashore Lines	49	46	59	76	89	64	58	66	123	171	164	116	1.8	1.7	2.1	2.8	3.2	2.3
Reading Co.	36	41	41	28	44	38	63	71	76	48	80	68	1.3	1.5	1.5	1.0	1.6	1.4
Staten Island Rapid Transit	43	45	72	52	23	48	110	89	126	49	33	81	1.8	1.7	2.6	1.9	0.8	1.8
Western Maryland	202	226	194	128	191	188	253	294	267	190	282	257	7.0	7.9	6.7	4.5	6.8	6.6
Wheeling & Lake Erie	221	220	211	90	157	180	277	290	295	122	207	238	7.3	7.3	7.0	3.0	5.2	6.0
POCAHONTAS REGION:																		
Chesapeake & Ohio	73	91	66	85	83	80	86	99	75	104	100	93	2.4	3.0	2.1	2.8	2.7	2.6
Norfolk & Western	75	61	42	22	38	48	82	64	45	27	49	53	2.4	2.0	1.3	0.7	1.2	1.5
Richmond, Fred. & Potomac	314	281	305	268	268	287	231	255	422	437	433	356	11.0	9.9	10.7	9.4	9.4	10.1
Virginian	215	220	225	178	173	202	181	236	224	262	248	230	6.9	7.1	7.2	5.7	5.6	6.5
SOUTHERN REGION:																		
Alabama Great Southern	253	217	183	149	115	183	335	278	256	215	194	256	8.2	7.0	5.9	4.8	3.7	5.9
Atlanta & West Point	151	156	196	162	175	168	231	219	201	158	199	202	4.9	5.1	6.4	5.3	5.7	5.5
Western Ry. of Alabama	138	141	165	175	164	157	194	188	169	201	187	188	4.5	4.6	5.4	5.8	5.4	5.1
Atlanta, Birmingham & Coast	156	183	179	151	150	165	106	155	186	148	132	145	5.6	6.5	6.2	5.2	5.2	5.7
Atlantic Coast Line	154	140	112	129	126	132	116	103	98	131	137	117	5.3	4.8	3.9	4.4	4.3	4.5
Central of Georgia	121	126	136	145	156	137	96	104	118	149	140	121	4.3	4.5	4.9	4.9	5.3	4.8
Charleston & Western Carolina	177	172	157	146	136	158	166	166	155	159	146	158	6.1	5.9	5.4	5.0	4.7	5.4
Cincinnati, New Orleans & Tex. Pac.	145	138	109	86	82	112	222	208	166	142	143	176	4.7	4.4	3.5	2.8	2.6	3.6
Clinchfield	304	308	312	252	228	281	274	284	307	263	230	272	10.0	10.1	10.3	8.3	7.5	9.2
Columbus & Greenville	271	209	223	203	216	224	196	210	257	203	240	221	8.6	6.6	7.0	6.4	6.8	7.1
Florida East Coast	141	131	133	134	194	157	102	99	143	119	180	129	4.9	4.6	6.4	4.7	6.3	5.5
Georgia R.R.	110	111	143	161	168	139	148	116	180	199	185	166	3.6	3.6	4.7	5.3	5.5	4.5
Georgia & Florida	278	269	266	181	201	239	148	167	179	116	129	148	10.3	10.0	9.8	6.7	7.4	8.8
Georgia, Southern & Florida	79	84	88	77	105	87	60	67	87	80	101	79	2.5	2.7	2.8	2.5	3.3	2.8
Gulf & Ship Island	152	144	174	194	227	178	100	133	175	202	232	168	5.0	4.7	5.7	6.3	7.4	5.8
Gulf, Mobile & Northern	207	201	318	257	277	252	177	173	310	274	265	240	6.5	6.3	10.0	8.1	8.8	7.9
Illinois Central	133	144	142	147	171	147	120	137	144	156	190	149	4.4	4.7	4.6	4.8	5.6	4.8
Yazoo & Mississippi Valley	149	144	152	170	195	162	109	115	142	159	183	142	4.9	4.7	5.0	5.6	6.4	5.3
Louisville & Nashville	107	110	115	113	118	113	131	135	144	152	169	146	3.8	3.9	4.0	3.9	4.1	3.9
Mississippi Central	218	338	376	221	338	298	145	289	378	218	340	274	6.9	10.7	11.9	7.0	10.7	9.4
Mobile & Ohio	314	317	289	299	345	313	205	209	235	234	323	241	10.0	10.0	9.1	9.4	10.9	9.9
Nashville, Chattanooga & St. Louis	140	118	114	109	106	117	144	129	129	149	144	139	4.7	4.0	3.9	4.0	3.9	4.1
New Orleans & Northeastern	159	137	131	116	98	128	207	171	178	165	153	175	5.1	4.4	4.2	3.7	3.1	4.1
Norfolk Southern	362	280	367	279	335	325	206	163	272	192	208	208	12.7	9.9	12.0	9.1	12.1	11.2
Northern Alabama	377	384	393	394	367	383	267	431	486	501	483	434	12.1	12.3	12.6	12.6	11.7	12.3
Seaboard Air Line	237	226	204	187	185	208	182	183	189	194	199	189	8.2	7.5	6.8	6.2	6.1	7.0
Southern Ry.	273	259	240	205	198	235	244	256	280	266	287	267	8.7	8.3	7.7	6.5	6.3	7.5
Tennessee Central	288	294	254	200	227	253	295	245	169	143	164	203	9.2	9.7	8.4	6.6	7.5	8.3

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TABLE C

NUMBER AND AGGREGATE COST OF NEW WOODEN CROSS TIE RENEWALS PER MILE OF MAINTAINED TRACK AND RATIO OF NEW WOODEN TIE RENEWALS TO TOTAL CROSS TIES IN MAINTAINED TRACK

Class I roads in the United States and large Canadian roads, by years, and for the average of the five years 1935 to 1939, inclusive

Note: All figures are exclusive of bridge and switch ties.

Road	Number of new wooden cross tie renewals per mile of maintained track						Aggregate cost of new wooden cross tie renewals per mile of maintained track						Per cent new wooden cross tie renewals to all ties in tracks					
	1935	1936	1937	1938	1939	5 year average	1935	1936	1937	1938	1939	5 year average	1935	1936	1937	1938	1939	5 year average
NORTHWESTERN REGION:																		
Chicago & North Western	120	143	149	139	140	138	$110	$126	$139	$143	$145	$133	4.1	4.8	5.0	4.7	4.7	4.7
Chicago Great Western	165	151	178	157	157	162	162	185	225	200	184	191	5.7	5.1	6.0	5.3	5.3	5.5
Chicago, Milwaukee, St. Paul & Pac.	241	212	138	125	177	179	263	211	135	125	200	187	8.1	7.1	4.6	4.1	5.8	5.9
Chicago, St. Paul, Minpls. & Omaha	146	167	189	182	176	172	129	151	178	187	211	171	4.9	5.6	6.4	6.1	5.9	5.8
Duluth, Missabe & Iron Range	52	76	120	63	84	79	71	110	148	82	117	106	1.8	2.5	4.0	2.1	3.0	2.7
Duluth, South Shore & Atlantic	203	223	247	193	178	209	99	126	152	118	106	120	7.1	7.8	8.7	6.8	6.3	7.3
Duluth, Winnipeg & Pacific	369	376	306	320	293	333	193	223	210	238	209	215	12.3	12.5	10.2	10.7	9.8	11.1
Great Northern	104	112	121	106	132	115	112	126	141	132	170	136	3.3	3.6	3.9	3.4	4.3	3.7
Green Bay & Western	417	441	352	320	333	373	322	391	343	314	298	334	14.8	15.3	12.2	11.1	11.5	13.0
Lake Superior & Ishpeming	198	225	193	168	148	186	117	136	125	114	101	119	7.0	7.5	6.4	5.6	4.9	6.3
Minneapolis & St. Louis	136	206	199	198	221	192	116	168	195	193	197	174	4.5	6.8	6.6	6.5	7.3	6.3
Minneapolis, St. Paul & S.S. Marie	179	179	169	161	133	164	146	162	143	122	111	137	6.1	6.1	5.7	5.5	4.5	5.6
Northern Pacific	91	122	129	128	136	121	94	126	126	144	160	130	3.2	4.2	4.4	4.4	4.7	4.2
Spokane International	300	341	370	329	351	338	123	153	168	150	160	151	10.6	12.1	13.1	11.6	12.4	12.0
Spokane, Portland & Seattle	130	166	173	237	183	178	76	120	150	223	200	155	4.3	5.5	5.7	7.3	6.3	5.8
CENTRAL WESTERN REGION:																		
Alton R.R.	247	240	233	248	251	244	266	287	296	352	354	311	8.2	7.9	7.7	8.2	8.3	8.1
Atchison, Topeka & Sante Fe (see note)	108	120	125	84	101	108	117	136	143	102	118	123	3.6	4.0	4.1	2.8	3.3	3.6
Chicago, Burlington & Quincy	120	138	149	153	155	143	146	170	186	201	201	181	3.9	4.5	4.8	4.9	5.0	4.6
Chicago, Rock Island & Pacific (see note)	69	100	126	118	120	107	65	96	117	122	119	104	2.3	3.3	4.2	3.9	4.0	3.5
Colorado & Southern	133	123	86	78	87	101	112	100	89	92	103	99	4.4	4.1	2.9	2.6	2.9	3.4
Denver & Rio Grande Western	134	151	137	81	76	116	129	147	145	93	81	119	4.3	4.8	4.4	2.6	2.4	3.7
Denver & Salt Lake	315	468	395	42	174	279	284	589	502	60	234	334	10.3	15.3	12.9	1.4	5.7	9.1
Fort Worth & Denver City	46	64	73	94	104	76	49	67	78	106	121	84	1.5	2.1	2.4	3.1	3.5	2.5
Nevada Northern	132	131	140	162	173	148	108	102	112	143	144	122	4.6	4.6	4.9	5.6	6.0	5.1
Northwestern Pacific	73	64	128	104	177	109	44	43	99	84	138	82	2.5	2.2	4.4	3.6	6.1	3.8
Southern Pacific Co.- Pac. Lines	62	78	92	99	95	85	67	91	107	114	108	97	2.1	2.6	3.1	3.3	3.1	2.8
Toledo, Peoria & Western	230	278	399	356	225	298	298	372	568	505	313	411	7.2	8.8	12.6	11.2	7.1	9.4
Union Pacific (see note)	139	159	178	150	155	156	155	166	183	170	178	170	4.9	9.6	6.3	5.3	5.5	6.3
Utah Ry.	272	259	155	97	79	172	415	403	228	153	173	274	10.5	10.0	5.8	3.6	2.8	6.5
Western Pacific	295	361	393	243	313	321	192	237	361	282	371	239	10.1	12.2	13.2	8.2	10.6	10.9
SOUTHWESTERN REGION:																		
Burlington-Rock Island	54	76	69	59	87	69	41	59	41	54	75	54	1.7	2.4	2.2	1.9	2.8	2.2
Gulf Coast Lines:																		
Beaumont, Sour Lake & Western	92	77	110	104	102	97	86	83	122	111	104	101	3.1	2.6	3.7	3.5	3.4	3.3
New Orleans, Texas & Mexico	107	119	175	217	211	166	102	124	190	224	208	170	3.5	3.9	5.7	7.1	6.9	5.4
St. Louis, Brownsville & Mexico	66	81	113	115	121	99	58	82	120	117	121	100	2.2	2.7	3.7	3.8	4.0	3.3
San Antonio, Uvalde & Gulf	96	89	125	164	147	124	90	110	142	180	150	134	3.3	3.1	4.3	5.7	5.1	4.3
International-Great Northern	115	106	101	105	116	109	103	103	102	105	115	106	3.9	3.5	3.4	3.5	3.9	3.6
Kansas City Southern	102	117	132	137	143	126	101	121	137	143	150	130	3.2	3.7	4.2	4.3	4.5	4.0
Kansas, Oklahoma & Gulf	240	233	205	172	128	196	237	245	206	182	136	201	7.6	7.8	6.8	5.7	4.3	6.4
Louisiana & Arkansas (see note)	278	277	225	274	217	254	157	178	156	201	166	172	8.8	8.9	7.2	8.8	6.7	8.1
Midland Valley	86	115	115	92	86	99	85	120	119	93	91	102	2.7	3.8	3.8	3.1	2.9	3.3
Missouri & Arkansas	227	405	430	346	351	352	100	161	191	145	156	151	7.3	13.0	13.8	11.1	11.2	11.3
Missouri-Kansas-Texas Lines	125	110	124	99	116	115	127	107	116	105	118	115	4.0	3.5	3.9	3.1	3.7	3.6
Missouri Pacific	218	214	195	171	188	197	193	204	212	185	196	198	7.0	6.9	6.3	5.5	6.1	6.4
Oklahoma City-Ada-Atoka	127	211	233	243	241	211	79	136	123	147	128	123	4.1	7.0	7.8	8.1	8.4	7.1
St. Louis-San Francisco	215	199	206	180	142	188	220	206	209	192	150	195	6.8	6.3	6.5	5.7	4.5	6.0
St. Louis, San Fran. & Texas	380	266	165	152	166	226	383	262	142	145	166	220	12.0	8.4	5.2	4.8	4.9	7.1
St. Louis Southwestern Lines	68	179	190	158	176	154	77	184	205	177	205	170	2.1	5.7	6.0	5.0	5.6	4.9
Texas & New Orleans	66	122	132	133	135	118	49	100	122	129	126	105	2.4	4.5	4.8	4.8	5.0	4.3
Texas & Pacific	88	105	88	94	104	96	74	95	88	97	104	92	3.0	3.5	3.0	3.2	3.6	3.3
Texas Mexican	197	241	266	135	111	190	202	256	306	156	124	209	6.8	8.4	9.2	4.3	3.5	6.4
CANADIAN ROADS:																		
Canadian National (see note)																		
Canadian Pacific (see note)	161	160	164	166	156	162	135	142	143	142	124	137	5.7	5.7	5.8	5.9	5.5	5.7
Temiskaming & Nor. Ontario	229	209	241	251	257	237	156	151	160	180	179	165	7.9	7.4	8.4	8.8	8.9	8.3

Note: Statement applies to Class I roads and includes consolidated data for Class I roads merged during the period 1935 to 1939 as follows:
Atchison, Topeka & Santa Fe - includes Fort Worth & Rio Grande.
Chicago, Rock Island & Pacific - includes Chicago, Rock Island & Gulf.
Louisiana & Arkansas - includes Louisiana, Arkansas & Texas.
Union Pacific - includes Los Angeles & Salt Lake; Oregon-Washington R.R.& Nav.Co.; Oregon Short Line; and St.Joseph & Grand Island.
Canadian National Rys.- includes lines in New England; Grand Trunk Western; and Duluth, Winnipeg & Pacific.
Canadian Pacific - includes all lines in Canada.

Compiled by
Association of American Railroads
Bureau of Railway Economics
Washington, D.C.

Report on Assignment 5

Investigate and Report on the Dimensions of Ties, and Bring up to Date the Information in the 1924 and 1932 Proceedings

W. J. Burton, (chairman, subcommittee), W. C. Bolin, W. H. Brameld, H. F. Brown, S. B. Clement, R. L. Cook, W. R. Gillam, C. T. Jackson, J. E. Lockhart, A. F. Maischaider, E. F. Salisbury, W. D. Simpson, Raymond Swenk, Sverre Thorvaldson.

The following report substantially completes the work on this assignment, and the recommendations at its conclusion are submitted with a view to their adoption and inclusion in the Manual in 1942. Consideration of the proposals during 1941 by all concerned is desired.

At the 1939 convention, in response to this assignment, your committee reported on the present practice as to tie length and discussed the tie functions from the standpoint of length. The report embodied the conclusion that an increase in supporting power of the roadway could be obtained by an increase in tie length at less expense than by other means and that considering cost, 8½-ft. ties were a better buy than 8-ft. ties, as the longer ties will give added support out of proportion to the added tie cost.

At the 1940 convention, and in response to the same assignment, your committee presented résumés of the 1924 and 1932 Proceedings and also a tabulation, complete for the Class I railroads of the United States and the principal Canadian roads, giving the percentages purchased of each standard size and length of crossties. This report included a discussion of the present practices, especially as to length, pointing out that precedent, rather than effective service, appeared to govern choice of length to a considerable extent, at least in certain regions.

Recommendations

Based upon the studies and data mentioned above, your committee offers the following recommendations for comment and criticism, with a view to their submission in 1942 for adoption and publication in the Manual:

(a) The adoption of nine-foot ties and the discontinuance of the purchase of eight-foot ties as rapidly as practicable and economical.

(b) The use of nine-foot ties at least for lines of heavy traffic.

(c) The adoption of the nine-foot length whenever change is made from the eight-foot length.

Report of Committee 17—Wood Preservation

H. R. Duncan, *Chairman,*
W. P. Arnold
W. G. Atwood
S. J. Buckman
Walter Buehler
C. S. Burt
G. B. Campbell
W. F. Clapp
H. R. Condon
E. A. Craft
John Foley
E. B. Fulks
W. R. Goodwin
L. H. Harper
L. B. Holt
H. E. Horrocks
R. S. Hubley
R. P. Hughes
M. F. Jaeger
A. L. Kammerer
Edward Kelly
A. M. Knowles
A. J. Loom
R. S. Belcher, *Vice-Chairman,*
L. J. Reiser*
F. B. Robins
Henry Schmitz
L. B. Shipley
O. C. Steinmayer
G. C. Stephenson
T. H. Strate
W. A. Summerhays
J. E. Tiedt
Hermann von Schrenk
Committee

* Died June 5, 1940.

To the American Railway Engineering Association:

Your committee reports on the following assignments:

1. Revision of Manual.

No report.

2. Service test records for treated ties.

Progress report—submitted as information .... page 490

3. Piling used for marine construction.

Progress report—submitted as information .... page 508

4. Effect of preservation treatment by use of—(a) Creosote and Petroleum, and (b) Zinc Chloride and Petroleum.

No report.

5. Destruction by termites and possible ways of prevention.

Progress report—submitted as information .... page 513

6. Revision of specifications for the treatment of Douglas fir.

No report.

7. Incising of all forest products material, collaborating with Committee 3 Ties.

No report.

8. Investigations being made for the determination of toxicity value of creosote and creosote mixtures.

No report.

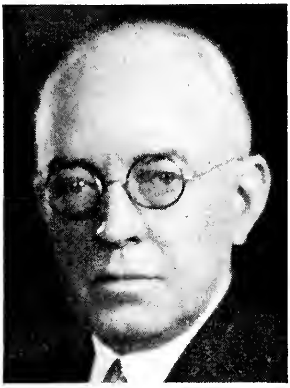
9. Present practice as to preservative used.

No report.

The Committee on Wood Preservation,
H. R. Duncan, *Chairman.*

Bulletin 423, February, 1941.

Charles Finley Ford



Charles Finley Ford was born at Morrisonville, Ill., on December 17, 1869, and moved to Cameron, Mo., in 1878. He entered the service of the Chicago, Rock Island & Pacific Railway on May 1, 1886, and spent his entire professional life with that company, until his death on June 9, 1940.

Following his first employment as water boy on construction his personality and outstanding abilities were recognized by successive promotions to roadmaster's clerk, maintenance clerk, chief clerk to general roadmaster, chief clerk to engineer maintenance of way system, and chief clerk to general manager.

On November 11, 1907, he was appointed assistant to engineer maintenance of way, with supervision over tie inspection and distribution, and on April 27, 1911, he was appointed supervisor tie and timber, with jurisdiction over timber preservation, which position he held at the time of his death, June 9, 1940, having completed more than 54 years' continuous service with the Rock Island Lines.

Mr. Ford was an active member of Committees 3—Ties, and 17—Wood Preservation. He served as vice-chairman of the latter during 1926–1935 and as chairman, from 1935 to the time of his death. Mr. Ford was also an active member of the American Wood-Preservers' Association and served as a member of the Executive committee and as second vice-president, first vice-president, and president of that association during the period 1922 to 1926, inclusive.

He served on various committees of both organizations and gave unsparingly of his time and experience to the furtherance of the activities of these associations, and was widely known in his profession among the railroads and wood-preserving companies of this country.

A man of broad experience, keen judgment, fairness and kindliness in his dealings, Mr. Ford endeared himself to all with whom he came in contact. A sense of personal loss has been felt by his associates who remain to mourn the loss of a kind friend and lovable companion.

Report on Assignment 2

Service Test Records for Treated Ties

A. J. Loom (chairman, subcommittee), G. B. Campbell, W. R. Goodwin, L. H. Harper, L. B. Holt, R. S. Hubley, R. P. Hughes, M. F. Jaeger, Edward Kelly, T. H. Strate, W. A. Summerhays.

The table of tie renewals per mile maintained on various roads has been revised to include data for 1939.

Reports of special test tracks are submitted for the following roads:

Baltimore & Ohio
Chicago, Burlington & Quincy

City of Minneapolis Filtration Plant Railway
Northern Pacific

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Service

	A.7
YEAR	MILE
1911	1421
12	1483
13	1511
14	1566
15	1597
16	1615
17	1621
18	1648
19	1664
1920	1688
21	1690
22	1708
23	1742
24	1779
25	1813
26	1855
27	1793
28	1820
29	1904
1930	1933
31	1965
32	1962
33	1950
34	1940
1935	1934
36	1932
37	1969
38	1956
39	1949
1940	
YEAR IN WHICH PERCENTAGE OF TREATED TIES IN TRACK REACHED 20%	
AVGE. No. OF TIES PER MI. OF ALL TRACKS	30
PERCENTAGE TREATED OF ALL TIES USED	19 ... 19
PERCENTAGE TREATED TIES IN TRACK	19 ... 19 ... 19

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removed from track. The destruction effect of these derailments on the remainder will be given consideration when the ties are removed. There have also been 117 ties removed because of switch installations.

Committee 7 A.W.R.A.

CROSS TIE RENEWALS PER MILE OF ALL TRACK MAINTAINED 1911-1940

Roads (column headings): [illegible] | [illegible] | C.B.&Q. | C.&E. | C.&St.L. | [illegible] | C.R.I.&P. | [illegible] | Gt. Northern | [illegible] Central | K.C. Sou. | Lehigh Valley | Mich. Cent. | M.K.&T. | [illegible] | N.Y.C. (East) | N.Y.C. (West) | Nor. Pac. | Penna. | [illegible] | [illegible] | [illegible] | Reading | Boston & Maine | C.&O. | New York Central

TOTALS FOR ALL ROADS

Miles	No. of Roads	Ties per Mile	[illegible]
36 29	22	[illegible]	269
[illegible]	[illegible]	[illegible]	249
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	26	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	93	[illegible]
[illegible]	27	203	223
96245	27	210	[illegible]
196720	27	211	205
197297	27	208	264
198892	27	198	205
[illegible]	27	183	201
203330	27	188	96
204654	27	83	[illegible]
[illegible]	27	85	[illegible]
[illegible]	27	184	94
204368	27	76	93
201810	27	152	[illegible]
200817	27	[illegible]	83
[illegible]	27	83	[illegible]
[illegible]	27	[illegible]	[illegible]
200883	27	95	[illegible]
98804	27	95	83
[illegible]	27	115	92
[illegible]	27	[illegible]	98
[illegible]	27	104	[illegible]
193574	27	115	108

⊗ Main Line Only

① Includes [illegible]

City of Minneapolis Filtration Plant Railway
Northern Pacific
Southern

(Inspection reports for 1940 are submitted by the U. S. Forest Products Laboratory covering the Hartford, Fair Grounds, and University Avenue test tracks of the Chicago, Milwaukee, St. Paul & Pacific, also experimental ties in tracks of the Public Service Company of Indiana.)

The report is presented as information.

Baltimore & Ohio

Herring Run Tie Test

Annual Report—1939, End of 25 Years' Service

INTRODUCTORY

The Herring Run test tie section is located in the eastward main track at Herring Run, Md., on the Baltimore division, about seven miles east of Baltimore, Md.

Eighty-five percent of the test was installed in November, 1914, and the remainder in August, 1915, in cooperation with the Forest Service of the United States Department of Agriculture.

The development to date, as set forth in the accompanying report, indicates the total service life of the untreated ties and the trend of what is to be expected in service life from the treated.

PURPOSE OF TEST

The purpose of the Herring Run test is to determine the economic value of various kinds of preservative treatments, and incidentally, to note the life of red oak treated ties compared with red oak ties untreated.

CONDITIONS OF TEST

(1) *Time.* All ties in test except Section 14 were installed in November, 1914. Section 14 was placed in August, 1915. Test, therefore, is now completing its twenty-fifth year.

(2) *Traffic.* An average of 16,204,000 gross tons per year has been handled over this track.

(3) *Rainfall.* The average annual rainfall has been 41.7 in. This is, no doubt, sufficient to have caused leaching of soluble preservatives.

(4) *Temperature.* Mean average, January, 35.8 deg. F., mean average, July, 77.8 deg. F. Extremes, 8.8 deg. F. to 99.5 deg. F.

(5) *Maintenance.* Maintenance conditions have been uniform over entire test. Track on entire test raised and ties respaced for 39-ft. rails during summer of 1926. Track from tie 0 to tie 1916 is pick-tamped, from 1916 to east end of test, machine-tamped. Track on entire test raised in 1929, 1933 and 1936 and machine-tamped.

DERAILMENTS

Four derailments have occurred within the limits of the test, damaging 2,473 ties, or 70 percent of the total. Of this number, 121 were so badly damaged that they were removed from track. The destruction effect of these derailments on the remainder will be given consideration when the ties are removed. There have also been 117 ties removed because of switch installations.

Age of Test—Twenty-Five Years—Kind of Wood—Red Oak

Sec. No.	Tie numbers	Treatment: Process	Treatment: Per cu. ft.	Ties placed Note	Ties in test Note	Removed to date: No.	Removed to date: Per cent	Average life to date of ties in test
1	3—300	Untreated		298	289	289	100.0	5.1
2	301—600	Burnettizing	0.35 lb. zinc chl.	300	161	160	99.4	12.7
3	601—900	Burnettizing	0.63 lb. zinc chl.	300	211	192	91.0	15.3
4	901—1200	Str. creo.	4.02 lb. creosote	300	300	283	94.5	16.7
5	1201—1500	Str. creo.	9.78 lb. creosote	300	300	225	75.0	21.7
6	1501—1630	Straight w. g. tar cr.	5.16 lb. w. g. tar cr.	150	150	149	99.3	17.4
7	1631—1800	Straight w. g. tar cr.	6.12 lb. w. g. tar cr.	150	150	146	97.3	17.7
8	1801—1950	Straight w. g. tar cr.	7.09 lb. w. g. tar cr.	150	150	148	98.7	15.6
9	1951—2100	Straight w. g. tar cr.	10.90 lb. w. g. tar cr.	150	150	144	96.0	16.9
10	0-212 Cull	Straight w. g. tar cr.	11.00 lb. w. g. tar cr.	212	211	199	94.3	15.4
11	2101—2400	Sodium Fluoride	0.41 lb. sodium fluoride	300	300	300	100.0	14.5
12	2401—2700	Card	0.63 lb. zinc chl. 0.76 lb. creosote	300	300	300	100.0	13.2
13	2701—3000	Card	0.59 lb. zinc chl., 1.35 lb. w. g. tar cr., 0.37 lb. creosote	300	300	283	94.3	16.1
14	3001—3300	Card	0.5 lb. zinc chl., 2.0 lb. creo.†	300	288	288	100.0	13.2

Note: The difference between Ties Placed and Ties in Test results from elimination from test of ties account of removals from derailments and installation of switches.

†—This group installed 9 months (.75 year) after other ties in this test.

The indications are that the life of many ties in this test has been and will continue to be materially reduced as a result of decay starting in the crushed fibers of the wood marked by derailed wheels. Attention is directed to the fact that all groups in the test, excepting Section 5 of the straight creosote group, have suffered more or less from wheel marks at various times. For this reason the test still retains an important value as a basis for a comparison of the effectiveness of the various methods of treatment, although any conclusions regarding the average life of ties so treated must be drawn with a proper regard for the damage resulting from these derailments.

Baltimore & Ohio—Tie Test, Backus, Pa.

Length of Test—29 Years—Report for 1939 Renewals
Installed—November 1910

Straight Creosote—10 Lb. Per Cu. Ft.

Kind of wood	Ties placed	In test	Removed to Date Number	Removed to Date Per cent	Av. life to date
Red oak	72	68	11	16.2	28.0
Black oak	260	258	31	12.0	28.2
Pin oak	316	315	44	14.0	28.2
Maple	543	530	49	9.2	28.4
Beech	824	797	140	17.6	28.0
Birch	19	17	2	11.8	28.3
Cherry	9	9	3	33.3	26.6
Gum	12	11	0	0.0	29.0
Chestnut	170	170	136	79.6	21.0
Hickory	146	143	40	28.0	27.6
Total	2371	2318	456	19.7	27.5

Average Life of Untreated Ties in Years

Kind	Total placed	Average years
Ash	116	5.1
Beech	208	5.0
Red birch	217	3.6
Chestnut	259	9.7
Cottonwood	86	2.9
Cypress	225	8.3
White elm	191	5.3
Hemlock	190	4.9
Hickory	110	5.5
Loblolly pine	248	5.3
Hard maple	122	4.7
Soft maple	125	3.6
White oak	125	11.1
Red oak	204	5.3
Pin Oak	126	6.3
Poplar	126	5.3
Red gum	152	4.1
Sycamore	131	3.3
Tamarack	175	5.1
Tupelo gum	136	3.5
Total placed	3272	5.6

Report of Thirtieth Annual Inspection of Chicago, Burlington & Quincy Experimental Ties

The results of the 1939 inspection of the experimental ties in the tracks of the Chicago, Burlington & Quincy are given in the accompanying tabulations. These ties were laid in 1909 and 1910, some treated with coal-tar creosote by the full-cell process, with 10 to 12 lb. per cu. ft.; some with zinc chloride (Burnett process) with ½ lb. per cu. ft.; some with a mixture of these two preservatives (Card process), with an absorption of ½ lb. of zinc chloride and 3 lb. of creosote per cu. ft.; and some were untreated.

1939 Inspection of Cross Tie Test Track, Chicago, Burlington & Quincy—Results of 30 Years' Service

Process	Lines East: Total placed	Total removed to date	Per cent removed account decay	Per cent removed account other causes	Esti-mated years average life	Actual years average life to date	Lines West: Total placed	Total removed to date	Per cent removed account decay	Per cent removed account other causes	Esti-mated years average life	Actual years average life to date
Ash												
Creosote	19	19	32	68	----	16.7	15	13	20	67	25.	20.5
Card	289	281	21	77	----	18.9	103	98	22	74	----	18.2
Burnett	16	16	44	56	----	18.3	15	15	47	53	----	17.2
Untreated	70	70	99	1	----	5.1	46	46	100	----	----	5.3
Beech												
Creosote	321	158	15	35	33.0	26.7	163	70	12	31	34.5	25.7
Card	807	793	46	52	----	17.7	418	406	42	55	----	17.3
Burnett	210	209	56	43	----	16.	105	105	60	40	----	15.8
Untreated	134	134	98	2	----	4.6	74	74	93	7	----	5.4
Birch												
Creosote	75	74	72	27	----	22.9	59	44	15	59	27.5	22.8
Card	715	694	42	55	----	18.1	360	349	36	61	----	18.
Burnett	73	73	48	52	----	13.0	30	30	43	57	----	14.4
Untreated	139	139	99	1	----	3.6	78	78	100	----	----	3.6
Chestnut												
Creosote	----	----	----	----	----	----	----	----	----	----	----	----
Card	164	164	18	82	----	10.1	89	89	9	91	----	10.2
Burnett	----	----	----	----	----	----	----	----	----	----	----	----
Untreated	169	169	28	72	----	9.4	90	90	22	78	----	10.2
Cottonwood												
Creosote	88	49	9	47	31.	25.6	45	18	16	24	35.	24.7
Card	296	261	33	55	24.5	19.5	160	145	28	63	----	18.1
Burnett	----	----	----	----	----	----	----	----	----	----	----	----
Untreated	56	56	95	5	----	2.6	30	30	100	----	----	3.5
Cypress												
Creosote	25	21	8	76	25.5	26.3	29	28	41	55	----	19.8
Card	409	373	12	79	----	19.7	254	286	25	69	----	18.5
Burnett	25	25	12	88	----	21.6	30	30	50	50	----	14.7
Untreated	135	135	79	21	----	8.8	90	90	89	11	----	7.5

					Elm							
Creosote	208	150	34	38	28.	24.5	119	55	11	36	33.	24.8
Card	594	527	31	58	24.5	21.8	371	312	31	53	25.5	20.7
Burnett	224	221	50	48	----	18.9	73	73	63	37	----	16.1
Untreated	113	113	91	9	----	4.8	78	78	96	4	----	5.9
					Hemlock							
Creosote	136	127	33	61	----	20.1	99	87	24	64	25.	19.0
Card	816	787	30	66	----	18.3	488	471	39	56	----	15.9
Burnett	125	125	48	52	----	17.3	87	86	41	57	----	15.6
Untreated	112	112	100	----	----	4.7	78	78	99	1	----	5.3
					Hickory							
Creosote	10	8	20	60	26.5	25.	15	14	13	80	----	21.8
Card	185	184	32	67	----	16.3	105	102	43	54	----	16.0
Burnett	9	8	22	67	24.5	21.7	15	15	53	47	----	17.3
Untreated	65	65	89	11	----	5.5	45	45	100	----	----	5.5
					Pine—Loblolly Sap							
Creosote	145	109	12	63	27.5	24.1	72	56	19	58	26.5	19.0
Card	949	871	31	61	----	19.7	386	371	2	69	----	15.8
Burnett	128	128	74	26	----	12.4	72	72	46	54	----	12.0
Untreated	157	157	99	1	----	5.5	91	91	100	----	----	4.8
					Hard Maple							
Creosote	82	70	55	30	25.5	24.5	34	23	18	50	28.5	23.1
Card	560	492	46	42	25.	20.8	272	253	37	56	----	19.3
Burnett	50	50	52	48	----	19.6	15	15	87	13	----	16.7
Untreated	77	77	98	2	----	4.3	45	45	100	----	----	5.3
					Soft Maple							
Creosote	139	129	48	45	----	19.8	63	42	29	38	29.	22.3
Card	462	431	50	43	----	17.2	264	237	32	58	24.5	19.0
Burnett	125	125	64	36	----	13.4	57	57	39	61	----	13.6
Untreated	82	82	99	1	----	3.4	43	43	95	5	----	4.0
					White Oak							
Creosote	25	18	16	56	28.	26.9	15	14	27	67	----	19.5
Card	234	233	39	60	----	17.2	152	152	31	69	----	17.1
Burnett	28	28	60	40	----	17.4	15	15	40	60	----	15.3
Untreated	81	81	88	12	----	10.8	44	44	81	19	----	11.7
					Red Oak							
Creosote	165	114	9	60	29.	25.3	120	94	13	65	27.	22.7
Card	776	737	27	68	----	20.1	510	504	35	64	----	17.4
Burnett	158	158	56	44	----	17.2	116	115	47	52	----	15.3
Untreated	129	129	96	4	----	5.1	75	75	93	7	----	5.7

1939 Inspection of Cross Tie Test Track, Chicago, Burlington & Quincy—Results of 30 Years' Service (Continued)

	Lines East						Lines West					
Process	Total placed	Total removed to date	Per cent removed account decay	Per cent removed account other causes	Estimated years average life	Actual years average life to date	Total placed	Total removed to date	Per cent removed account decay	Per cent removed account other causes	Estimated years average life	Actual years average life to date
Pin Oak												
Creosote	189	117	8	54	30.	26.1	133	88	14	53	29.	25.3
Card	512	473	27	66	----	21.8	321	310	27	70	----	19.8
Burnett	23	21	57	35	----	22.6	44	44	32	68	----	16.0
Untreated	81	81	96	4	----	6.4	45	45	98	2	----	6.2
Poplar												
Creosote	50	38	18	58	27.	24.	30	27	17	73	24.5	17.4
Card	396	390	44	54	----	15.5	253	245	44	53	----	15.5
Burnett	50	50	44	56	----	14.3	30	30	57	43	----	13.0
Untreated	81	81	94	6	----	5.1	45	45	96	4	----	5.6
Red Gum												
Creosote	89	69	36	42	27.	21.	48	33	27	42	29.	17.4
Card	429	384	44	45	24.5	19.4	233	192	46	36	26.	20.2
Burnett	75	75	67	33	----	11.6	43	43	74	26	----	12.4
Untreated	98	98	97	3	----	3.8	54	54	98	2	----	4.6
Sycamore												
Creosote	75	49	39	27	29.	24.4	15	4	----	27	39.	26.9
Card	399	354	53	35	24.5	19.9	121	115	65	30	----	14.7
Burnett	75	75	71	29	----	13.7	15	15	80	20	----	13.5
Untreated	81	81	98	2	----	2.9	50	50	96	4	----	3.9
Tamarack												
Creosote	106	97	14	77	----	21.6	108	91	15	69	25.5	19.3
Card	813	808	22	77	----	18.1	494	469	33	62	----	17.7
Burnett	108	108	44	56	----	18.1	107	106	32	67	----	16.0
Untreated	98	98	96	4	----	4.9	77	77	99	1	----	5.3
Tupelo Gum												
Creosote	99	77	28	49	27.	22.5	54	37	24	44	29.	21.0
Card	436	331	27	49	27.	23.0	237	138	31	28	31.	24.9
Burnett	76	76	47	53	----	15.2	41	41	61	39	----	14.0
Untreated	88	88	98	2	----	3.0	48	48	98	2	----	4.4

SUMMARY OF 1939 INSPECTION OF CROSS TIE TEST TRACKS, CHICAGO, BURLINGTON & QUINCY—RESULTS OF 30 YEARS' SERVICE

	Lines East						Lines West					
Process	Total placed	Total removed to date	Per cent removed account decay	Per cent removed other causes	Actual average years life to date	Forest Products Lab. curve estimated years average life	Total placed	Total removed to date	Per cent removed account decay	Per cent removed other causes	Actual average years life to date	Forest Products Lab. curve estimated years average life
Str. Creosote	2,046	1,493	25	48	24	28.	1,236	838	17	51	22.4	28.5
Card	10,241	9,568	34	60	19.1	----	5,591	5,195	34	58	17.9	----
Burnett	1,578	1,571	55	44	16.1	----	910	907	49	50	15.0	----
Untreated	2,046	2,046	90	10	5.4	----	1,226	1,226	91	9	5.8	----
Total Treated	13,865	12,632	35	56	19.5	----	7,737	6,940	33	56	18.3	24.5
Grand Total	15,911	14,678	----	----	----	----	8,963	8,146	----	----	----	----

Note: These percentages include only the ties placed in what are termed the thousand-tie lots on the various divisions.

City of Minneapolis, Minn.—Filtration Plant Railway—4200—6 in. by 8 in. by 8 ft. Red Oak Crossties

Treated and placed in fall of 1916

Average absorption 10.08 lb. per cu. ft. creosote-tar mixture, 40 per cent M. of W. creosote, 20 per cent coke-oven tar, and 40 per cent water-gas tar.

Analyses

	Treating Mixture 40–20–40 Actual	Treating Mixture 40–20–40 Computed	M. of W. creosote	Coke oven tar	Water gas tar
Distillation to 170 deg. C	0.9%	------	------	------	------
210 deg. C	2.5%	2.2%	0.1%	0.5%	5.2%
235 deg. C	12.8%	12.1%	13.4%	5.7%	14.1%
315 deg. C	41.1%	41.5%	51.8%	19.1%	42.4%
355 deg. C	56.6%	57.8%	72.1%	29.0%	58.0%
Sp. Gr. at 380 deg. C	1.111	Sp. Gr. at 60 deg. F	1.096	1.207	1.093
Water	1.8%	------	0.6%	1.9%	0.2%

Sp. Gr. 235 deg.-315 deg. Fraction—1.024 at 60 deg. C/60 deg. C

The city filtration engineer of Minneapolis, Arthur F. Mellen, reports under date of October 1, 1940, that 25 of these ties have been removed to date, i. e., after 24 years of service.

Northern Pacific—Hemlock Test Track

Designated by U. S. Forest Service as Project L–214

1800 Montana-Idaho Hewed and Sawed Ties placed between Mile Post 120 and Mile Post 121 + 2350, Westward Main Track, Missoula, Montana.

Treated at Paradise, Montana with 80–20 Creosote-Coal Tar Solution, 6¾ pounds per cubic foot. Lowry Process, and placed in track in 1910.

Summary of Ties by Species

Year	Western hemlock	Western larch	Douglas fir	True fir	Spruce	White pine	Ponderosa pine	Aspen	Total
1910	1,072	436	166	102	18	2	3	1	1,800
Year				Renewals					
1917	1								1
1924	1								1
1926	4								4
1928	43								43
1929	26	8	6	14	5				59
1932	49	9			3				61
1933	28	8	4	1	1				42
1934	43	18	1	6					68
1935	29	9	5	4					47
1936	42	11	3	1			1		58
1937	78	24	4	5	4				115
1938	72	24	1	6					103
1939	42	16	3	4	1				66
1940	80	22	5	8		1			116
Total	538	149	32	49	14	1	1	0	784
Per cent renewed	50.19	34.17	19.28	48.04	77.78	50.00	33.33	0	43.55
Avg. yrs. per tie	25.40	26.32	25.19	24.86	22.93	30.00	26.00	0	25.49

Six ties removed prior to 1928 were broken by derailment. Others all removed account decay hastened by damage from past derailments and mechanical attrition at rail base.

43.55 per cent renewals in 30 years.

Average life of ties replaced—25.49 years.

Estimated total life based on Tie-life Curve of the United States Forest Products Laboratory—33 years.

Northern Pacific—Tamarack Test Track

44,159 hewed Minnesota tamarack ties placed between mile posts 88 and 103½, in eastward main track, Rice, Minn., to Gregory.

Treated at Brainerd, Minn. with 80–20 creosote-coal tar solution, 6¾ lb. per cu. ft.—Lowry process and placed in track in 1917.

Renewals

None previous to 1928.

1928----	1	Tie account decay. Showed signs of having been partially decayed when treated.
1929----	239	Ties account derailment.
1930----		No renewals.
1931----	3	Ties account decay.
1932----		No renewals.
1933----		No renewals.
1934----		No renewals.
1935----	214	decay at rail base caused by mechanical wear.
1936----	1,785	decay at rail base caused by mechanical wear.
1937----	3,002	decay at rail base caused by mechanical wear.
1938----	3,454	decay at rail base caused by mechanical wear.
1939----	2,448	decay at rail base caused by mechanical wear.
1940----	8,872	decay at rail base caused by mechanical wear.
	20,018	Ties renewed, 45.33% after 23 years.

Average life of ties renewed—21.54 years.

Estimated total life based on tie life curve of the United States Forest Products Laboratory—27 years.

SOUTHERN RAILWAY SYSTEM—RECORD OF CREOSOTED TEST TIES INSTALLED

Group No.	Kind of wood	Size	Preservative: Kind	Preservative: Lb. per cu. ft.	Year installed	No. ties installed	No. ties removed	Percent removed	Indicated service life—yrs.†
1	Heart pine	7x9x8'6"	Creo. oil	17.4	1910	50	29	58	30
2	Sap pine	7x9x8'6"	Creo. oil	17.4	1910	50	42	85	25
3	Pine	7x9x8'6"	Creo. oil	----	1911	2100	1800	86	24
4	Red oak	7x9x8'6"	Creo. oil	8.7	1914	3200	672	21	35
5	Heart Pine	7x9x8'6"	Creo. oil	----	1915	256	123	48	27
6	Sap Pine	7x9x8'6"	Creo. oil	----	1915	181	134	74	23
7	Sap Pine	7x9x8'6"	Creo. oil	12	1916	7500	6261	83	20

† Based on Forest Products Laboratory curve.

Condition of Experimental Ties in the Chicago, Milwaukee, St. Paul & Pacific Test Track Near Hartford, Wis., After About 29 Years' Service

Ties Set October, 1911

Preservative	Process	Tie plates	Average absorption lb. per cu. ft.	Ties in test	Condition of ties—October, 1940: Serviceable		Removed: Mainly for decay		Removed: Mainly for causes other than decay[a] and unknown causes[b]		Average life years
				No.	Number	Per cent	Number	Per cent	Number	Per cent	
			Chestnut								
Zinc chloride	Burnett[c]	Flat	.50	10	----	----	5	50.0	5	50.0	15.6
Zinc chloride	Burnett[c]	Ribbed	.50	13	----	----	6	46.1	7	53.9	13.4
			Spruce								
Mercuric chloride	Kyan	Flat	----[d]	13	3	23.1	9	69.2	1	7.7	24.7[h]
Mercuric chloride	Kyan	None	----[d]	12	2	16.7	8	66.6	2	16.7	21.2[h]
			Maple								
Creosote	Full cell	None	10.7	50	50	100.0	----	----	----	----	----
Creosote	Full cell	Flat	12.2	49	49	100.0	----	----	----	----	----
Creosote	Rueping	Flat	5.0	50	49	98.0	1	2.0	----	----	----
Creosote	Rueping	None	4.8	50	50	100.0	----	----	----	----	----
20% creosote, 80% zinc chloride	Card	None	14.7[f]	50	46	92.0	3	6.0	1	2.0	----
20% creosote, 80% zinc chloride	Card	Flat	17.3[f]	50	47	94.0	2	4.0	1	2.0	----
Semi-refined paraffin oil	Full cell	Flat	11.1	50	44	88.0	3	6.0	3	6.0	45.0[e]
Semi-refined paraffin oil	Full cell	None	14.3	49	45	91.8	2	4.1	2	4.1	----
Zinc chloride—creosote	Two movement	Flat	16.4[g]	50	38	76.0	7	14.0	5	10.0	38.0[e]
Zinc chloride—creosote	Two movement	None	15.1[g]	50	23	46.0	24	48.0	3	6.0	30.0[e]
Zinc chloride	Burnett	None	.50	49	1	2.0	26	53.1	22	44.9	19.0[h]
Zinc chloride	Burnett	Flat	.50	50	20	40.0	21	42.0	9	18.0	29.0[e]
Untreated		None	----	50	----	----	50	100.0	----	----	6.4
Untreated		Flat	----	50	----	----	50	100.0	----	----	7.8

C. M. & St. P. & P. Test Track at Hartford (Continued)

Ties Set October, 1911

Preservative	Process	Tie plates	Average absorption lb. per cu. ft.	Ties in test	Condition of ties—October, 1940: Serviceable		Removed: Mainly for decay		Removed: Mainly for causes other than decay[a] and unknown causes[b]		Average life years
				No.	Number	Per cent	Number	Per cent	Number	Per cent	
			Red Oak								
Creosote	Full cell	None	11.2	52	51	98.1	----	----	1	1.9	----
Creosote	Full cell	Flat	10.9	50	48	96.0	----	----	2	4.0	----
Creosote	Rueping	Flat	5.0	50	48	96.0	1	2.0	1	2.0	----
Creosote	Rueping	None	5.7	50	47	94.0	2	4.0	1	2.0	----
20% creosote, 80% zinc chloride	Card	None	15.5[f]	50	39	78.0	3	6.0	8	16.0	39.0[e]
20% creosote, 80% zinc chloride	Card	Flat	15.2[f]	50	50	100.0	----	----	----	----	----
Semi-refined paraffin oil	Full cell	Flat	8.4	50	44	88.0	5	10.0	1	2.0	45.0[e]
Semi-refined paraffin oil	Full cell	None	6.2	49	30	61.2	10	20.4	9	18.4	33.0[e]
Zinc chloride—creosote	Two movement	Flat	14.7[g]	50	37	74.0	8	16.0	5	10.0	37.0[e]
Zinc chloride—creosote	Two movement	None	16.0[g]	50	28	56.0	15	30.0	7	14.0	32.0[e]
Zinc chloride	Burnett[c]	Flat	.50	206	5	2.4	135	65.6	66	32.0	19.1[h]
Zinc chloride	Burnett[c]	Ribbed	.50	53	2	3.8	32	60.4	19	35.8	20.4[h]
Zinc chloride	Burnett	None	.47	50	10	20.0	30	60.0	10	20.0	25.0[e]
Zinc chloride	Burnett	Flat	.49	50	33	66.0	10	20.0	7	14.0	35.0[e]
Untreated		None	----	50	----	----	50	100.0	----	----	8.7
Untreated		Flat	----	50	----	----	50	100.0	----	----	9.2

Note: This test is being conducted in cooperation with the U. S. Forest Products Laboratory.
[a] Rail cutting, splitting, etc.
[b] Ties not available for examination after removal to determine the cause of removal.
[c] Obtained from regular stock of C. M. St. P. & P.
[d] Steeping treatment in cold mercuric chloride solution—absorption figures not available.
[e] Estimate—Based on United States Forest Products Laboratory tie-renewal curve.
[f] Emulsion of 80 parts of 3% zinc chloride solution and 20 parts of creosote by volume at approximately 70 deg. F.
[g] 3% zinc chloride solution plus creosote. Treatment consisted of bath in hot creosote for 30 min. at atmospheric pressure followed by pressure treatment with 3% zinc chloride solution.
[h] An additional life of 2 years was estimated for each remaining tie in arriving at this value.

Condition of Experimental Ties in the Chicago, Milwaukee, St. Paul & Pacific Test Track Near the Fair Grounds, Madison, Wis.

Condition at August, 1940 Inspection

Species	Preservative	Average absorption lb. per cu. ft.	Ties in test No.	Serviceable		Removed				Average life years
						Mainly for decay		Mainly for causes other than decay[a]		
				Number	Per cent	Number	Per cent	Number	Per cent	
Ties set 1916—24 years service										
Red oak	Zinc chloride	0.55	163	----	----	157	96.3	6	3.7	16.8
Red oak	25% creosote & 75% gas oil	10.20	75	61	81.4	7	9.3	7	9.3	33.0[b]
Red oak	10% creosote and 90% gas oil	10.00	98	66	67.3	8	8.2	24	24.5	29.0[b]
Ties set 1917—23 years service										
Douglas fir[c]	Creosote	11.50	28	9	32.2	1	3.6	18	64.2	22.0[b]
Douglas-fir[c-d]	Untreated	----	38	----	----	36	94.7	2	5.3	6.5
Douglas-fir[c]	Untreated	----	47	1	2.1	38	80.9	8	17.0	13.3[e]
Western larch	Untreated	----	44	----	----	43	97.7	1	2.3	10.7
White oak	Untreated	----	95	1	1.1	92	96.8	2	2.1	11.6[e]
Red oak	Sodium fluoride	0.52	99	12	12.1	72	72.8	15	15.1	19.0[b]
Red oak	Water gas tar	9.79	99	99	100.0	----	----	----	----	----
Ties set 1919—21 years service										
Douglas-fir[c]	Zinc chloride	0.52	104	1	1.0	61	58.6	42	40.4	16.6[e]
Western larch	Zinc chloride	0.48	95	----	----	33	34.7	62	65.3	16.2
Red oak	50% c. t. creo. & 50% w. t. creo.	9.50	62	46	74.2	9	14.5	7	11.3	27.0[b]
Slippery elm	50% c. t. creo. & 50% w. t. creo.	10.85	25	17	68.0	2	8.0	6	24.0	26.0[b]
Butternut	50% c. t. creo. & 50% w. t. creo.	9.00	9	1	11.1	7	77.8	1	11.1	19.3[e]
White oak	50% c. t. creo. & 50% w. t. creo.	7.30	1	1	100.0	----	----	----	----	----
Cherry	50% c. t. creo. & 50% w. t. creo.	10.50	3	3	100.0	----	----	----	----	----
Red oak	Wood tar creosote	10.08	98	30	30.6	44	44.9	24	24.5	20.0[b]
Ties set 1921—19 years service										
Red oak	Low temperature coal tar oil	10.30	100	98	98.0	1	1.0	1	1.0	----
Red oak	20% coal tar and 80% low temp. coal tar oil[f]	10.50	100	100	100.0	----	----	----	----	----
Red oak	Vertical retort c. t. creo.	9.60	100	100	100.0	----	----	----	----	----
Red oak	Pintsch gas tar	10.50	100	98	98.0	2	2.0	----	----	----
Ties set 1927—13 years service										
Jack pine	Zinc chloride	0.52	381	328	86.1	44	11.5	9	2.4	19.0[b]

Note: This test is being conducted in cooperation with the U. S. Forest Products Laboratory.
[a] Rail cutting, splitting, etc.
[b] Estimate—Based on United States Forest Products Laboratory tie renewal curve.
[c] Western Washington and Oregon type.
[d] Switch ties.
[e] An additional life of 2 years was estimated for the remaining ties in arriving at this value.
Reported as 50% tar and 50% low temp. coal tar oil prior to 1935.

Condition of the Experimental Ties in the University Avenue Test Track of the Chicago, Milwaukee, St. Paul & Pacific at Madison, Wis., at an Inspection in September, 1940

Preservative	Treating method[a]	Species	Form[b] of ties	Average absorption of preservative lb. per cu. ft.	Ties in test No.	Serviceable		Removed: Mainly for decay		Removed: Causes other than decay[c] and unknown causes		Not inspected (under crossings)		Missing or eliminated
						Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number
Ties set 1922—18 years service														
Aczol	F	Red oak	S	16.38[d]	95	----	----	90	94.7	----	----	5	5.3	3
Zinc chloride (high iron content)	F	Red oak	S	.58[e]	87	7	8.1	33	37.9	47	54.0	----	----	----
Ties set 1923—17 years service														
25% low temp. c. t. distillate, 75% mid continent oil	F	Red oak	H	8.22	100[f]	94	94.0	4	4.0	----	----	2	2.0	----
50% low temp. c. t. distillate, 50% mid continent oil	F	Red oak	H	9.24	98[g]	91	92.9	3	3.1	2	2.0	2	2.0	1
Ties set 1924—16 years service														
C. t. creo., Grade 1[h]	F	Red oak	H-S	14.60	16	14	87.4	----	----	1	6.3	1	6.3	----
Low temp. c. t. distillate	F	Red oak	H-S	8.94	86	74	86.0	3	3.5	8	9.3	1	1.2	----
10% low temp c. t. distillate, 90% topped California oil	F	Red oak	H-S	8.94	99	91	91.9	2	2.0	6	6.1	----	----	----
25% low temp. c. t. distillate, 75% topped California oil	F	Red oak	H-S	8.28	100	81	81.0	11	11.0	7	7.0	1	1.0	----
Ties set 1925—15 years service														
Basilit	F	Red oak	H-S	.28[e]	49	43	87.7	2	4.1	4	8.2	----	----	----
10% c. t. creosote, 90% petroleum grade 1[h]	F	E. hemlock	S	10.26	87	74	85.1	4	4.6	9	10.3	----	----	----
50% c. t. creosote, grade 1[h] 50% petroleum	F	E. hemlock	S	11.91	82	75	91.5	2	2.4	5	6.1	----	----	2
Sodium fluoride	F	Red oak	H-S	.52[e]	50	42	84.0	3	6.0	5	10.0	----	----	----

C. M. St. P. & P. Test Track at University Avenue (Continued)

Preservative	Treating method[a]	Species	Form[b] of ties	Average absorption of preservative lb. per cu. ft.	Ties in test No.	Serviceable Number	Serviceable Per cent	Removed: Mainly for decay Number	Removed: Mainly for decay Per cent	Removed: Causes other than decay[c] and unknown causes Number	Removed: Causes other than decay[c] and unknown causes Per cent	Not inspected (under crossings) Number	Not inspected (under crossings) Per cent	Missing or eliminated Number
Sodium fluoride	F	Red oak	H-S	.26[e]	50	37	74.0	5	10.0	8	16.0	----	----	----
Triolith	F	Red oak	H-S	.25[e]	50	43	86.0	2	4.0	5	10.0	----	----	----
Zinc chloride	F	Red oak	H-S	.52[e]	50	24	48.0	19	38.0	7	14.0	----	----	----
Zinc chloride	F	Red oak	H-S	.26[e]	50	30	60.0	14	26.0	6	12.0	----	----	----
Zinc chloride Petroleum emulsion	E	Red oak	H	.34[e] 4.87[i]	49	31	63.3	11	22.4	7	14.3	----	----	----
Zinc chloride- Petroleum emulsion	E	So. yel. pine	H	.69[e] 9.21[i]	42	34	80.9	1	2.4	7	16.7	----	----	----
Zinc chloride- Petroleum emulsion	E	So. yel. pine	H	.39[e] 7.92[i]	49	48	98.0	----	----	1	2.0	----	----	----
Zinc chloride- Petroleum emulsion	E	So. yel. pine	H	.27[e] 9.34[i]	47	43	91.5	1	2.1	3	6.4	----	----	----
Ties set 1926—14 years service														
Basilit	F	Red oak	H-S	.52[e]	49	41	83.6	4	8.2	4	8.2	----	----	----
Basilit	F	E. hemlock	S	.18[e]	44	27	61.4	3	6.8	13	29.5	1	2.3	2
Sodium fluoride	F	E. hemlock	S	.17[e]	49	22	44.9	10	20.4	17	34.7	----	----	----
Triolith	F	Red oak	H-S	.56[e]	50	42	84.0	4	8.0	4	8.0	----	----	----
Triolith	F	E. hemlock	S	.18[e]	48	30	62.5	4	8.3	14	29.2	----	----	----
Ties set 1927—13 years service														
Borax	F	Red oak	H-S	.59[j]	100	93	93.0	3	3.0	3	3.0	1	1.0	----
Borax	F	Red oak	H-S	.24[j]	100	87	87.0	5	5.0	8	8.0	----	----	----
Zinc chloride	F	E. hemlock	S	.62[e]	112	78	69.6	2	1.8	32	28.8	----	----	2
Zinc chloride	F	Yel. birch	S	.67[e]	129	69	53.5	33	25.6	27	20.9	----	----	4
Zinc chloride	F	Corkbark fir	H-S	.45[e]	80	39	48.7	3	3.8	38	47.5	----	----	----
C. t. creosote, grade 1[b]	F,E	Corkbark fir	H-S	10.11	40	29	72.5	----	----	11	27.5	----	----	----
Ties set 1925 to 1927—13 to 15 years service														
C. t. creosote, grade 1[b]	F	E. hemlock	S	15.51	284	248	87.3	4	1.4	28	9.9	4	1.4	6

C. M. St. P. & P. Test Track at University Avenue (Continued)

				Ties set 1928—12 years service										
Arsenious acid	F	Red oak	S	.47[k]	95	88	92.6	1	1.1	6	6.3	----	----	----
Arsenious acid	F	Red oak	S	.27[k]	99	92	93.0	2	2.0	5	5.0	----	----	1
C. t. creosote, Grade 1[h]	F	Yel. birch	S	21.43	21	20	95.2	----	----	1	4.8	----	----	----
Sodium dichromate	F	Red oak	H-S	.52[m]	96	3	3.1	86	89.6	6	6.3	1	1.0	2
Sodium dichromate	F	Red oak	H-S	.27[m]	87[n]	----	----	82	94.3	5	5.7	----	----	2
Zinc-meta-arsenite	F	Red oak	S	.50[o]	97	83	95.9	1	1.0	3	3.1	----	----	2
Zinc-meta-arsenite	F	Red oak	S	.26[o]	112	104	92.8	3	2.7	3	2.7	2	1.8	2
				Ties set 1929—11 years service										
C. t. creosote, Grade 1[h]	E	Engl. spruce	H	6.67	49	47	96.0	1	2.0	----	----	1	2.0	3
Natural brine	F	E. hemlock	S	16.70[p]	197	76	38.6	94	47.7	27	13.7	----	----	2
Nickel chromate	F	Red oak	S	.50[q]	97	24	24.8	72	74.2	1	1.0	----	----	3
Nickel chromate	F	Red oak	S	.25[q]	99	2	2.0	97	98.0	----	----	----	----	3
Zinc chloride	E	Engl. spruce	H	1.07[e]	75	52	69.3	6	8.0	15	20.0	2	2.7	3
Zinc chloride-	T	Engl. spruce	H	.61[e]	84	76	90.4	1	1.2	4	4.8	3	3.6	4
C. t. creosote, Grade 1[h]				8.36[r]										
				Ties set 1927 to 1929—11 to 13 years service										
Untreated	----	Corkbark fir	H-S	----	150	27	18.0	91	60.6	28	18.7	4	2.7	----
				Ties set 1940										
Untreated	----	Blackjack oak	S	----	24	24	100.0	----	----	----	----	----	----	----
C. t. creosote, Grade 1[h]	F, E	Blackjack oak	S	4.45[s]	69	69	100.0	----	----	----	----	----	----	----
Zinc chloride	F	Blackjack oak	S	.32[e]	38	38	100.0	----	----	----	----	----	----	----

Note: This test is being conducted in cooperation with the United States Forest Products Laboratory. For a detailed description of this test see "University Avenue Test Track at Madison, Wis.", page 136, Proceedings of the American Wood Preservers' Association for 1935.

[a] F = full-cell method.
E = empty-cell method.
T = two Movement method.

[b] H = Hewed ties; S = sawed ties; H-S = both hewed and sawed ties.

[c] Rail and plate cutting, splitting, crushing, etc.

[d] 6% solution made by adding 6 gal. of concentrated Aczol solution furnished by Zinsser and Co. to each 94 gal. of water.

[e] Dry salt.

[f] Includes 2 white oak ties.

[g] Includes 4 white oak ties.

[h] A. W. P. A. specifications.

[i] Petroleum.

[j] $Na_2B_4O_7.10H_2O$

[k] Based on available As_2,O_3 in solution.

[m] $Na_2Cr_2O_72H_2O$

[n] Average life 5.9 years.

[o] Based on available $ZnAs_2O_4$ in solution.

[p] Estimated absorption of brine.

[q] Based on sum of nickel sulphate and sodium chromate in solution. The available nickel chromate constitutes 55.1% of the total weight of the two salts.

[r] Creosote.

[s] Based on 45 tis.

CONDITION OF EXPERIMENTAL BLACK AND RED OAK TIES IN THE TRACKS OF THE PUBLIC SERVICE COMPANY OF INDIANA (FORMERLY INDIANAPOLIS, COLUMBUS AND SOUTHERN TRACTION COMPANY), NEAR EDINBURG, IND., AFTER ABOUT 31 YEARS SERVICE

Ties set September, 1909 **Ties inspected June, 1940 (final)**

Preservative	Approximate average absorption Lb. per cu. ft.	Number of ties in test	Serviceable		Removed: Mainly for decay		Removed: For causes other than decay[1] and unknown causes[2]		Estimated average life Years
			Number	Per cent	Number	Per cent	Number	Per cent	
Coal-tar creosote	14	100	62	62.0	15	15.0	23	23.0	35.0[a]
Coal-tar creosote	12	60	39	65.0	2	3.3	19	31.7	37.0[a]
Coal-tar creosote	7 to 8	430	139	32.3	84	19.5	207	48.2	29.0[a]
Creosote and zinc chloride	Creo. 3-4 $ZnCl_2$ .45-.55	204	4	2.0	60	29.4	140	68.6	20.8[b]
Asphaltic crude oil	Indeterminate	182	1	0.5	157	86.3	24	13.2	13.5[c]

Note: This test was conducted in cooperation with the U. S. Forest Products Laboratory.

[1] Spike killed, rail cut, split, etc.

[2] Information on cause of removal not available.

[3] Two movement treatment—creosote treatment followed by treatment with 4½ per cent zinc chloride solution.

[a] Based on U. S. Forest Products Laboratory tie renewal curve.

[b] An additional average life of 2 years was estimated for each of the remaining 4 ties in arriving at this value.

[c] An additional life of 2 years was estimated for the remaining tie in arriving at this value.

General Information

Ballast—Gravel
Tie plates—None
Spikes—Cut
Traffic—light
Track curvature—All but 12 ties in tangent track.

Report on Assignment 3

Piling Used For Marine Construction

W. G. Atwood (chairman, subcommittee), C. S. Burt, W. F. Clapp, E. A. Craft, John Foley, H. E. Horrocks, A. L. Kammerer, A. M. Knowles, F. B. Robins, Hermann von Schrenk.

The committee submits a report of the results of the inspections of the test pieces under its supervision, together with such information on the subject assigned to it as has come to its knowledge.

Turpentine Wood

The specimens in the Canal Zone show little change in the last year. The heaviest attack was by the pholads.

The Southern Pacific Company reports on the condition of 32 turpentine wood piles in a pier at Oakland, Calif. No teredo attack is evident. Six of these piles show no limnoria attack, 3 a light and 7 a moderate limnoria attack and 16 a heavy limnoria attack. This entire attack is in the sapwood and on one or two piles the sapwood is nearly eaten off.

Panama Canal

The report by Mr. James Zetek has been made available through the courtesy of Brigadier General Glenn B. Edgerton, governor of the Canal Zone. The inspections were made October 2 and the report is quoted below:

> We encountered considerable silt, especially in the center well of dock 10, and Mr. Olsen will shorten the chains enough to keep the timbers free from silt. It would appear that the upper and middle wells are fast filling with silt and this will interfere with our tests.
>
> The results this year are particularly interesting. The highly resistant timbers from Dutch Guiana, New South Wales, the Philippines, Sumatra and the Celebes, show practically no change from last year. The teredo is not able to make much headway, they are few in number, and small in size, confined close to the surfaces. The gribble (*Limnoria lignorum* Rathke) is relatively unimportant except in a few cases. The really destructive agents are the two boring clams, *Martesia striata* L, and *Hiata infelix* Zetek and McLean. In some timbers these can be considered as plentiful. Although necessarily confined to the surfaces, their work, because of the size and shape of the cavity they inhabit, extends inward at least one inch. This year I found few live pholads, and I believe the silt killed off most of them. Even the gribble seems to have been affected by the silt.
>
> Neither *Sphaeroma* nor *Chelura* were found.
>
> The only treated timber, Chemonite (No. 2447), in rack 1721–31 was removed from the test, being thoroughly invaded by teredo.
>
> Perhaps the most interesting results were found in the two 10 x 5 x 48-in. pieces of red mangrove, which were installed April 19, 1940, only five months ago. Both showed what I consider to be an active teredo invasion. It is only a question of time, brief at that, so that it would appear that red mangrove is not resistant to teredo. Samples of this same lot of red mangrove in our termite resistance showed last month active attack by *Coptotermes niger*.
>
> The two pieces of red mangrove in racks 16 and 17 had a species of teredo which is different from those known from this region. The pallets are large and massive, not frail, 3.5 cm. long. This same species was collected by me several years ago and was sent to Dr. Paul Bartsch of the U. S. National Museum who at the time said it was new but as yet did not describe it. This one was found where there was much silt. (Fig. 1)

Fig. 1.

A—Untreated Timbers

1609–2 Anoura, *Conepia* sp., Dutch Guiana, submerged September 13, 1923 (Rack 26). Some silt. Considerable marine growth. Gribble damage about the same, worse on one face, about ½ in. deep. Both pholads present, plentiful. Teredo as before, not many, small close to surfaces. Most of the destruction is due to the pholads and gribble. The timber, except for this external deterioration is very sound.

1612–3 Basra-Locus (ANGELIQUE), *Dicornia paraensis* Bentham, Dutch Guiana (Rack 29), submerged September 13, 1923. Some silt. Fair amount of marine growth, especially sponges. Gribble not serious, less than in Anoura. Both pholads quite plentiful, also working on the cut face. Teredos are small, few in number (more so than in Anoura), but all seem to be confined close to the surfaces. Except for this surface work the timber is very sound.

1608–4 Foengo, *Parinarium campestre* Aubl., Dutch Guiana, submerged September 13, 1923 (Rack 32). Some silt. Marine growth abundant, especially sponges. Gribble about as in Anoura, one face is badly attacked but in general progress is slow; working also on the cut face. Teredoes few in number, small, close to surfaces. Both pholads plentiful, also starting on the cut face. Except for the surface damage, this timber is very sound.

1610–5 Sponse Hoedoe, *Licania macrophylla* Bentham, Dutch Guiana, submerged September 13, 1923 (Rack 33). Much silt. Marine growth very plentiful on all surfaces. Gribble attack about as in Basra Locus, one face considerably worn away, about ⅜ in.; also on cut face. Pholads are quite abundant and have started on the cut face. Teredos are confined close to the surfaces, few in number, small in size. Otherwise the timber is very sound.

1613–7 Manbarklak, *Eschwilera longipes* Miers., Dutch Guiana, submerged September 13, 1923 (Rack 34). Marine growth plentiful. Some silt. Gribble damage very light except on one face; cut face free of attack. It would seem that the gribble works very slowly on this timber. Both pholads fairly abundant. Teredos small, few in number, close to surfaces. Except as noted, the timber is very sound.

1606–9 Malabayabas, *Tristania decorticata* Merr., Philippine Islands, submerged September 13, 1923 (Rack 35). Marine growth scant. Some silt. Gribble damage is light, slightly more so on one face. Teredos seem to be all small, unimportant, few in number, close to surfaces. Both pholads are abundant, also on the cut face. Pholads cause most of the deterioration; otherwise this timber is very sound.

1615–11 Kajol Lara, *Metrosideros Sp.*, Celebes, submerged October 26, 1925 (Rack 36). Considerable silt. Marine growth, especially sponges, fairly abundant. Gribble work very light. Teredos few in number, close to surfaces, all small. Both pholads present but few in number. This timber is in exceptionally good shape.

1616–12 Kajol Malas, *Parastemon urophyllum*, Sumatra, submerged October 26, 1925 (Rack 23). Some silt. Marine growth pronounced, especially oysters and ascidians. Gribble light, more on one face, and more than on Kajol Lara. Both pholads are represented only in very limited number. Teredos unimportant, small, close to surfaces. Timber very sound.

1637–13 Kolaka, Celebes, submerged April 15, 1932 (Rack 13). Very much silt. Marine growth, especially bryozoa, plentiful. Gribble work very light almost nil, cut surface practically not attacked. Both pholads present in small number. Teredos not important, all small and close to surfaces. Timber very sound.

1617–14 Alcornoque, *Dimorphandra mora* B. & H., Panama (all heartwood), submerged September 22, 1927 (Rack 14). Very much silt. Marine growth very abundant. Both pholads present, not plentiful, more on one face. Gribble work is very light. Teredos seem to be very limited in number, all close to surfaces, all small. The surfaces of this timber are in quite good shape. Timber very sound.

1625–22 Brush Box, New South Wales, submerged April 19, 1929 (Rack 22). Some silt. Marine growth fairly plentiful. Gribble work almost nil except one face (not heavy, however); cut face almost none. Both pholads few in number. Teredos seem to be scant in number, near the surface, and all small. Timber very sound.

1645–16 Red Mangrove, *Rhizophora mangle* L., Colombia (Pacific Side), 10 x 5 x 48 in., submerged April 19, 1940 (Rack 16). Very much silt, resting on bottom. Marine growth nil. Gribble nil. No pholads observed. *Teredos very abundant,* seems to be a very healthy attack. Surfaces have great numbers of tiny holes and in those could be seen the ends of the pallets of the teredos. One edge has many teredos 3/16 to 5/16 in. diameter from which I extracted pallets for purposes of identification. These pallets agree with those of a new species collected a few years ago. These pallets are 3.5 cm. long, massive and rugged, not frail. As soon as this species is identified (or described since it is undoubtedly a new species) its name will be given in a supplementary report.

There can be no question but that this timber was attacked by teredo in our waters and that this red mangrove is not as resistant to teredo as it is reputed to be. I did not feel justified to chop into either of these two samples, but next year we should remove one of these for a thorough examination. The teredo is in both heart and sapwood.

B—Treated Timbers

1721–31 Chemonite Treatment, Southern Yellow Pine (2447), 6 in. diam. by 7 ft. long submerged March 12, 1937 (Rack 31). Considerable silt. Much marine growth, especially sponges, oysters and bryozoa. The timber was removed from the test and the attached *photographs give testimony to the thoroughness of the work of the teredos, more pronounced than No. 2468 reported in last year's supplement to the 1939 Annual Report. Test closed.

Chemical Warfare Service Specimens

Series No. 1

No. 1. 1 percent ammoniacal copper carbonate. Only two pieces remain. The one at San Juan, P. R., shows no change. The one at Oakland Pier, San Francisco bay shows a very light limnoria attack.

No. 2. 1 percent diphenylamine in creosote. There is no change in the piece at San Juan. There is no attack on the piece at Oakland Pier and a very light attack by limnoria on the piece at Peralta Wharf. The untreated control pieces at Oakland Pier showed a light attack by limnoria and a few teredo. The similar pieces at Peralta Wharf had a heavy attack by limnoria, teredo and Bankia.

* Photographs omitted from this report.

Series No. 2

The specimens in this series were treated at Edgewood Arsenal by the Chemical Warfare Service in 1931. Control pieces were treated with AREA No. 1 creosote. Several series of five pieces each were treated with AREA No. 1 creosote to which had been added various proportions of methyl arsenious oxide, diphenylamine chlorarsene, and dinitrophenol. A similar series was treated with fuel oil to which the same chemicals were added.

A long series of experiments at the Edgewood Arsenal had indicated that these chemicals were lethal to both the teredine and crustacean borers. The purpose of the tests was to find out whether fuel oil to which any of these chemicals had been added would resist attack and whether their addition to creosote would increase its resistance to attack. Unfortunately the treating was not well done and while the treatment was to refusal the end penetration was small. The first attack on all the pieces was in the lightly treated ends.

Reports have been made annually since the tests were installed in 1931 and 1932. Test pieces have been so badly damaged at the Panama Canal Zone, The Cavite Naval Station and the Puget Sound Navy Yard that the tests were closed. The reports this year from the Pearl Harbor Navy Yard show that the destruction has been so heavy that the remaining pieces may well be discarded and the test stopped at that location.

The inspection report from Fort Tilden, N. Y., shows little change in the condition of the test pieces since last year though the untreated control pieces were destroyed. All the pieces treated with fuel oil carrier have been heavily attacked but have some little strength left after nine years immersion. The untreated controls have been destroyed and replaced several times.

The report on the pieces at Castle Pinckney, in the harbor of Charleston, S. C., states that the pieces treated with straight creosote and with creosote to which methyl arsenious oxide had been added have been 75 percent destroyed and will probably be entirely gone in another year. The pieces to which dinitrophenol had been added to the creosote are reported to be 50 percent destroyed but no distinction is made between those to which 0.77 percent and 2½ percent had been used.

The Coast Guard report on the pieces at San Juan, P. R., states that there is no change in condition since last year.

The Naval Air Station at Pensacola, Fla., reports that the inspection shows that the heavy limnoria attack on the ends of the creosoted pieces continues and that there is some teredo attack in the same places. All pieces show some limnoria attack on the sides. It would appear that the pieces treated with cresote to which dinitrophenol had been added were less heavily attacked than the others. Those containing 2½ percent dinitrophenol were in the best condition.

The pieces at Oakland Pier showed no new attack on the creosoted pieces but a heavy limnoria and a light teredo attack on the oil treated pieces. The untreated controls showed a heavy limnoria attack.

At Peralta Wharf three of the creosoted pieces showed a light limnoria attack on the sides and a heavy one on the ends while the one with 2½ percent dinitrophenol added to the creosote showed no new attack on the sides and a light limnoria attack on the ends. The oil treated pieces showed a heavy limnoria and a light Bankia attack. The untreated controls showed a heavy limnoria attack and some attack by teredo and Bankia.

The report from the Pearl Harbor Navy Yard showed that the pieces treated with creosote and creosote with methyl arsenious oxide were not in as good condition as those treated with creosote and dinitrophenol. Pieces in the best condition were those treated with creosote and 2½ percent dinitrophenol.

San Francisco Bay Tests

The test pieces prepared by the Barrett Manufacturing Co. were placed in test at Pier 7 San Francisco in January 1923 and moved to Oakland Pier in 1925. They show little change in condition since the last report. A few of them showed a slightly increased limnoria attack. The untreated control pieces showed a moderately heavy limnoria attack.

Test Piles

At Tiburon two of the piles are missing, one shows no sign of deterioration, four of them have been attacked, one of which is nearly cut off.

At San Pedro there are three of the Long Wharf piles originally driven in 1890. Two of these are intact and the third has lost 30 percent of its section by limnoria attack. Two piles treated in 1919 are so placed that the mud line is exposed at low tide. There is no attack on these piles.

At Long Beach one of the 1890 piles was lost by accident, one is intact, and the third has been 30 percent destroyed by limnoria. The one Long Wharf pile originally driven in 1901 has been 80 percent eaten away by limnoria. The two 1919 piles show some attack at the low water line.

New England Report

The operation and regular inspection of the many test boards and blocks was continued. Reports follow:

At Corner Brook, Newfoundland, there was a very marked decrease in the intensity of attack. A large part of the wharf area has been filled, covering the piles, and those not covered have been replaced by creosoted piles.

At Liverpool, N. S., teredo have been very active at locations where they did not appear at all from 1935 to 1938 and where there were very few in 1938.

At Luneberg teredo have been and are very active.

A diver's inspection was made of two wharves at Searsport, Me., which were built on creosoted piles with 16 lb. treatment in 1925 and one wharf built in 1932 on oak piles with the bark left on. The creosoted piles showed no damage from teredo and penetration by limnoria in a few places to a depth of from ¼ to ½ in. The oak piles in the adjoining wharf showed an average reduction of section of about 25 percent while some spruce piles driven at the same time were entirely destroyed.

Limnoria are very destructive in the harbor of Portland, Me., but teredo, while present do little or no damage at the present time. A diver's inspection of the piles under two wharves on islands in the harbor, where to all appearances the conditions are the same, show opposite results. These wharves were built on oak piles with the bark left on in 1909. One of them was uninjured and the other was practically destroyed by limnoria. No teredo were found.

There has been little change in conditions between Portland and Cape Cod though there seems to be a trend toward increasing activity by teredo and limnoria.

Teredo have appeared in the upper harbor of Providence, R. I., but have, as yet done little damage.

Examinations made of the untreated piles in several wharves in Narraganset bay have shown heavy attack by teredo, limnoria and chelura.

At Saybrook, Conn., the damage done by teredo is increasing rapidly. The salinity, at one stage of the tide, falls to 3 parts per 1,000 and rises to full ocean salinity at another stage.

Many piles have been examined on Fishers, Plum and Gull islands in Long Island sound. There is a heavy attack by chelura and in some places by teredo.

All three species of borers continue to be active in New London harbor and teredo have become plentiful as far up the river as Allyn's Point.

New York Investigation

The study of test boards, the examination of piles in various parts of the harbor, and the study of water analyses has been continued. The committee in charge does not think that there is any valuable information available for publication.

"Sea Action Committee"

This committee of the Institution of Engineers, London, has recently issued its 18th interim report. This report is a discussion of the results of the 5, 10, and 15-year corrosion tests which have been referred to in the reports of this committee from time to time.

The test pieces were placed at Halifax, N. S., Auckland, N. Z., Colombo, Ceylon, and Portsmouth, England. Three sets were placed above high tide, three at half tide and three fully immersed at each of the cities indicated. One set was removed at each place at the end of 5, 10, and 15 years and sent to laboratories in England for examination. Each set was made up of three irons, several commercial steels of varying compositions, two copper-bearing steels, chromium and nickel steels and cast irons.

The results were extremely variable. Some of the materials that gave the best results above high water did not show as well as some others at half tide or completely immersed and some that showed best in temperate zone harbors did not do so well in tropical harbors.

The information in this report is of great value, but it must be used with care and with reference to the climate in which the structure is to be built. It is not possible to condense the information in such an abstract as can be here presented.

Summary

The test pieces prepared by the Chemical Warfare Service have not given the information that was hoped for when they were prepared, principally because the treatment was defective at the ends. The borers attacked the ends and opened up an easy zone of attack of which all borers present took advantage.

It would probably be safe to say that the life of timber in badly infested water is somewhat prolonged by treatment with fuel oil to which 2½ percent of dinitrophenol has been added. This treatment is more effective against *teredo navalis* than it is against some other species of borers. It is not so effective against limnoria. This type of treatment might be useful for the treatment of piles to be used in temporary structures, especially if the price of creosote were high. The other chemicals tried gave some protection but did not seem as effective as dinitrophenol.

The imperfect end treatment will prevent the gaining of much information with regard to the creosoted pieces. The destruction through the ends will be so great before the attack on the periphery goes far that no conclusions can be drawn. There are some indications that the addition of 2½ percent dinitrophenol does add to the resistance of creosote but that can not be said with certainty.

The Panama Canal tests of tropical timbers show clearly that there are a number of timbers which have a high resistance to attack by the species present in the Canal Zone.

This report is offered as information. It is recommended that the subject be continued.

Report on Assignment 5

Destruction By Termites and Possible Ways of Prevention

Hermann von Schrenk (chairman, subcommittee), W. G. Atwood, E. A. Craft, W. F. Clapp, John Foley, A. M. Knowles, F. D. Mattos, F. B. Robins, W. A. Summerhays.

The committee on termites has continued its investigations as to methods for preventing the attack of these insects. There is little to add this year to the recommendations made in previous reports. The experimental installation at Florissant, Mo., is as yet too recent to warrant pulling up the stakes. Some of them may possibly be pulled during the coming year, but that will be decided after further consideration by the committee.

One matter which the committee wishes again to stress is the importance of the proper installation of termite shields. Numerous cases have come to the committee's attention where termites have gotten into buildings, in spite of the fact that they were supposed to be protected by termite shields. Examination in these cases has shown that the shields were not properly applied. Shields to be effective must cover the entire foundation wall, top of posts, under stairways, etc.; the horizontal surface of the shield must project three inches from the edge of the wall or pier. It should then be bent at a 45-deg. angle for a distance of three inches. If the shields are bent down at the edge of the wall or pier, the termites can fill in the space between the vertical part of the wall and the shield, and thus get on top of the shield. There must be a three inch space between the point where the shield is bent and the vertical wall. There must also be at least three inches between the point where the shield is bent and the end of the shield.

Another point in connection with shield failure is that frequently shields are put in in short lengths and the end of one shield is simply put on top of the next shield. This makes the shield useless because termites will get in at the joint. All shields laid next to each other should be soldered so as to make a continuous piece of metal.

This report is presented as information with the recommendation that the subject be continued.

Report of Committee 12—Rules and Organization

W. T. Dorrance, *Chairman*,
J. B. Akers
W. C. Barrett
D. P. Beach
Richard Brooke
W. O. Cudworth
G. H. Harris
G. W. Harris
E. M. Hastings
A. A. Jackson
B. R. Kulp
C. H. Mottier
R. C. White
F. B. Wiegand
Committee.

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

The committee recommends the elimination of all material heretofore adopted by the Association on the recommendation of Committee 12 and published in the 1929 Manual and supplements thereto, and withheld from publication in the present Manual by order of the Board of Direction.

2. Prepare rules and regulations for the guidance of employees of the maintenance of way department, collaborating with appropriate standing committees.

The committee offers as a substitute for the above deleted material the following material as found in the report.

The Committee on Rules and Organization,
W. T. Dorrance, *Chairman*.

RULES AND REGULATIONS GOVERNING MAINTENANCE OF WAY AND STRUCTURES EMPLOYEES

I GENERAL

GENERAL NOTICE

Safety is of the first importance in the discharge of duty.

Obedience to the rules is essential to safety.

To enter or remain in the service is an assurance of willingness to obey the rules.

The service demands the faithful, intelligent and courteous discharge of duty.

EMPLOYMENT, PROMOTION AND DISCIPLINE

1. *Application for Employment.*—Employees must pass the required examinations.

2. *Employment of Minors.*—Minors must not be employed, except as allowed by law, and then only after written consent and release on the proper form has been obtained from parents or guardians.

3. *Physical Defects.*—A person whose hearing, sight or color perception is known to be defective must not be employed in any capacity where such defect may endanger the safety of persons or property.

4. *Promotion.*—Employees will be regarded as in line of promotion. Their advancement will be dependent upon the faithful, intelligent and courteous discharge of duty and capacity for increased responsibility.

Bulletin 423, February, 1941.

5. *Requirements for Promotion.*—No appointment or promotion to the position of foreman or assistant foreman will be made until the applicant has been examined as to his knowledge and understanding of all rules which relate to his duty, and has received a certificate of qualification signed by the proper officer.

6. *Re-employment.*—Employees whose duties are prescribed by these rules, if dismissed, will not be re-employed without the approval of the proper officer.

7. *Discipline Record.*—Employees are subject to record discipline, suspension or dismissal for cause.

CONDUCT

20. *General Conduct.*—Civil, gentlemanly deportment is required of all employees in their intercourse with the public, their subordinates and each other.

21. *Carelessness.*—Employees who are careless of the safety of themselves or others will be subjected to proper discipline.

22. *Use of Intoxicants and Narcotics.*—The use of intoxicants or narcotics is prohibited.

Responsibilities and Restrictions

30. *Books of Rules and Regulations.*—Employees whose duties are prescribed by these rules and regulations must provide themselves with copies. They must familiarize themselves with the rules and regulations affecting their duties, whether or not they appear under the head of their specific duties, and must be prepared to pass an examination on them at any time. If in doubt as to the exact meaning of any rule or regulation they must apply to the proper authority for explanation.

31. *Devote Services Exclusively to Company.*—Employees must devote themselves exclusively to the service of the Company, and must not connect themselves with any other trade or business without permission from the proper officer.

32. *Attend to Duties.*—Employees must attend to their duties during prescribed hours, and obey promptly instructions of their superiors.

33. *Absence from Duties.*—Employees must not absent themselves from duty without permission. They must not exchange duties with others, or engage substitutes without proper authority.

34. *Leave Address.*—Employees must leave their address with the proper officer or head of department, and give prompt notice of any change of residence.

35. *Assignment of Wages.*—Employees must not, without proper authority, assign their wages.

36. *Incurring Company Obligations.*—Employees must not incur any obligation on account of the Company, or use the Company's credit, unless authorized by the proper officer.

37. *Sale of Company Property.*—Employees must not sell or in any way dispose of Company property except by proper authority.

38. *Receiving Fees and Contributions.*—Employees must not ask for or accept fees or commissions from subordinates, fellow employees, patrons of the Company or the public.

39. *Color of Garments.*—Employees working on or about the track must not wear red outer garments which might be mistaken for signals.

40. *Experimental Installations.*—Employees must not permit, except by proper authority, experimental trials of appliances or devices, nor give out information of the result of any such trial. They must not answer communications from manufacturers of

or dealers in tools or appliances but should forward such communications to their immediate superior with complete expression of views.

41. *Railroad Records.*—Those who are entrusted with the records of the Company must not permit unauthorized persons to have access thereto; or without proper authority, must not divulge any of the Company's affairs.

42. *Cooperation.*—Cooperation is required between all employees whose work or duties may be jointly affected.

43. *Switch Keys.*—Any employee whose duties require, will be provided with a switch key, for which a receipt will be taken. In case key is lost, or not returned upon leaving the service .... dollars will be deducted from the amount due him. Employees must keep their switch keys in their possession at all times. Under no circumstances will they give the key to any person, other than a substitute foreman or allow anyone to use it for them.

44. *Return of Railroad Property.*—The articles furnished by the Company for the use of employees must, on their leaving the service, be returned to the proper officer.

45. *Misuse of Coal.*—Employees must not take revenue coal for any purpose, nor Company coal, except when so authorized.

46. *Railroad Mail.*—Letters of a personal nature must not be sent by railroad mail, as it is a violation of the U. S. postal laws.

Conduct of Work

50. *Jurisdiction of Officers.*—Employees whose duties require service on more than one division or district are under the jurisdiction of the officers of the division or district on which the service is being performed.

51. *Obeying Calls from Trainmen.*—Should trains be delayed by accident or from other cause, the conductor is authorized to call on any employee for assistance.

52. *Handling Switches.*—Immediately upon closing and locking a main track switch, the employee doing so must observe that the points fit properly. Main track switches must not be unlocked or handled within view of approaching trains.

53. *Obstructing View of Switches.*—Employees must not stand where they will obstruct the view of a switch-stand from passing trains and should not stand within .... feet of a switch when a train is approaching or passing.

54. *Not Throw Switches for Trainmen.*—Except to prevent accident, employees must not handle switches for trainmen or switch tenders.

55. *Train in Both Directions.*—Trains may be run at any time, upon any track in either direction, without notice to employees. Employees must be governed accordingly and exercise proper care to avoid accident.

56. *Observe Signals on Trains.*—Employees must observe signals displayed by all trains and assure themselves before obstructing track that all scheduled trains and sections due have passed.

57. *Watching Passing Trains.*—Employees must observe trains closely, and if anything dangerous is noted, such as loose wheel, broken wheel flange, broken rim, hot box, defective coupling, dragging equipment, badly pounding wheel, shifted load in open-top car; or if trains are running too closely together, must call attention of train and enginemen to the fact by signal; and failing to accomplish this, must notify the dispatcher.

58. *Working During Fogs.*—Work should not be done on track or track structures during fogs or heavy storms, but when unavoidable, the greatest care must be taken to insure full protection to men and trains.

59. *Protection of Company Property.*—In case of danger to the Company's property, employees must unite to protect it. They must report promptly to their superior

officers any apparently unauthorized encroachment upon or occupancy of company property. Supervisory officers should familiarize themselves with the boundary lines of the Company's property and must not permit encroachment or occupancy of Company property except upon proper authority.

60. *Protection of Wires.*—Wires found broken must be repaired temporarily or fastened to clear other wires when such wires are safe to handle, and reported to dispatcher by telegraph or telephone. Dispatcher must also be advised promptly of damaged wires which cannot be repaired temporarily. Location of train-order wires must be known and preference be given to repairing them. Dead and leaning trees which may endanger wires during storms should be removed. In case they are not located on the right-of-way, efforts should be made to obtain permission from owner of land to remove them.

61. *Wire Service.*—Employees must not use the telegraph unnecessarily. All messages must be as brief as is consistent with a clear understanding of their meaning. Messages referring to personal affairs are not to be offered for transmission on Company wires, except in case of accident or sickness.

62. *Position of Derail.*—Employees must notice side track derails and see that they are set to derail and locked in that position.

63. *Re-lighting Signal Lamps.*—An employee finding an oil-burning signal or switch lamp not burning between sunset and sunrise, must light it immediately and report it to the section foreman or signal maintainer.

64. *Keep Stock off Right-of-way.*—Employees must drive stock off the right-of-way and close any farm gates left open.

Reports

70. *Reporting Nonobservance of Signals.*—Disregard of stop or caution signals, excessive speed of trains, or failure to answer signals properly must be reported, with a full statement of facts.

71. *Reporting Violation of Rules.*—Any violations of the rules, regulations or instructions, or any misconduct, irregularities or negligence affecting the interest of the Company must be reported.

72. *Reporting Defects.*—Any defect discovered in track, bridge or signals, any failure of fuel or water supply, or any other condition noted, that may hinder the movement of trains, must be reported promptly by wire to the proper officers. In case the passage of trains is endangered, employees must remain and protect traffic until relief can be secured.

73. *Public Improvements and Ordinances.*—The proper officer of the Company must be informed promptly regarding contemplated public improvements or ordinances which would in any way affect its interests. Supervisors, foremen and other employees must make prompt report and forward at once to their immediate superiors any printed public notice, or other matter pertaining to such improvements or ordinances, with all the information available.

Accidents and Emergencies

80. *Assumption of Authority.*—In case of accidents or other emergencies prompt action is essential. In the absence of designation, the employee upon whom the responsibility most naturally falls must assume authority until the arrival of a superior officer. In case of an accident or menace to a passenger train he must, when necessary, see that all passengers are removed to a place of safety, render all assistance possible, police the location, cause the removal or prevent the approach of all lights, open flames or fires other than closed electric lights where there is danger of a fire or explosion, notify the

local fire and police authorities and keep all unauthorized persons away. Any material which may be of use in determining the cause of accident must be preserved and statements secured from employees and others who witnessed the accident. He must report fully to his superior all facts and particulars necessary for a clear understanding and make such suggestions as will be helpful.

81. *Witnesses to Accidents.*—Every reasonable effort must be made to procure the names and addresses of all persons, whether employees or others, who witness an accident.

82. *Accident Information.*—Employees who witness or have any knowledge whatever of an accident, should refrain from giving information to the injured person or anyone else except the Company's officers and claim agents, unless legally required. Persons seeking information should be referred to the claim agent or other officer of the Company.

83. *Watchmen at Accidents.*—In case of damage to a train or structure, wherein the security of freight or property is involved, it is the duty of all concerned to see that watchmen are immediately stationed and that arrangements are promptly made for protection against theft or loss from other causes.

84. *Unusual Conditions.*—Any employee having reason to believe that the safety of the track or any structure is endangered by flood, fire or other cause, before permitting its use, must make a personal inspection, using all precautions in the interest of life and property.

85. *Defective Equipment.*—When accidents occur that may have been caused by defective equipment, appliances, tools or machinery, such equipment, tools, etc., must be examined immediately by the person in charge to ascertain their condition. Any defective equipment, appliance, tool or machinery, or the defective part thereof involved, must be so marked as to be readily identified, and be withheld from further use, without modification, for investigation.

86. *Injuries to Trespassers.*—When trespassers are injured they should be turned over to county or town authorities. If this cannot be done, any available doctor should be called. He should be informed that the railroad company will be responsible for emergency attention only.

87. *Deaths from Accidents.*—In case of death from accident or otherwise, employees must see that the body receives appropriate care and is removed as soon as possible to proper place and left in charge of proper officer or an agent of the Company, unless there is a local or state law forbidding the removal of the body prior to the arrival of the coroner or other public official with like functions.

SUPERVISORY OFFICERS AND FOREMEN

90. *Books of Rules and Regulations.*—Supervisory employees must be fully conversant with the rules and regulations, must see that subordinates who should have copies are supplied, and see that they are receipted for, understood and complied with by those under them.

91. *Supervision.*—Supervisors shall see that foremen and others under their supervision are properly supplied with tools and material necessary for the efficient performance of their duties, and that they fully understand and properly perform the work assigned to them.

92. *Advise Whereabouts.*—Supervisory officers and foremen, when away from headquarters, must keep their superiors advised of their whereabouts.

93. *Govern Conduct of Men.*—Foremen shall govern the conduct of their men at all times while on Company property, and be responsible for the safe, proper and economical performance of the work assigned to them.

94. *Select and Instruct Men.*—Foremen must select their men with care, choosing only able-bodied men of proper age, alert and physically sound, in accordance with the rules governing employment, and endeavor to secure those who will develop into satisfactory employees. They must instruct their men in safe work-methods and see that they thoroughly understand all safety rules.

95. *Remain with Men.*—Foremen while on duty, unless otherwise directed, must remain with their men and personally superintend their activities.

96. *Training Substitute.*—Each foreman should train at least one of his men to fill his place in case of necessity.

97. *Substitute Foremen.*—Foremen must not absent themselves from duty without permission. If called from their work by sickness or other emergency, they must leave their most reliable man in charge of the gang and notify their superior officer by wire, giving him the name of the man left in charge.

98. *Avoidance of Accidents.*—Foremen or others in charge of employees working on or about tracks, must instruct their men to be alert, watchful, and to avoid accidents; and must take the necessary precautions to see that all men working under their immediate supervision receive warnings of approaching trains in time to reach a place of safety.

99. *Handling of Work.*—Foremen will be held responsible for the selection of properly qualified men, must instruct them to perform specific tasks, and see that work is performed in accordance with the rules, regulations and instructions. They must personally supervise the handling of all heavy material and the performing of the more hazardous work. They must plan such work carefully, using the most competent men for the more important tasks. When men are engaged in joint work, the foremen must see that each man has a thorough understanding of how the work is to be done and the moves to be made by each. When signals or instructions are necessary they will be given by the foreman personally, or by his personal delegate, the others remaining silent. In such work the foreman shall give special attention to inexperienced men, teaching them to work safely with the others.

100. *Joint Work.*—When two or more gangs are assembled on joint work, the proper supervisory officer must delegate one of the foremen to take complete charge, and this foreman shall be responsible for the proper handling of the work and safety of the men.

101. *Coordination of Work.*—When work is to be performed by one organization which requires the assistance of another, they shall cooperate in the conduct of such work and shall give each other proper notice to insure efficient prosecution of the work.

102. *Confusion of Signals.*—When gangs are working close together, care must be taken to prevent confusion of signals. The foremen must confer and arrange for full protection of the work as provided by the rules. Both foremen will be held responsible for any confusion of signals.

103. *Signal Interference.*—When work is to be done which may disturb interlocking or signal apparatus, the signal maintainer must be notified as far in advance as possible, and the foreman must cooperate with him in such work. If telegraph or telephone facilities are to be disturbed the dispatcher must be notified in advance and such work done with cooperation of the linemen. When a crossing alarm bell is out of order, or if it becomes necessary to spike an interlocked switch or derail, the foreman must make prompt wire report to the proper officers.

104. *Proper Signaling Appliances.*—Foremen must know that their gangs, trackwalkers and watchmen are always supplied with proper signaling appliances and must instruct employees as to their use.

105. *Overhead Work.*—Foremen must see that employees working overhead take special precautions to prevent falling, that they have safe footing and take no unnecessary chances.

106. *Working in Tanks or Pits.*—While men are working in tanks, excavations or other places, where assistance or attendance is necessary for safety, the foremen must see that such assistance or attendance is provided.

107. *Supplying and Using Goggles.*—Foremen and supervisory officers must see that employees, whose work requires, are equipped with goggles, and that they are worn when the employees are engaged in any work where their eyes may be endangered.

108. *Report Personal Injuries.*—In case of injury, however slight, to himself or to anyone under his supervision, or in case of injury to others which has not been reported by other employees, the foreman must immediately make a report by wire to his supervisor, followed by a written report on the prescribed form.

109. *Reporting Accidents.*—All accidents must be fully reported on the form provided for that purpose.

110. *Responsibility for Tools and Material.*—Foremen will be held responsible for care and proper and economical use of all tools and material furnished them. When these are received, they must be carefully inspected and checked against invoice. Foremen must anticipate their needs, keep their superior officers informed as to their requirements and must report promptly anything defective, any loss or any unnecessary accumulation of tools or material.

111. *Reports.*—Foremen must keep the required records and make the prescribed reports of the time of their men, and of the receipt, distribution, and use of tools and material furnished them.

112. *Examine Equipment.*—Foremen must examine ropes, cables, chains and other lifting equipment before using and be sure they are free from defects.

113. *Avoid Delaying Traffic.*—Except in case of emergency, repairs to track, bridges or other structures must be made, when practicable, at such time, and in such manner, as will avoid delay to trains.

114. *Standards and Plans.*—Foremen must conform to the prescribed standards, plans and specifications in the execution of work under their charge.

SAFETY

120. *Safeguarding Life and Property.*—The safeguarding of life and property is of first importance. The first duty and responsibility of employees is to prevent accidents, even though in so doing they may necessarily be performing the duty of others. Unsafe practices must be avoided. In case of doubt the safe course must be taken.

121. *Reporting Unsafe Conditions.*—Employees must keep a lookout at all times for conditions which might result in injury to persons, and if possible correct them promptly. If they cannot be corrected immediately they must be reported and protected to insure safety until remedied.

122. *Keep Tracks and Structures Clear.*—Materials or tools must not be left unguarded on station platforms or walkways, nor along the tracks where they may interfere with the safe passage of trains or the safe footing of persons.

123. *Working in Tunnels.*—Employees working in or near the end of a tunnel, when a train approaches from either direction, must stand clear of all tracks, and if in a tunnel must occupy the refuge niches if available. If there is insufficient clearance or no refuge niche, arrangements must be made to work under flag protection. Employees must carry lights when passing through any tunnel where men cannot readily be seen. When an

entire gang is working close together, an adequate number of lights, not less than two, must be used.

124. *Electric Wires.*—Repairs, changes or adjustments of electrical apparatus shall be made only by employees experienced in electrical work and authorized to do such work. When employees are in doubt as to their safety near electric wires or apparatus, they should notify the electrical department before commencing any work. They must avoid dangling wires which may be charged with electricity. If necessary to lift such a broken wire they must use a dry board or some non-conducting substance. They must inform themselves as to any high-voltage wires installed on or near the right-of-way and must use due care to avoid injury therefrom.

125. *Keep in Clear of Trains.*—Upon the approach of trains, men working on or near the tracks must promptly move to a place of safety. Those whose duties require them to walk track, where there are two or more tracks, shall, when practicable, walk against the current of traffic, keeping sharp lookout in both directions for approaching trains. When, due to storms, snow, fog, engines, cars or permanent obstructions, approaching trains cannot readily be seen, extra care must be taken to prevent accidents.

126. *Crossing Tracks.*—Employees must look in both directions for approaching trains, locomotives or cars before crossing tracks, and when crossing tracks in front of or behind standing cars or locomotives, must allow sufficient distance to cross in safety.

127. *Avoid Passing Over, Under or Between Cars.*—Employees must not climb over, between, or get under cars without adequate protection.

128. *Protruding Nails.*—Nails must not be left protruding where they may cause injury.

129. *Use of Goggles.*—Wherever goggles are provided for protection while doing certain classes of work, they must be worn as instructed.

130. *Safety Belts.*—Wherever safety ropes or belts are provided, they must be used by employees as instructed when working on poles, or in other similar work.

131. *Swinging Tools.*—When using a swinging tool, avoid endangering others. If necessary to work or pass within range of a swinging tool, first advise the user of the tool of your presence and exercise care to avoid injury.

132. *Do Not Step or Walk on Rails.*—Employees must not step or walk on rails.

133. *Do Not Watch Welders.*—Employees must not look at the electric or oxyacetylene flame with the naked eye.

134. *Open Flames Near Explosives.*—Employees must avoid smoking or the use of open flames in or near manholes where gas may be present or around gasoline, oxygen or acetylene tanks.

135. *Cutting Rivets, Bolts and Scrap.*—When cutting off rivets or bolts, or cutting up scrap, employees must use such protection as necessary to prevent injury from flying pieces.

136. *Handling Tools and Materials Overhead.*—Employees working overhead should be careful to prevent tools or material from falling, and should not drop objects without ample warning.

137. *Excavation Protection.*—Excavations must be properly protected when necessary to leave them open, and must be filled as promptly as possible.

138. *Placing Torpedoes.*—Torpedoes must not be placed near stations, road crossings, or at other locations where persons are likely to be injured by them, except when necessary to prevent accidents. All unexploded torpedoes found on Company premises not attached to track rail must be picked up.

139. *Storing Torpedoes.*—Torpedoes and fusees, when not in use, must be stored where outsiders cannot reach them.

STANDARD WATCHES

150. *Use Standard Watches.*—Watches that have been examined and certified to by a designated inspector must be used by all supervisors and foremen and by such other employees as may be designated by special instructions. The certificate in prescribed form must be renewed and filed with the .... every ....

151. *Compare Watches.*—Foremen, or others, required to carry standard watches who are not accessible to standard clocks, must compare their watches daily so far as practicable with a clock designated by .... or with dispatchers, conductors or enginemen.

TIME-TABLES

155. *Employees Must Have and Understand Time-Tables.*—Employees whose duties are in any way affected by the time-table must have a copy of the current time-table with them while on duty. They must be conversant with and obey the rules and special instructions contained therein.

156. *Destroy Old Time-Tables.*—Time-tables that have been superseded must be destroyed.

SIGNALS

160. *Proper Signaling Appliances.*—Employees whose duties may require them to give signals, must provide themselves with the proper appliances, keep them in good order and ready for immediate use.

161. *Signals.*—Flags of the prescribed color must be used by day, and lights of the prescribed color by night.

162. *Day and Night Signals.*—Day signals must be displayed from sunrise to sunset, but when day signals cannot be plainly seen, night signals must be used in addition. Night signals must be displayed from sunset to sunrise.

163. *Color Signals.*—See rule No. 10 Standard Code AAR.

164. *Hand, Flag and Lamp Signals.*—See rule No. 12 Standard Code AAR.

165. *Violent Signals.*—Any object waved violently by anyone on or near the track is a signal to stop.

166. *Engine Whistle Signals.*—See rule No. 14 Standard Code AAR.

167. *Use of Torpedoes.*—The explosion of two torpedoes is a signal to proceed at reduced speed. The explosion of one torpedo will indicate the same as two, but the use of two is required.

168. *Classification Signals.*—All sections of trains, except the last, will display two green flags and in addition, two green lights by night, in the places provided for that purpose on the front of the engine. Extra trains will display two white flags and, in addition, two white lights by night in the places provided for that purpose on the front of the engine.

169. *Switch Targets.*—Main track switch targets will show green or no indication when switches are set for the main track, and red when set for side tracks, crossings or junction tracks. All other switch targets will show green (or no indication) and yellow.

USE OF SIGNALS

175. *Imperfectly Displayed Signal.*—A signal imperfectly displayed, or the absence of a signal at a place where a signal is usually shown, must be promptly reported to the ....

176. *Crossing Watchman.*—Watchmen stationed at public crossings at grade must use stop signals when necessary to stop trains. They will use prescribed signals to stop highway traffic.

177. *Flagmen.*—The following signals will be used by employees when flagging:

Day Signals—A red flag, torpedoes and fusees.
Night Signals—A red light, torpedoes and fusees.

FLAGGING

180. *To Stop Trains.*—When a track for any cause is unsafe for the passage of trains at normal speeds, an employee, with proper flagman's signals, must be sent in each direction a sufficient distance to insure full protection, placing two torpedoes and, when necessary, in addition, displaying lighted fusees. In addition, appropriate stop or slow signals shall be displayed at the point to be protected. Crossovers or junction points between the flagmen and the unsafe track must also be protected.

181. *Recalling Flagmen.*—Foremen must know that flagmen are out the required distance before breaking or obstructing the track, and the flagmen must not be recalled by motions, but must remain at their posts and protect until other employees under the jurisdiction of the same foreman have verbally notified each of them that the track is safe.

182. *Removing Torpedoes.*—Flagmen, when recalled, must remove the torpedoes placed by them.

183. *Temporary Restricted Speed Signs.*—To facilitate the movement of trains over portions of track not in condition for normal speed, standard temporary slow signs may be used to control the speed of trains over such track when authorized by bulletin issued by the superintendent giving location and speed.

184. *Resume Speed Sign.*—A resume normal speed sign, painted green and displaying a green light by night, shall be placed on the engineman's side, ... feet beyond the protected track to indicate that normal speed may be resumed.

TOOLS AND MATERIAL

190. *Use of Tools and Material.*—Tools and material must not be loaned, disposed of or used in any unauthorized manner except under special instructions from the proper authority.

191. *Requisitions.*—Requisitions should be made sufficiently early to avoid delay to the work. The items desired should be fully described, making reference where practicable to standard drawings.

192. *Release Cars Promptly.*—Carload shipments must be unloaded promptly, cars released and the agent notified.

193. *Surplus and Second-Hand Material.*—Serviceable second-hand and surplus materials, defective tools and scrap must be collected and disposed of according to instructions.

194. *Passenger Train Shipments.*—The shipment of heavy or bulky material by passenger trains should be avoided, except in cases of emergency.

195. *Defective Material.*—When defective material or material unsuited for the purpose is observed it must be reported to the supervising officer and must not be used except on special instructions.

196. *Loading Material.*—Cars must not be loaded beyond their load limit, must be safely loaded and with the load distributed as uniformly as practicable.

197. *Unloading Material.*—Care must be exercised in unloading material to keep the car sufficiently balanced to avoid derailment.

198. *Piling Material.*—Materials must be piled in places designated for that purpose, a safe distance from the track.

199. *Piling Forest Products.*—Lumber, timber, ties and piling must be piled in accordance with instructions.

200. *Combustible Material.*—Combustible material should be piled at a safe distance from telegraph, telephone and signal lines, preferably on the opposite side of the track from such lines. Adjacent ground must be kept free from vegetation for sufficient distance to protect from fire.

201. *Distribution of Material.*—When necessary to leave over night, material distributed close to track, in the vicinity of switches or in yards, notice must be given.

202. *Rubbish.*—Rubbish must be cleaned up promptly and disposed of properly with due regard to fire hazard.

203. *Safekeeping of Tools.*—All tools and supplies, when not in use, must, as far as practicable, be kept locked in the tool box or tool house provided for the purpose, or where they can be carefully watched.

204. *Use of Tools.*—Employees must observe the condition of tools and equipment which they are to use. Defective tools should not be used.

205. *Use of Sledges.*—Track chisels or other tempered tools should not be struck with a spike maul. Sledges provided for that purpose should be used.

206. *Instruments.*—Electrical or other delicate instruments must be handled with extreme care, and when shipped must be packed in accordance with instructions.

ROADWAY MACHINES AND WORK EQUIPMENT

230. *Familiarity with Machine.*—The operator must familiarize himself with all parts, detail adjustments, and lubrication of the machine to which he is assigned.

231. *Cleaning and Lubricating.*—It is the duty of every man in charge of, or operating, a machine to keep it clean and well lubricated, using proper equipment for handling and applying lubricants. The lubricants used must comply with current instructions or chart. The receipt of a machine in dirty, unoiled, or poor running condition must be reported promptly to the proper officer.

232. *Shipments.*—Gasoline tanks and carburetors of machines must be drained before shipment.

233. *Fouling Track.*—A machine must not foul or obstruct any track before proper permission is obtained and protection provided.

234. *Lock Booms.*—Swinging portions of cranes or other similar equipment must be locked or mechanically fastened, with the boom of cranes parallel to the center line of track during the approach and passing of trains on adjacent tracks.

235. *Operations Endangering Wires.*—Employees handling derricks or pile drivers, or doing work likely to interfere with communication or power wires, must use every precaution to prevent damage.

236. *No Riders.*—Operators must see that no one rides on cranes or other similar equipment except when necessary in the discharge of duty.

237. *Inspection.*—Frequent inspections of all machinery, cables, etc., must be made by the operator so that repairs may be made when necessary.

238. *Load Limits.*—Loads heavier than indicated by the body plate on the machine should not be attempted.

239. *Blocking.*—When heavy loads are to be handled, operator must assure himself that the machine is properly blocked and that the brakes are set.

240. *Safety Guards.*—Operator must keep all safety guards in place when the machine is working.

MOTOR CARS, VELOCIPEDES, HAND AND PUSH CARS (TRACK CARS)

250. *Terminology.*—Unless otherwise indicated the term "track car," where used herein will apply to motor cars, hand cars, velocipedes, trailers and push cars.

251. *Running on Foreign Lines.*—Track cars must not be run over foreign lines unless permission has been secured from proper supervising officer.

252. *Use for Company Business.*—Track cars must be used only for company business. None but employees in the discharge of their duties shall be permitted to use or ride upon track cars except with proper authority.

253. *Responsibility.*—Employees to whom track cars are assigned are responsible for proper use and condition of cars in their charge. A report must be made to their superior officer if the car is in need of repairs.

254. *Operators' Qualifications.*—No one except a responsible employee who is qualified and has been authorized will be allowed to operate a motor car upon a main track.

255. *Unauthorized Attachments.*—Foremen and operators must not place unauthorized attachments on their track cars.

256. *Insulation.*—Only insulated track cars shall be used where there are track circuits.

257. *Shipment on Trains.*—Where necessary to ship motor cars on trains, gasoline tanks and carburetors must be drained.

258. *Protection of Cars.*—When not in service track cars must be protected as well as possible from weather and, when left in the open, must be locked.

Operation of Track Cars

270. *Keep Ready for Use.*—Motor cars must be kept ready for immediate use at all times.

271. *Inspection Before Starting.*—Foreman or operator must inspect his car carefully before starting a trip, seeing that it is in proper operating condition and properly equipped. The following flagging equipment must be carried on all motor cars:

Torpedoes
Fusees
Red flags
Red lanterns
White lanterns

Fusees and torpedoes must be carried in proper containers.

272. *Loading Tools and Material.*—Tools and material must be properly placed on track cars to prevent falling off or interfering with free operation of the brakes.

273. *Emergency Handling.*—There should be a thorough understanding as to the part that each person on a track car will take in the handling of the car and as to the side of the track to which the car will be removed if an emergency should arise necessitating prompt action.

274. *Position of Men on Track Car.*—Each man in a regular gang should be assigned to a place on the motor car where he will ride. Occupants must be seated.

275. *Look Out for Following Trains.*—When motor cars occupied by more than one man are running on the main track, at least one man must face the rear and keep a look out for following trains.

276. *Look Out for Obstructions.*—A sharp look out must be kept at all times for obstructions on the rail that are likely to derail car, and for workmen on or near the track.

277. *Run in Direction of Traffic.*—On lines of more than one main track, a motor car should generally move with the current of traffic.

278. *Throwing Switches.*—Main track switches must not be thrown for track cars when they can be lifted over.

279. *Spring Frogs and Switches.*—Track cars should not be run under power through spring side of frogs or spring switches.

280. *Remote Controlled Switches.*—Track cars must be stopped before passing over remote controlled switches and then pushed through.

281. *Interlocked Derail and Switches.*—Track cars must be stopped before passing over interlocked derails and switches.

282. *Approaching Crossings.*—When approaching road crossings at grade, a track car must be under complete control or stopped. If the crossing is protected by flagman, the operator must get the signal from him before proceeding. When required by rule or law, a proper warning must be given when approaching highway crossings at grade.

283. *Passing Standing Trains.*—Caution must be used in passing a train receiving or discharging passengers at a station, and, except where proper safeguards are provided, cars must not pass between the train and platform.

284. *Follow Spacing.*—A track car must not be attached to an engine or train and must not be run closer than 500 feet behind a moving train, and must stop not less than 200 feet from a standing train. Where two or more cars are traveling uncoupled, the space between cars must be not less than 500 feet. A car in advance must not be stopped until the following car has been signaled.

285. *Coupling of Trailers.*—A track car must never be pushed by a motor car regardless of whether the motor car is moving ahead or backward, unless the cars are equipped with an approved type safety coupler. Trailers and other track cars being towed must be coupled with an approved coupler. Under no circumstances must a makeshift coupler be used. Hand cars should not be coupled to motor cars except in emergency and then only when connecting rod has been disengaged from crank and made inoperative.

286. *Caution in Use of Track Cars.*—Track cars shall move at all times with care necessary for safety, expecting trains or other cars to appear at any time from either direction without notice. When necessary to operate them in foggy weather, severe storms, or at night, or where the view is obstructed in any way, or when the track cars cannot quickly be removed from track because of heavy load or insufficient side clearance, especial care must be used; and if conditions require, cars must proceed only under flag protection.

287. *Night Operation.*—When motor cars are operated at night or during storms or fog, or through tunnels, they must be equipped with a white light in front and a red light in the rear.

288. *Replace Torpedoes.*—Torpedoes exploded or damaged by track cars must be replaced.

289. *Protect Track Car on Track.*—A track car must not be left on the track while men are at work. It must not be left on the track unprotected.

290. *Removal from Track.*—A track car removed from track must be placed not less than .... feet from nearest rail. It must not be left standing at public or private crossings in a position that will interfere with the travel-way.

291. *Safe Loads.*—Track cars must not be overloaded. Heavy material, ties, etc., must not be handled on motor cars except in extreme emergencies.

292. *Speed.*—The speed of motor cars must not exceed that at which the cars can be stopped within the limits of safety.

293. *Handling Car.*—Care must be exercised in placing motor car on and off the track and in loading or unloading tools.

294. *Carbon Monoxide Gas.*—Cars must not be run in closed car house, as carbon monoxide gas is fatal.

FIRE PREVENTION AND PROTECTION

310. *Protection of Property.*—The protection of the property of the Company against fire is an important part of the duty of every employee and each is expected and required to give this his constant and personal attention. All employees should be acquainted with the nearest city or Company fire-alarm box and be thoroughly familiar with its use.

311. *Reporting Fires.*—Each fire must be promptly reported to the proper officer in order that thorough investigation of causes of fire can be made. All available details must be supplied.

312. *Fire Fighting Apparatus.*—Fire-fighting apparatus must be kept in condition for instant use, free from obstructions, and not used for other purposes than fighting fire. Its location must be understood by all employees concerned. Special attention must be given to condition of hose, hydrants, alarm systems and fire pumps.

313. *Fire Hose.*—Fire hose must at all times be properly maintained and ready for instant use. All fire hose, except unlined linen hose, should be tested at least once each year, preferably in the Spring. The hose should then be drained and the cotton covering allowed to become thoroughly dry before putting back on reel or in hose compartment.

314. *Fire Extinguishers.*—Fire extinguishers of all types should be inspected at regular intervals and any defects promptly corrected. Soda-acid and foam type extinguishers should be discharged once each year and re-charged, with date of recharging shown on tag attached to extinguisher. Carbon tetrachloride extinguishers should be given annual tests and kept filled at all times.

315. *Water Barrels.*—Water barrels equipped with buckets must be kept filled and precaution taken against freezing by dissolving salt or calcium chloride in the water in proper proportions.

316. *Sand Pails and Scoops.*—Dry sand with scoops must be maintained where oils, paints or inflammable liquids are used or stored.

317. *Inspections.*—Frequent inspections should be made of grounds and buildings to see that they are kept clean and free from accumulation of debris and unneeded materials which might cause or contribute to a fire.

318. *Metal Receptacles and Lockers.*—Standard metal receptacles with covers should be provided for ashes, rubbish, oily rags and waste, torches, small oil supplies and waste paper towels. Ventilated lockers should be provided for workmen's clothing, and clothing should be suspended from hooks. Metal waste baskets, with closed sides, should be provided in offices for scrap paper.

319. *Disposition of Ashes and Rubbish.*—Rubbish, ashes and sweepings should not be allowed to accumulate on the property, but should be disposed of daily. Burning of rubbish and old materials must be done with due regard to safety of buildings and material. Metal screens, trash burners, or incinerators should be used.

320. *Oil Drippings and Friction Hazards.*—Combustible materials must not be used as an absorbent to catch oil drippings from bearings and other parts of machinery; metal drip pans with sand should be provided. All belts should be examined to prevent friction against combustible materials and all bearings watched for heating.

321. *Fire Escapes, Doors and Automatic Devices.*—Fire escapes, fire lanes, fire doors and shutters must be kept free of obstructions at all times. When painting or white-washing is being done, care should be exercised to protect fusible links on fire doors, windows and sprinkler heads from being covered with paint or whitewash.

322. *No Smoking.*—Smoking is prohibited in shops, coaling stations, piers, wharves, warehouses, storehouses, freight houses and record rooms, and in buildings where explosives, gasoline or volatile liquids, oils or paints are used or stored.

323. *Electric Installations and Inspections.*—Electric wiring and apparatus must be installed and maintained in accordance with the regulations of the National Electrical Code. Inspections must be made at intervals to see that they are in safe condition and kept up to standard requirements.

324. *Electric Wires.*—Electric wires must not be hung on nails or other metal fixtures, or where they may come in contact with telephone, telegraph or high-tension wires. They should be supported by and hung from approved insulators.

325. *Vapor Proof Globes and Wire Cage Guards.*—Electric lamps must be equipped with vapor-proof globes in oil houses, paint rooms or other locations where volatile liquids are handled or stored, also in grain elevators, coal docks, coaling stations and other structures where explosive dust, vapors or gas may exist. The use of open lights in these locations is prohibited. Electric lamps on extension or drop cords in stationery storehouses, record and file rooms, or similar facilities must be equipped with wire cage guards.

326. *Switch and Fuse Cabinets and Fuses.*—Switch panel cabinets and fuse boxes must be kept closed and no materials stored therein. Fuses must not be exchanged or replaced with larger capacity fuses than design of circuit calls for as established by the National Electrical Code.

327. *Oil Lamps and Lanterns.*—Electric lighting should be used where available. Oil lamps, when used, must be rigidly and securely supported, and must have metal fonts, with metal or porcelain shade. Oil lamps or lanterns must not be filled while burning or near any open flame. Lamps should not be used when nearly empty, due to danger of accumulation of explosive gases.

328. *Oil Stoves and Lamps.*—Lamps or stoves, burning gasoline, oil or alcohol, should not be used except by special permission. Only those devices having the approval of the Underwriters Laboratories should be permitted.

329. *Chimneys, Stoves and Stovepipes.*—Stoves should be installed at least three feet from all wood-work, otherwise wood-work must be protected by asbestos backed metal shield with air space between shield and wood-work. Wood flooring underneath stoves and ranges must be protected by metal covering extending ...... inches on all sides. Stovepipes must be riveted at the joints and rigidly installed at a safe distance from combustible material. Particular attention should be given to protection where pipes pass through walls, ceilings, partitions or roofs. Where pipes are removed from chimneys, openings must be closed by proper size flue stops. Chimneys and flues shall be constructed and maintained in accordance with National Board of Fire Underwriters' rules and regulations.

330. *Stove and Chimney Inspections.*—All heating appliances must be examined every Fall and defects corrected before the appliance is used. Chimney inspection should be

made at this time, giving special attention to those parts of the chimneys which extend through attic and roof.

331. *Removal of Ashes.*—Ashes must be removed promptly from stoves, furnaces and boiler plants, and disposed of in such manner that they will not come in contact with combustible material.

332. *Steam Pipes and Radiators.*—Steam pipes and radiators must be properly installed and supported and kept clear of any wood-work, or other combustible material and should have sufficient clearance to permit cleaning in back of radiators and pipes. Steam pipes must be supported by metal brackets or supports.

333. *Oils, Paints and Varnishes.*—Where practicable, oils, paints, varnishes and similar compounds must be kept in a separate storehouse.

334. *Oil House, Dope and Paint Room Inspections.*—Frequent inspections of oil houses, paint rooms, dope and reclaim houses must be made, to see that all special instructions and rules in regard to them are being fully observed.

335. *Storing and Handling Volatile Liquids.*—Gasoline, benzine, naphtha, benzol, distillate, snow melting oil and similar volatile liquids must be stored in a separate isolated building and used only from Underwriters' approved type safety cans. Open flames, lamps, lanterns and torches will not be permitted where volatile liquids are being used.

336. *Bulk Oil Stations and Loading or Unloading Racks.*—All bulk gasoline and oil stations, and gasoline loading and unloading racks must conform to federal, state and city requirements.

337. *Extinguishing Oil Fires.*—For extinguishing an oil fire use foam, carbon dioxide or carbon tetrachloride fire extinguishers, if available, otherwise smother with steam, wet blankets, dry earth, sand or similar material. Except where fog nozzles are provided water should not be used.

338. *Parking of Automobiles.*—Automobiles must not be housed or parked in other than authorized buildings or locations.

339. *Fusees, Torpedoes and Matches.*—Fusees, torpedoes or matches must be kept separately and when transported must be placed in special container for safe handling.

HANDLING OF EXPLOSIVES

350. *Signs and Regulations.*—Danger signs must be conspicuously placed on all buildings and magazines (above the roof if practicable), in which explosives are stored, and must conform to federal, state and city requirements.

351. *Storing Explosives.*—Explosives must be stored in fire-resistant magazines a safe distance from Company buildings, or buildings and property of others in accordance with the law. In states where no laws are in effect, the American Table of Distances shall be used. When dynamite is being held for use and no adequate storage facilities are provided, it should be buried in the ground and suitable identification and warning signs posted.

352. *Keep Supply Limited.*—The supply of explosives in storage should be kept at the minimum for the requirements and be removed in quantities as needed.

353. *Storing Fuses and Blasting Caps.*—Fuses and blasting caps must not be stored in the same building with explosives.

354. *Qualifications of Employees.*—The supervisor must satisfy himself as to the qualifications of employees assigned to the handling of explosives.

355. *No Smoking or Use of Matches and Lights.*—Employees must not smoke and must not light matches while near or handling explosives. Lanterns or other open flames will not be permitted while handling explosives, or in the immediate vicinity of maga-

zines or storage areas. Electric flash-lights or incandescent lamps with wire cage guards must be used exclusively.

356. *Misfires and Partly Exploded Charges.*—When dynamite or other explosives, due to having become frozen, or from other causes fail to properly explode, all or part of the unexploded charge may have been left in the "bore" or hole or become mixed with broken rock or dirt. Such unexploded charges are liable to be set off if struck with a shovel or other tool and cause personal injury or loss of life. Such unexploded charges must be handled in accordance with the rules established in the Institute of Makers of Explosives Handbook, "Safety in Handling and Use of Explosives."

357. *Thawing Frozen Dynamite.*—Some dynamite is likely to freeze when its temperature falls below 50 degrees F. Dynamite of such temperature must be considered as frozen and should be thawed in an approved type kettle. The kettle must not be placed near a lighted lantern or other open flame. The water compartment must be filled with water of such temperature that the oven or thawing compartment in which dynamite is to be placed will not be higher than 100 degrees F. The thawing compartment must be clean and dry before the dynamite is placed therein.

358. *Transporting Explosives on Track Cars.*—When necessary to transport explosives on a track car, the car must be run slowly and where view of track from front or rear is insufficient to allow ample time to safely remove car from track in event of the approach of a train, it must be protected by flagging.

359. *Use of Explosives on Company Property.*—Dynamite or other explosives must not be used on Company property without the knowledge and consent of the proper officer.

SANITATION

370. *Drinking Water.*—Care must be taken to secure drinking water that is safe and free from contamination. When in doubt as to the purity of water for drinking purposes it should be boiled for a few minutes and allowed to cool, or be chlorinated, before using.

371. *Food Protection.*—Food should be stored and prepared in spaces protected from flies, and so far as practicable eaten in such spaces.

372. *Camp Sites.*—Camp sites should preferably be on high ground, be well drained and kept in clean and sanitary condition.

373. *Vermin.*—To prevent and exterminate vermin, camps or camp cars should be cleaned by scrubbing with soap and hot water, and the bedding should be aired and sunned.

374. *Toilets.*—Where temporary toilets are provided, a suitable trench for excretions shall be dug and the bottom covered with lime. Excretions should be covered periodically with lime, or with earth until lime is available.

PROCEDURE IN CASE OF PERSONAL INJURIES

390. *Summon Doctor.*—In case of serious personal injury, the nearest Company doctor must be summoned immediately. If a Company doctor is not immediately available, the most available doctor must be called to render emergency attention, until the arrival of a Company doctor, who will then take charge. When a number of persons are seriously injured doctors as needed and available should be summoned.

391. *Information to Doctor.*—In summoning doctors, information as to the number and needs of the injured should be given.

392. *Company Doctor Assume Charge.*—Upon arrival of the Company doctor, he shall assume charge of the injured.

393. *Fire Department Aid.*—If a local fire department is available, it may render valuable assistance and should be called on for aid when needed.

394. *Minor Injuries.*—In cases where injuries are minor, the patient should be sent to the nearest Company doctor.

395. *Employees Go to Company Doctor.*—Employees will be expected, whenever able, to visit the Company doctor for treatment, except where their residence is too far away.

FIRST AID TO INJURED

See "First Aid Instructions for Railroad Employees," approved and published by Operating-Transportation Division, Association of American Railroads, 30 Vesey Street, New York City.

II ROADWAY AND TRACK

Section Foremen

500. *Instructions.*—Section foremen report to and receive instructions from the designated officer.

501. *Responsibility.*—They are in charge of and responsible for the safe condition of tracks, roadway and right-of-way on their sections, and for the economical use of labor and material in their maintenance. They must do no work thereon that will interfere with the safe passage of trains, except under proper protection.

502. *Inspection.*—Unless otherwise provided, they must go over their sections or send a competent reliable man with suitable tools, at designated intervals, to make a thorough inspection, and see that the track, culverts, highway crossings, bridges, fences, and other railway property are in safe condition. If, in their judgment, the track or any bridge or culvert is not safe, they must at once put out proper signals to warn approaching trains, notify the proper officers of the condition and do everything in their power to make the necessary repairs.

503. *Accidents.*—They must, in case of accident, immediately proceed to the scene. In the absence of a ranking officer, the section foreman on whose section the accident occurs, will have charge of the assembled track forces, and shall be responsible for the character of the repairs made.

504. *Investigation.*—They must investigate all accidents resulting in derailment or in damage to the track, roadway, or structures on their sections, and make report.

506. *Obstructions.*—They must give special attention to points where obstructions are likely to occur.

507. *Storms.*—They must, during heavy storms or high water whereby tracks or structures are likely to be damaged, patrol their sections to make sure that the track is safe.

508. *Watchmen.*—They must see that watchmen are properly detailed to patrol the track, watch bridges or perform other duties, whenever necessary.

Extra or Floating Gang Foremen

515. *Instructions.*—Extra or floating gang foremen, in charge of trackmen, shall report to and receive instructions from the designated officer. They shall perform such duties and employ the number of men as directed.

Watchmen

520. *Instructions.*—Track, bridge and tunnel watchmen report to and receive instructions from the designated officer or employee.

Drainage

525. *Roadbed.*—Drainage of the roadbed is essential for economical maintenance of track and must be given careful attention.

526. *Ditches.*—Ditches should be provided in cuts in conformity with the standard roadbed sections and be kept open.

527. *Drainage of Slopes.*—Ditches should be provided where necessary, along the tops of slopes of cuts to intercept water from higher ground.

528. *Waterways.*—Waterways through culverts, under bridges, and adjacent thereto should be kept clear of obstructions.

Care of Roadway

540. *Cross-section.*—The cross-section of the roadway should conform to the standard plans and deviation therefrom must not be made without proper authority.

541. *Vegetation.*—Growth of vegetation on the slopes of cuts and embankments should be encouraged in order to prevent erosion. When erosion damaging roadbed is discovered protective action should be taken.

Ties

550. *Inspection.*—The selection of ties to be renewed must be made by careful inspection of the ties in track, and those to be removed designated as directed.

556. *Installation.*—All ties must be placed in track square to line of rail, spaced, and lined as directed.

557. *Handling.*—Care must be taken to prevent damage to new or serviceable ties.

558. *Tie Plugs.*—Treated tie plugs should be driven into all holes from which spikes have been drawn, in ties that are to remain in track.

563. *Handling.*—Ties removed from track, after all ties plates and rail fastenings have been removed, shall be collected and held for disposition, as directed.

568. *Distribution.*—Ties delivered but not to be installed within a short time must be stacked as directed.

Rail

573. *Distribution.*—When distributing rail it should, as far as practicable, be so placed that it can be laid with the least handling. Care must be exercised to prevent damage to rails during handling.

578. *Renewal.*—Temperature of rail shall be taken with rail thermometer and openings provided for expansion by placing expansion shims of the designated thickness between the ends of the rails.

579. *Laying.*—Rails shall be laid consecutively to line and gage, one rail at a time wherever practicable. Joints must be fully bolted and bolts drawn up before spiking the rail and joint to gage.

580. *Closures.*—Closures, both temporary and permanent, shall be made as directed.

587. *Gaging.*—Correct gage is essential to good track and must be maintained.

Joints and Bolting

594. *Bolting.*—All main track joints must be fully bolted. Care must be taken to maintain prescribed tension.

597. *Washers.*—Spring washers or nut locking devices should be used, as directed.

598. *Step Joints.*—Compromise or step joints must be used to connect adjoining rails of different sections.

599. *Holes.*—All holes in rails must be drilled.

605. *Spikes.*—Track spikes of the size prescribed must be used as directed.

606. *Spiking.*—The track shall be fully spiked to the gage required. Care must be taken to drive spikes vertically.

Rail Braces and Tie Plates

614. Fixtures must be used in track as directed. Ties should be properly adzed for even bearing of the tie plates.

Anti-Creepers or Rail Anchors

620. Approved anti-creeping devices should be applied to retard the creeping or running of rail as directed.

Shims for Surfacing Track

627. The use of shims for surfacing track should be avoided, but when necessary, shims of the size and type directed shall be applied on top of ties to the height required to restore proper cross-level, and must be removed from the track as soon as possible.

Track Centers

640. The distance between track centers must be maintained as directed.

Surface and Alinement

645. *Alinement.*—On tangent track, the two rails should be kept to cross-level.

646. *Super-elevation.*—The super-elevation on curves and easements must be maintained in accordance with requirements and prescribed standards.

Turnouts, Switches, Frogs and Guard Rails

660. *Installation.*—Turnouts must be installed and maintained in conformity with prescribed standards.

663. *Switch Locks.*—Switch locks must be maintained on all non-interlocked main line switches, and as directed at other turnouts. Main track switches must be locked in main line position when not in use.

Signs and Posts

681. Roadway signs must be installed and maintained as directed.

Street or Highway Grade Crossings

690. Public or private crossings at grade must be constructed and maintained in accordance with prescribed plans and instructions.

Fences, Gates and Cattle Guards

699. Fences, cattle guards and gates shall be built and maintained as directed.

III BRIDGES AND BUILDINGS, WATER SERVICE AND WORK EQUIPMENT

701. Supervisors of bridges and buildings are in charge, on their respective districts, of the maintenance of bridges and structures, and of the employees engaged thereon.

702. Supervisors of water service are in charge, on their respective districts, of all matters pertaining to water service, and of the employees engaged thereon.

703. When necessary to take out of service, or in case of trouble, facilities affecting water supply, designated officer, including dispatcher if train operation is involved, must be promptly advised and informed of the amount of the water on hand. Notice must be given when facility is restored to service.

704. Pumpers will be in charge of local water supply and will be responsible for the general condition of the plant, and see that an ample supply of water for locomotive use is available at all times.

705. In case of trouble affecting the water supply, pumpers must wire the dispatcher and designated officer, stating fully the difficulty, what is needed for repairs and approximately how much water remains on hand.

706. In freezing weather pumpers must see that all parts liable to freeze are properly protected.

707. Pumpers shall keep a daily record of water pumped.

708. Supervisors of work equipment will be in charge, on their respective districts, of such work equipment as may be under the general supervision of the division engineer.

709. Supervisors of work equipment must keep a daily record of the location of each machine, together with such records of performances as are required.

710. Supervisors of work equipment will instruct all operators of work equipment in the operation and care of the machines.

IV SIGNALS AND INTERLOCKING

801. Supervisors must make frequent inspections of signals and interlocking plants and have necessary repairs made as promptly as conditions require. They must see that all failures of signals and interlocking plants are properly investigated and report made on proper form.

802. Supervisors must keep themselves informed in regard to all work performed on their district by contractors, or others who do not come under their charge, to see that nothing is done that will interfere with the safe operation of signals.

803. Supervisors must investigate and report on accidents which may be attributable to defects in, or result in damage to the signal apparatus.

804. Supervisors must not make or permit to be made any alterations or additions to the interlocking or signal apparatus without proper authority. Such authorized changes or additions as are made must be reported to the proper authority immediately upon their completion, so that the other departments affected may have such information.

805. Signal foremen must do no work on signals and interlocking plants that will interfere with the safe passage of trains, except under proper protection.

806. When any part of an interlocking plant is to be repaired, an understanding must be reached with the signalman on duty, in order to insure safe movement of trains and engines during repairs. The signalman on duty must be notified when the repairs are completed.

807. Signal foremen must notify the supervisor of signals in advance of any work requiring the removal from service of any part of signal or interlocking apparatus, and such apparatus must not be taken out of service until proper authority is obtained.

808. Signal maintainers are responsible for the inspection, adjustment and proper maintenance of signal and other apparatus assigned to their care.

809. Signal maintainers must personally instruct their subordinates with a view to safety, efficiency and economy.

810. Signal maintainers must systematize their work, consulting the supervisor of signals as to the most efficient system to be followed.

811. Signal maintainers must not make any alterations or additions to the interlocking or signal apparatus unless authorized by the supervisor of signals.

812. A thorough investigation must be made of every reported failure and the trouble must not be reported as due to a cause which is only suspected. In all cases an endeavor must be made to definitely determine the trouble and eliminate the cause.

Conduct of Work

See AAR Signal Section Manual, also ICC Order dated April 13, 1939, covering rules, standards, and instructions for installation, inspection, maintenance, and repair of automatic block signal systems, interlocking, centralized traffic control systems, automatic cab signal systems continuously controlled—without automatic train stop or train control—dragging equipment and slide detectors and other similar protective devices, other similar appliances, methods, and systems.

V TELEPHONE AND TELEGRAPH

901. Line gang foremen must use every precaution to avoid causing wire trouble while doing work, and keep wire chief advised at all times, while on duty, where they can be located.

902. Linemen must maintain pole lines and wires and equipment and inside wiring on their respective territories. They must clear trouble reported to them, reporting to the designated officer the details of work they are not able to take care of, or which would interfere with their regular work.

903. Linemen after clearing trouble must immediately report to the designated officer the cause of trouble and time cleared.

904. Wire chief, or other designated officer, must locate all trouble in wires and equipment used by the Railroad Company, and take charge of and issue instructions in regard to clearing of trouble.

905. Wire chief must make a test of all Railroad wires each morning to determine whether they are in serviceable condition, and make reports as prescribed.

906. Instructions from the wire chief govern in the rerouting of circuit facilities.

Conduct of Work

See AAR Telephone and Telegraph Section Manual.

VI ELECTRIFIED TERRITORY

1001. Power supervisors are responsible for the general operation of the electric power system, and in all cases of trouble likely to affect the operation of the electric power system must promptly report same to the designated officer and take such further steps as may be necessary to insure continuity of operation.

1002. Supervisors of transmission must frequently inspect transmission system and appliances, keeping a complete record of such inspections and recommending such changes as may seem desirable.

1003. Patrolmen must carefully examine all facilities under their care and make sure that everything is safe. They must report at frequent intervals, by telephone or telegraph, advising of any defects noticed, and must report at once any serious defects which they cannot correct without assistance.

1004. Wires and overhead conductors, third rail and conductors are to be considered alive at all times unless positive knowledge to the contrary is shown. Employees must not place dependence for their safety on the insulating covering of wires.

1005. When persons other than qualified employees are required to work near third rail or high tension overhead wires or apparatus, they must be protected by a qualified employee, who will take necessary precautions for their safety before starting and during the progress of the work.

1006. Employees noticing dangling wires must avoid coming in contact with them. They must so protect the wires that they will not endanger other persons and must correct the condition or promptly notify the proper authority.

1007. Employees (excepting qualified employees authorized to do so in the discharge of their duties) are prohibited from going on top of box cars, locomotives, tenders or other high equipment while on tracks electrified with overhead wires or while movements are being made to such tracks from sidings, yards or other tracks which are not electrified.

1008. Umbrellas, clothing and other material must not be placed where they may come in contact with disconnecting switches or other portions of electric circuits.

1009. When fire occurs near high voltage overhead wires or when fire apparatus is tested near live wires the power should preferably be shut off and the wires grounded. When this is not possible special nozzles with grounding jumpers securely attached must be used.

1010. In case of an electrical fire, water must not be used to extinguish it. Sand, pyrene and other extinguishers containing carbon of tetrachloride may be used on electrical fires on arcs or other live parts. The extinguishers containing carbon of tetachloride must not be used in closed places due to danger of asphyxiation.

1011. No high tension disconnecting switch must be operated except by means of the wood poles or other approved devices provided for that purpose.

1012. Hand lines, or measuring tapes containing metal strands or steel tapes must not be used where they may come in contact with live wires.

1013. When necessary to work on transmission lines, either aerial or underground, or any apparatus in connection therewith, the employees before doing so must notify the proper officer, giving him full information as to what work is necessary, location and length of time required.

1014. If the section or apparatus on which work is to be performed may be de-energized, the power director will arrange for opening the necessary disconnecting switches in the power stations and sub-stations affected, or on the line, will have them properly tagged and grounded at each switch, opened for the protection of the employees, and will then notify such employee that power has been shut off the section or apparatus. Before allowing men to work on such section or apparatus or before doing so himself, the said employee must make out a permit on the prescribed form and repeat the information entered theieon to the power director, who will answer "correct" if the permit is properly made out. Said employee must then see that all wires or apparatus upon which work is to be done are properly grounded at each side and near where the work is to be done, first making test according to prescribed methods to ascertain that apparatus is de-energized, not only at the source but also at point where work is being done, and if men are working with him caution them by calling their attention to any adjacent high tension wires or fixtures.

1015. After work has been completed the employee who has obtained the permit must assure himself that all men are in the clear and that the grounds have been removed. He must then personally notify the power director that the work has been completed, that all men are in the clear and that the power may be turned on.

1016. When working on high voltage trolley system, the employee must see after current has been shut off that grounds are placed on each side and near the point where work is to be done. He must also ascertain from the power director that the line has been grounded at each disconnecting switch opened for his protection. If work is to be done near a section break, on both sides of which the power has been shut off the trolley wire, he must see that grounds are placed on each side of this section break.

1017. Where physical and electrical conditions will permit and adequate safeguards are provided, authorized employee may perform work on energized overhead trolley wires.

Third Rail

1018. When working on the third rail system the employee must either see that the current is first shut off of the section on which work is to be done or must take proper precautionary measures to avoid shock.

1019. Employees working on the track must be instructed previously on the dangers of the third rail and must use every precaution to avoid coming in contact with it or allowing any track tool to make contact with the third rail.

Track Bonding

1020. Loose connections to impedance bonds in the tracks must be regarded as alive and prompt report made to the train dispatcher.

1021. Tracks carrying power current must be bonded at each joint to insure free flow of current, the joints in tracks carrying power current must be bonded, and the bonds maintained in good condition.

1022. When one or more rails are removed, bonding must be done at the time of renewal or, in emergency, a jumper placed around joints until joints can be bonded.

Conduct of Work

See Manuals of Electrical Section—Engineering Division and Electrical Section—Mechanical Division, AAR.

Report of Committee 1—Roadway and Ballast

A. E. Botts, *Chairman,*
F. W. Alexander
E. J. Bayer
E. J. Beugler
Clifton Brannon
H. F. Brown
G. H. Burnette
F. W. Capp
Paul Chipman
A. P. Crosley
L. J. Drumeller
R. L. Dyke
Herbert Ensz
J. A. Given
A. T. Goldbeck
F. L. Guy
Albert Haertlein
F. W. Hillman
A. R. Jones
O. N. Lackey
G. E. Ladd*
H. W. Legro
P. J. McCarthy
Paul McKay
G. W. Miller
W. S. Moore
C. P. Nicholson
J. A. Noble
M. C. Patton
G. W. Payne
J. M. Podmore
T. P. Polson
A. D. Kennedy, *Vice-Chairman,*
W. C. Pruett
C. S. Robinson
L. H. Roden
L. S. Rose
E. M. Smith
W. C. Swartout
Raymond Swenk
H. E. Tyrrell
Stanton Walker
G. B. Wall, Jr.
C. S. Wicker
P. H. Winchester
A. H. Woerner
Committee

* Died December 23, 1940.

To the American Railway Engineering Association:

Your committee reports on the following subjects:

Bulletin 423, February, 1941.

5. Roadway drainage:
   (a) Adherence to recommended practice.
   No report.
   (b) Effect of locomotive blow-offs on track maintenance, collaborating with Committee 13—Water Service, Fire Protection and Sanitation.
   No report.
6. Roadway protection:
   (a) Slope protection, including protection against slides and rock falls, collaborating with Committee II—Signal Section, AAR.
   No report.
   (b) Retaining structures:
      (a) Cribbing; timber; concrete.
      (b) Walls; dry rubble; masonry.
      (c) Report on results obtained with sub-ballast slabs.
   No report.
7. Tunnels:
      Lighting
   Final report—with recommendations for inclusion in the Manual ...... page 565
8. Fences:
   (a) Corrosion-resisting fence wire, collaborating with appropriate subcommittees of Committee A-5 on Corrosion of Iron and Steel, ASTM.
   Progress report—submitted as information .... page 566
   (b) Wood fence posts, Specifications, etc.
   Progress report—submitted as information with the expectation of offering specifications for adoption in 1942 .... page 567
   (c) Electrified fences, collaborating with Committee 3—Overhead Transmission Line and Catenary Construction of the Electrical Section, Engineering Division, AAR.
   Progress report—submitted as information .... page 569
9. Signs:
   (a) Design of signs.
   Progress report—submitted as information .... page 570
   (b) Specifications and plans for telltales—overhead and side.
   No report.
10. Ballast:
   (a) Section design.
   Final report—with recommendations for inclusion in the Manual ...... page 571
   (b) Develop relationship of ballast materials between service behavior and results obtained from Los Angeles testing machine.
   No report.
   (c) Investigate the use of asphalt in ballast.
   Progress report—submitted as information .... page 571
   (d) Adherence to stone specifications, particularly size.
   Final report—with recommendations for inclusion in the Manual ...... page 572
11. Revision of the Manual.
No report.

THE COMMITTEE ON ROADWAY AND BALLAST,
A. E. BOTTS, *Chairman.*

Report on Assignment 1 (b)

Physical Properties of Earth Materials

Structural Bearing Power

H. W. Legro (chairman, subcommittee), E. J. Beugler, H. F. Brown, Herbert Ensz, F. L. Guy, Albert Haertlein, G. E. Ladd, Paul McKay, A. H. Woerner.

106. STRUCTURAL FOUNDATION SOILS

The purpose of a foundation is to support dead and live loads upon the earth in such manner that the soil will not fail or undergo unequal deformation which would harm the structure or be otherwise objectionable.

Certain fundamental principles concerning the relation of the footing to the foundation must be observed; for example, the importance of the coincidence of the center of pressure and the center of mass of the footing. In design, the distribution of dead and live loads on the foundation depends greatly on the type of structure and nature of the loads and requires trained judgment of the engineer. These matters must be taken into account in the application of soil mechanics to foundation problems.

A. SETTLEMENT

In respect of settlement, soils under load may be classified under two basic divisions: (a) Cohesive soils which include clays and sandy clays, and (b) cohesionless soils of which sand, gravel and silt are the principal varieties. The behavior of these two classes of soils differs greatly. Clay, for example, compresses very slowly due to the slowness with which the contained moisture escapes. When a load is applied to a mass of clay, the water first takes practically all the load. Then, as the water gradually escapes under pressure, the soil skeleton composed of the clay particles carries more of the applied load. Continued application tends to break down the internal structure, consolidation takes place and settlement of the supported load results. Plastic or lateral flow, if present, will also contribute to settlement.

With sand, the action is quite different. Each particle transmits its share of the pressure received more directly to the adjacent particles. Consolidation is more rapid and of a smaller magnitude, and unless vibration is present, a density will be reached beyond which addition of load will have no effect until the ultimate resistance of the soil is reached. Frictional resistance to lateral flow is much greater in granular soils.

The approach to the computation of settlement in cohesive soil is not, in theory, different from the computations of deformations and deflections in a structure. The procedure is, first, compute the stresses; then, by means of the relations between stress and deformation, compute the strains; and finally, by summation of the strains, obtain the total movement, or settlement, at the surface.

The first part, the stress distribution in soil, is determined by equations developed for the computation of stress distribution in elastic, isotropic and homogeneous solids. As soils, however, possess these properties to little degree, these computations can be approximations only, but are useful if suitable allowances are made for the effects of variations in soils.

The information required for the second part, that is, the relation between stress and deformation in soil, may be obtained from laboratory tests of an undisturbed sample of the soil. A comparatively simple test serves to determine the physical properties of the material for this condition. From the test, a pressure-void ratio curve is obtained by measuring change in thickness due to increments of pressure at definite intervals of time until equilibrium is reached. Thus a relation between load, time and ultimate deformation may be obtained.

Deformation due to lateral flow, that is, failure in shear, generally is to be taken into account in determining ultimate bearing capacity. In building construction, it seems quite unlikely that ultimate bearing capacity will be reached with anything like present practice as progressive settlement under such conditions would be excessive. Bridge piers, earth embankments, dams, dikes, cofferdams, retaining walls and other structures producing a highly concentrated load on soil are more likely to cause failure in shear, or, otherwise expressed, exceed the ultimate bearing capacity.

An additional item to be considered in settlement of structures is the manner in which the load is applied. The ratio of the depth of a foundation to its width or diameter has a marked effect on its settlement under a given unit load. In cohesionless soils, the settlement of a foundation under a given unit load is practically independent of its width for large areas and directly proportional to the width for smaller areas; while in soils having high cohesion and low internal friction, the settlement under a given unit load increases directly with the diameter of the loaded area.

While it is important to design for the distribution of loads in soil with respect to its moisture content at the time of construction, it is also important to anticipate future changes in moisture content. These may occur either by the raising or the lowering of the water table.

If the moisture content of soil in which wood piles have been driven is materially decreased, the preservative quality due to continuous submersion is lost and piling fails from decay. When the ground water level is lowered in cohesive soils, the soil structure undergoes change and structures with foundations designed for stability in the moisture-bearing soil are likely to settle largely because of shrinkage of the soil mass. Granular soil, if confined, may have considerable supporting power when merely saturated, but that supporting power disappears if hydrostatic head is introduced. So-called quicksand illustrates the effect of this condition.

B. BEARING CAPACITY

An assumption very commonly made is that for any given kind of soil there exists a definite safe load intensity. Safe bearing values are not based alone upon a knowledge of the properties and behavior of soils, but also upon the experience gained from observations made of existing foundations regarding which many pertinent facts are known.

Field loading tests and laboratory tests have a definite place in soil mechanics but in the absence of other information, their results may be misleading. Field loading tests are usually conducted with small-scale areas relative to the size of the foundation for the structure. As above mentioned, bearing values for large and small areas are not comparable.

Laboratory tests are valuable for measuring the physical properties of soil, but it is necessary to consider that the soil sample under test has undergone some change during the process of sampling that to some degree makes it different from the soil left undisturbed in the ground. It should be remembered also, that natural soil is not homogeneous, and laboratory measurements reveal the properties of only the soil at the few spots where the samples were taken.

Safe bearing loads for various kinds of soil as shown even in modern building codes should be used for important structures only by an experienced engineer who can evaluate the effect of the many variables of his particular problem and modify as necessary the application of tabular bearing values to his design.

Piling Foundations

The bearing capacity of piles depends on two different factors; first, the frictional resistance acting along the sides of the pile, and second, the point resistance or resistance of the soil against compression and displacement at the foot of the pile.

If the structure of clay is broken down during construction, by pile-driving for instance, the effect is to increase the compressibility of the foundation area. A large portion of the settlement of a foundation may be due to consolidation of the remolded soil under its own weight rather than to the load distributed by the piles into the soil.

Usual pile-driving formulas are based on the energy of blow and penetration of the pile, or a dynamic condition. What is desired is satisfactory static bearing capacity. Thus, the driving formula is of value only in such cases as the dynamic resistance, or rapid penetration, is some measure of the static bearing capacity, or slow penetration. In sands, gravels and other relatively permeable, cohesionless soils, driving penetration and static-load penetration are about the same. The dynamic formula in this case may give a close approximation of the static resistance of an individual pile. In clays, silts and other relatively impermeable, cohesive soils, there is no known relation between the dynamic resistance and the static bearing capacity of piles, so that for such soils, a pile-driving formula has not been developed that contains all factors necessary to produce satisfactory results.

Comparing the penetration per blow immediately before with that after a period of rest of at least 24 hours will determine whether the material of the foundation belongs to the first or to the second class. If these two penetrations are alike, it is quite certain that the material belongs in the first class, and that a pile-driving formula can be expected to furnish fairly reliable results.

In all cases where the piles do not act strictly as columns, the summation of the bearing power of the individual piles in a foundation may not represent the bearing power of the foundation as a whole. The effect either of consolidating the soil by pile-driving or of increasing the compressibility through re-molding must be considered in the light of experience.

This report is presented as information.

Report on Assignment 2 (a)

Size of Waterway Openings, Formulas

L. S. Rose (chairman, subcommittee), E. J. Bayer, G. W. Miller, C. P. Nicholson, J. A. Noble, M. C. Patton, G. W. Payne, T. P. Polson.

203. SIZE OF WATERWAY OPENINGS

A. FORMULAS

After all available data have been collected for the area under consideration the next step in determining the proper size of a waterway opening is to reduce these data to the quantity of water in cubic feet per second which will reach the opening. Where no record of actual runoff measurement is available this is done with the aid of a runoff formula or by tables or curves developed from formulas.

Many years of research have failed to develop a single formula which is applicable, with any degree of accuracy, to all conditions. A bewildering number of factors, constants and variants have been more or less ingeniously combined to make various formulas fit the needs of given conditions. Nearly all such formulas contain some coefficient C which groups many of these variables and the user is left with the problem of an accurate evaluation of these factors. Text books, scientific papers and published discussions all indicate that every runoff formula in more or less common use today has been qualified either by the author, who has pointed out its limitations, or by other authorities who have been free in their criticism. It is therefore apparent that the selection of a formula and its factors must be made in each case with excellent judgment backed by experience and careful observation.

Former reports of this committee contain practically all the formulas in use today, with descriptive matter setting forth their limitations and usage. These will not be repeated, but an understanding of the basic principles from which most of these formulas evolve may be of value.

A study of runoff data in cubic feet per second platted against the square miles of drainage areas, as analyzed by Jarvis,[1] indicates the relation,

$$q = \frac{C}{M^{\frac{1}{n}}}$$

in which C and n are constants, M representing the square miles of drainage area and q the runoff in cubic feet per second per square mile (See Fig. 1). Some authorities do not agree with this conclusion, the principal reason being that it is based upon only one factor of runoff, i.e., that of area. It is believed, however, that with the large number of observations made and for the purpose intended it does indicate the trend.

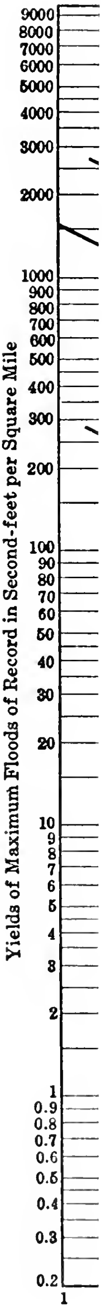
Based upon the above equation, the total runoff from the basin then would be

$$qM = \frac{CM}{M^{\frac{1}{n}}}, \text{ or } Q = CM^{\frac{n-1}{n}}$$

This fundamental form is followed, with slight variations, by many of the widely used formulas in which n generally takes a value between 1.5 and 6, and results in expressions such as $\sqrt[3]{M}$ and through to $\sqrt[6]{M^5}$. For example, where $n = 4$, $Q = CM^{\frac{4-1}{4}}$, or $Q = CM^{\frac{3}{4}}$, or $Q = C\sqrt[4]{M^3}$.

In an attempt to reduce the many formulas to a common ground for comparison Jarvis has selected the Myers type for modification and extension. In Myers formula $a = C\sqrt{A}$ in which a equals the necessary area of opening, if velocity of flow is assumed at 10 feet per second, A equals the area of the drainage basin in acres, and C is a coefficient varying from 1 to 4. Changing the area from acres to square miles; $a = C \times 25.3 \sqrt{\frac{A}{640}}$, or $a = C \times 25.3 \sqrt{M}$. Then assuming $C = 40$ we have approximately $a = 1{,}000 \sqrt{M}$ and substituting Q, quantity, for a, area of opening, $Q = aV$ or, with a 10-ft. velocity, $Q = 10{,}000 \sqrt{M}$. The resulting graph for Q, correlated with recorded flood flows (Fig. 1) is found to lie above all but two platted points representing runoff

[1] Paper No. 1589—Flood Flow Characteristics—ASCE Transactions Vol. 89, 1926.


Yields of Maximum Floods of Record in Second-feet per Square Mile
9000
8000
7000
6000
5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
1

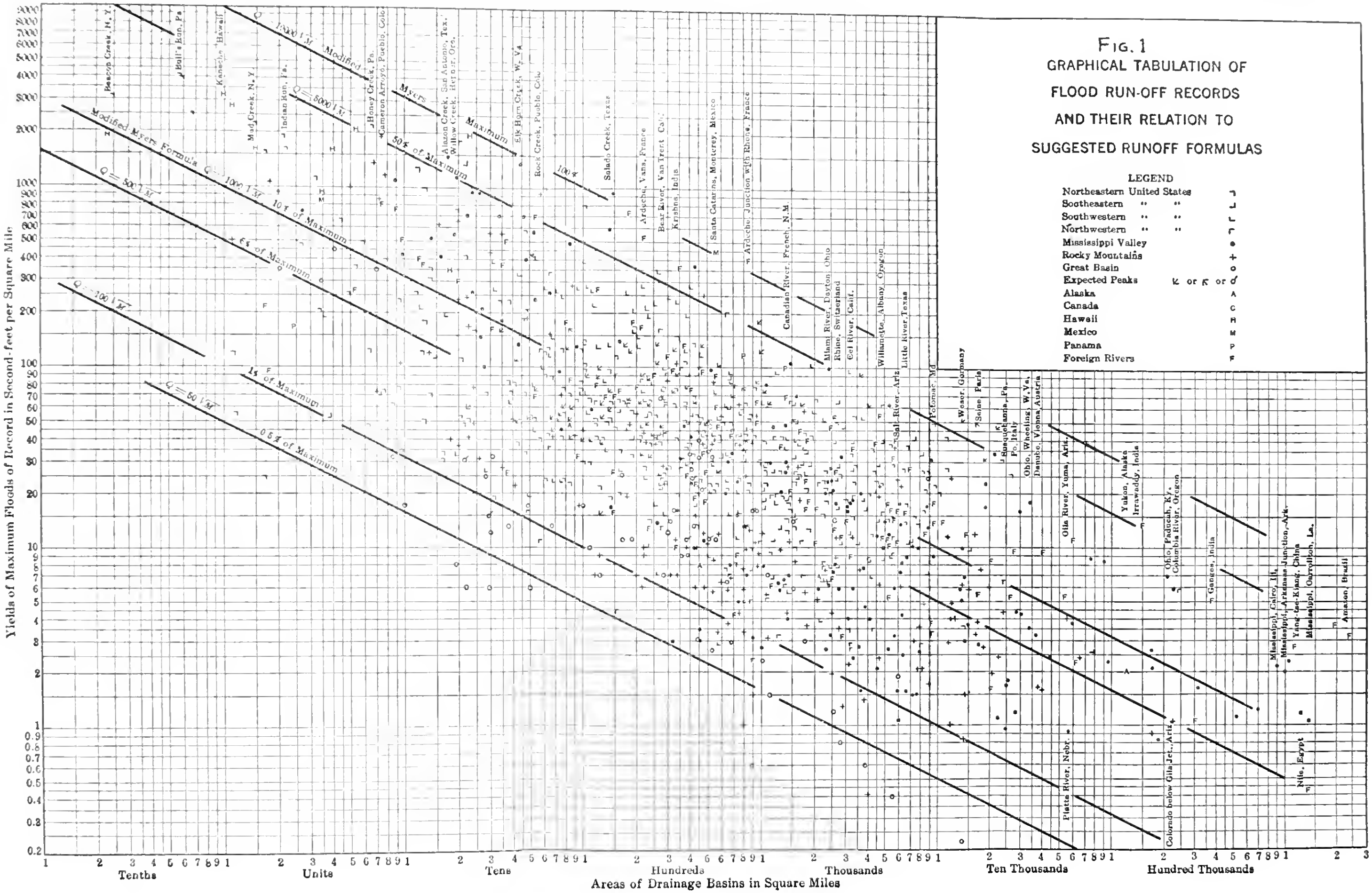
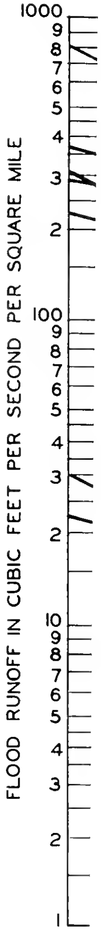


FIG. 1
GRAPHICAL TABULATION OF FLOOD RUN-OFF RECORDS AND THEIR RELATION TO SUGGESTED RUNOFF FORMULAS


FLOOD RUNOFF IN CUBIC FEET PER SECOND PER SQUARE MILE
1000
100
10
1

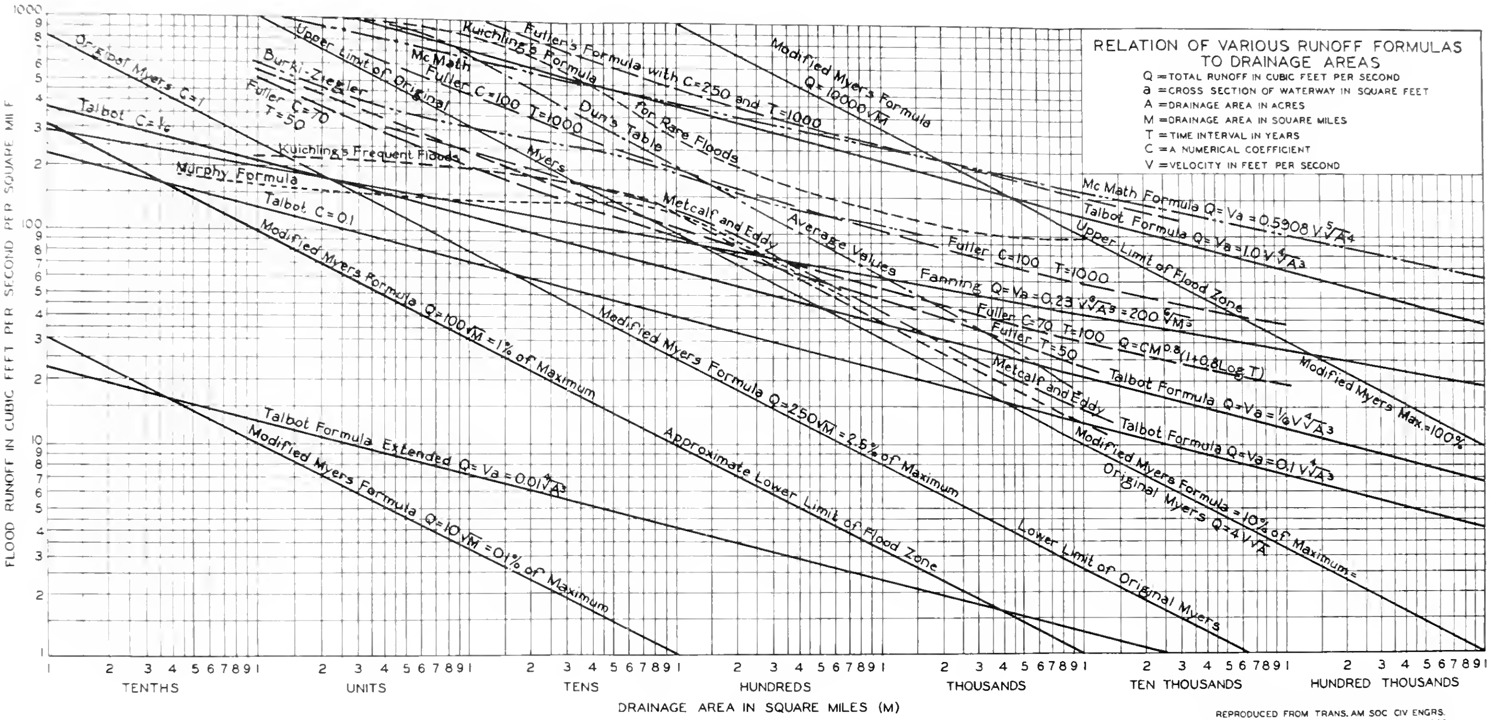


FIG. 2

REPRODUCED FROM TRANS. AM SOC CIV ENGRS. VOL 89 - PAPER NO.1589 BY C.S.JARVIS ON FLOOD FLOW CHARACTERISTICS rates and to conform closely with the enveloping curve, thus justifying the assumption of $C = 40$ for maximum. This indicates that Myers maximum of $C = 4$ would correspond to 10 percent of the maximum enveloping curve in Fig. 1.

Similarly for lower limits the path of the point, $Q = 100\sqrt{M}$, conforms well with the general slope and lies above only 5 percent of the more than 1,000 platted flood runoff rates.

The wide range between the maximum and minimum curves illustrates clearly the need of excellent judgment and careful consideration of all available data before any important waterway structure is designed. As further evidence, recent studies made by U. S. Army engineers, using the formula $Q = C\sqrt{M}$, indicates the danger of transferring a coefficient, which has been determined by actual measurements, from one watershed to another nearby or even to different areas in the same watershed. For example: the curve for the upper Susquehanna basin follows the formula $Q = 2{,}840 \sqrt{M}$ for areas from 10 to 300 square miles, but for the remaining portion of the curve the coefficient gradually increases until at 10,000 square miles it reaches a value of 4,000. Certain sections of the area have coefficients varying from 1,700 to 2,500 and in the Finger Lakes region they run as high as 6,000.

Only the basic type of formula as correlated to actual measured flood discharges has been considered. For a graphic illustration of the relationship between this formula and other best known expressions of runoff see Fig. 2.

A very important factor in determining the quantity of runoff for which a structure is to be designed is that of the time element or periodic expectancy of flood flows. Unfortunately stream flow records cover only a comparatively recent period and do not yet permit the establishing of a dependable flood cycle if such a cycle actually exists. For convenience, floods of different magnitudes are classified as 1, 10, 100 or 1,000-year floods. It should be kept in mind, however, that the 100-year flood may occur next year, followed a year later possibly by the 1,000-year flood. Several formulas have been advanced f r determining the relationship of major floods of T years to those of a one year maximum. Jarvis in his paper, referred to above, treats of this subject.[2] In spite of the fact that no assurance can be had as to when so-called great floods will occur a flood of some fixed maximum in most cases must be selected for design. This selection should be based upon the following.

(a) First cost of structure
(b) Importance of structure
(c) Available detour lines
(d) Probable duration of flood flows
(e) Time required for replacement and cost
(f) Probable damage from back water
(g) Available overflow channels and areas.

SIZE OF OPENING

After the quantity of runoff has been determined for which the structure is to be designed the wetted area of the opening then becomes $a = \frac{Q}{V}$, in which Q = the total yield of the watershed in cubic feet per second and V = velocity of flow in feet per second. In most runoff formulas which solve direct for a, V is assumed at ten feet per

[2] See also, Flood Flows by Allen Hazen—Relief from Floods by Alvord and Burdick.

second. This figure however should not be taken arbitrarily. Consideration should be given to the average rate of flow above and below the opening, the nature of the channel material and the bridge foundation. In many cases, to avoid erosion the velocity should not exceed two or three feet per second. It should also be kept in mind that if the hydraulic gradient of the stream is to be maintained no portion of the computed area required should be above the elevation of the flood crest. However, additional headroom should be provided to permit the free passage of floating debris. In general, this results in low structures of long spans for wide streams and high structures of shorter spans for narrow gorges. For pipe culverts, the elevation of the water surface may necessitate a battery of smaller pipes instead of a large one of equivalent area.

CONCLUSIONS

Runoff formulas for determining the required sizes of waterway openings, although not recommended, may be used where structures of low cost and minor importance are involved, and when the formula is applied with an appreciation of its limitations, its use is intended only as a guide, and the results are to be modified as other known data and experience seem to demand.

This report was presented to the 1940 convention as information with the statement that it would be offered this year for adoption and inclusion in the Manual, and it is therefore so recommended.

Report on Assignment 3 (a)

Vitrified Clay Pipe Culverts—Specifications

W. C. Swartout (chairman, subcommittee), F. W. Capp, J. A. Given, Paul McKay, G. W. Payne, L. H. Roden, E. M. Smith.

Last year your committee presented for your consideration as information, a specification for Vitrified Clay Culvert Pipe adapted from ASTM Specification C13–35. No criticisms of the specification have been received from any source and it has received the approval of ASTM Committee C–4 on Clay Pipe to which it had been submitted.

The specification as presented below, with a few corrections of the form in which it was published last year, is therefore submitted with the recommendation that it be adopted and published in the Manual.

III CULVERTS

302. VITRIFIED CLAY PIPE CULVERTS

A. SPECIFICATIONS FOR VITRIFIED CLAY CULVERT PIPE

Extra Strong or Triple Strength
Adapted from ASTM Specification C 13-35

GENERAL

1. Scope

These specifications cover vitrified clay pipe intended to be used for the construction of culverts and other projects where conditions require that extra-strength pipe be used.

2. Materials

(a) Clay pipe shall be manufactured from surface clay, fire clay, or shale or a combination of these materials.

(b) These materials or any combination thereof, when molded into pipe and subjected to suitable temperatures, shall produce a product that will be strong, durable, serviceable, free from objectionable defects and shall conform to these specifications.

RESISTANCE TO ACTION OF ACIDS

3. Resistance to Action of Acids

The following tests as to the resistance of clay culvert pipe to the action of acids may be prescribed.

When testing with either hydrochloric, nitric, sulfuric or acetic acid, as specified by the purchaser, the acid having a normality of one (1.0 N)[1], the percentage of acid-soluble matter shall not exceed 0.25 percent, calculated as sulfates. The purpose of this test is to determine the resistance of pipe to the action of acids and its use is optional.

4. Test specimens

Where possible the specimens intended for these tests shall be selected from pipes which have been previously subjected to the crushing strength test. Specimens shall be sound with all edges freshly broken, free from cracks or shattered edges, about 2 inches square, not weighing more than 200 g. and shall be thoroughly cleaned with a wire brush.

5. Number of Tests

A test shall be made on at least one specimen cut from each size of pipe. The results shall be reported separately for each individual specimen.

6. Weighing Apparatus

The weighing shall be made on a balance accurate to 0.01 g. when loaded with 200 g.

7. Test Procedure

(a) Specimens to be tested shall be dried to constant weight at a temperature of from 210 to 230 degrees F.

(b) The specimens upon reaching constant weight shall be completely immersed in the test solution at a temperature of from 70 to 90 degrees F. for a period of 48 hours, then removed from the solution, carefully and thoroughly washed with hot water, allowing the washings to run into the solution in which the specimen was immersed. This solution shall be filtered and to the filtrate shall be added 5 ml. of concentrated sulfuric acid. This solution shall then be evaporated (avoiding loss of spattering) to about 5 ml.; transferred to a porcelain crucible (previously ignited to constant weight) and heated cautiously to dryness. It shall then be ignited to constant weight.

8. Calculation

The weight of the residue in the porcelain crucible divided by the weight of the dry specimen before immersion, multiplied by 100, is the percentage of acid-soluble matter calculated as sulfates.

$$\text{Percentage acid-soluble matter} = \frac{\text{Wt. of residue in grams} \times 100}{\text{Wt. of dry specimen in grams.}}$$

[1] The following percentages are required to make an acid of a normality of one: sulfuric acid, 4.90 percent; hydrochloric acid, 3.65 percent; nitric acid, 6.30 percent; acetic acid, 6.00 percent.

PHYSICAL PROPERTIES AND TESTS

9. Physical Requirements

The crushing strength and absorption of clay culvert pipe shall conform to the requirements given in Table 1. The individual results of the various tests for each size of pipe and for each shipment shall be tabulated separately so as to show the percentage which fails to conform to the requirements of each test.

10. Test Specimens

The specimens for purpose of tests shall be sound full-size pipe and shall be selected by the purchaser or his representative at the point or points designated by him when placing the order.

11. Number of Tests

(a) The manufacturer or seller shall furnish specimens for test, without charge, up to 0.5 percent of the number of pipes in each size of pipe furnished, except that in no case shall less than two specimens be furnished.

(b) In any case where more than five specimens are required for testing, not more than five specimens shall be crushed to the point of failure. All specimens in excess of five which show a testing strength of 10 percent above the requirements of this specification shall be removed from the testing apparatus without being broken.

12. Measurement and Observation of Specimens

The specimens taken from pipe tested to destruction, shall be first freed from all visible moisture. When dry, each specimen shall be measured and inspected. The results of these observations shall be recorded.

13. Defective Specimens

Specimens which are observed to have fire cracks or other defects in form or dimensions in excess of the limits permitted in these specifications, shall be discarded and replaced with additional specimens from the shipment.

TABLE 1

PHYSICAL TEST REQUIREMENTS OF CLAY CULVERT PIPE

Internal Diameter, Inches	*Average crushing strength minimum, Pounds per Linear Foot* — *Three-Edge Bearing Method*[1]	*Average crushing strength minimum, Pounds per Linear Foot* — *Sand-Bearing Method*[2]	*Average Absorption Maximum Percent*
12	2,000	2,860	8
15	2,500	3,570	8
18	3,000	4,290	8
21	3,500	5,000	8
24	4,000	5,710	8
27	4,500	6,430	8
30	5,000	7,140	8
33	5,500	7,860	8
36	6,000	8,570	8

[1] See Section 16.
[2] See Section 17.

CRUSHING STRENGTH

14. Crushing Strength Tests

Pipe shall be tested for crushing strength by either the three-edge-bearing method or the sand-bearing method. Either of the two specified bearing methods shall be used on retests as provided for in Section 24 (a) and (b).

15. Application of Load

(a) Any prime mover or hand power which will apply the load at a uniform rate of about 2,000 pounds per minute or in increments of not more than 100 pounds at the same rate, may be used in making the test.

(b) The center of the load shall be applied to the top bearing block at a point distant from the spigot end of the pipe equal to one-half of the over-all length of the pipe. The test load shall be applied to the upper bearing block in such a way as to leave the bearing free to move in a vertical plane passing midway between the lower bearings. In testing pipe that is "out of straight," the lines of the bearings chosen shall be free from those which appear to give most favorable conditions for fair test.

(c) The pipe shall not be allowed to stand under load longer than is required to apply the load and to observe and record it.

(d) The testing machine shall be substantial and rigid throughout, so that the distribution of the load will not be affected appreciably by the deformation or yielding of any part. The bearings shall be sufficiently rigid to transmit and receive uniform loads throughout their lengths without deflection, and shall be so attached to the machine as to transmit and receive the maximum loads produced by the tests without lost motion, vibration, or sudden shock.

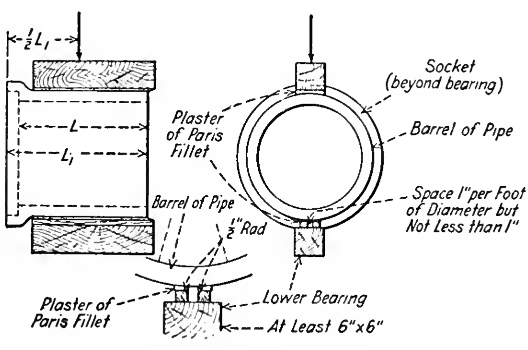


Fig. 1.—Three-Edge Bearings.

(e) The bearings and the specimen shall be accurately centered so as to secure a symmetrical distribution of the loading on each side of the center of the pipe in every direction.

(f) The load shall be applied until the pipe yields by cracks passing through the shell.

(g) The crushing strength shall be calculated by dividing the total load required to break each pipe by the net inside length of the barrel of the pipe, measuring from the bottom of the socket to the end of the spigot.

A

16. Three-Edge-Bearing Method

When the three-edge-bearing method (See Fig. 1) is used, the ends of each specimen of pipe shall be accurately marked in halves of the circumference prior to the test. The two lower bearings shall consist of two wooden strips with vertical sides having their interior top corners rounded to a radius of approximately ½ inch. The strips shall be straight and securely fastened to a rigid block at least 6 by 6 inch in cross-section. The interior vertical sides of the strips shall be parallel and a distance apart of 1 inch per foot of pipe diameter but in no case less than 1 inch. Before the pipe is placed, a fillet of plaster of Paris or other equalizing material, such as sand and sulfur, thick enough to compensate for the inequalities of the pipe barrel shall be cast on and between the two lower bearings. The pipe shall be placed on the fillet while the plaster of Paris is still somewhat plastic. The use of the plaster of Paris fillet may be dispensed with when mutually agreeable to the manufacturer and the purchaser. The upper bearing shall be a rigid wooden block at least 6 by 6 inch in cross-section, straight and true from end to end. A fillet of plaster of Paris thick enough to compensate for the inequalities of the pipe barrel shall be cast along the length of the crown. The upper bearing shall be brought in contact while the plaster of Paris is still somewhat plastic. The upper and lower bearings shall extend the full length of the pipe exclusive of socket.

17. Sand-Bearing Method

When the sand-bearing method (see Fig. 2) is used the ends of each specimen of pipe shall be accurately marked in quarters of the circumference prior to the test. Specimens shall be carefully bedded, above and below, in sand, for one-fourth the circumference of the pipe measured on the middle line of the barrel. The depth of bedding above and below the pipe at the thinnest points shall be one-half the radius of the middle line of the barrel.

The sand used shall be clean and moist, and shall be such as will pass a 4760-micron (No. 4) sieve.[2] The sand in the lower bearing shall be loose when the pipe is placed.

The top bearing frame shall not be allowed to come in contact with the pipe nor with the top bearing plate. The upper surface of the sand in the top bearing shall be struck off level with a straight edge, and shall be covered with a rigid top bearing plate, with lower surface a true plane, made of heavy timbers or other rigid material, capable of distributing the test load uniformly without appreciable bending. The test load shall be applied at the exact center of this top bearing plate in such a manner as to permit free motion of the plate in all directions. For this purpose a spherical bearing is preferred, but two rollers at right angles may be used. The test may be made without the use of a testing machine by piling weights directly on a platform resting on the top bearing plate, provided, however, that the weights shall be piled symmetrically about a vertical line through the center of the pipe, and that the platform shall not be allowed to touch the top bearing frame.

The frames of the top and bottom bearings shall be made of timbers so heavy as to avoid appreciable bending by the side pressure of sand. The interior surfaces of the frames shall be dressed. No frame shall come in contact with the pipe during the test. A strip of cloth may, if desired, be attached to the inside of the upper frame on each side, along the lower edge, to prevent the escape of sand between the frame and the pipe.

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[2] For requirements for this sieve, see Standard Specifications for Sieves for Testing Purposes (ASTM Designation: E-11), 1933 Book of ASTM standards, Part II, p. 1244.

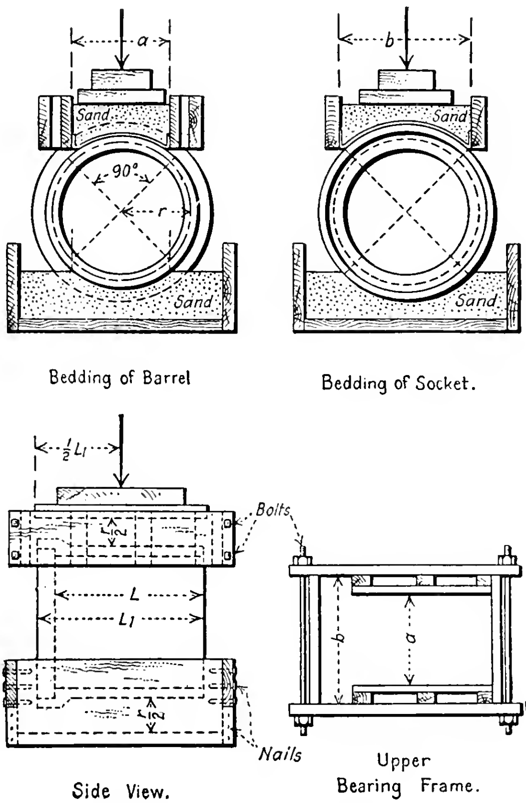


Fig. 2.—Sand Bearings.

ABSORPTION TEST

18. Test Specimens

The specimens shall be sound pieces, with all edges broken, and may be from pipes broken in the crushing tests. They shall be from 12 to 20 sq. in. in area, and shall be as nearly square as they can be readily prepared. They shall be free from observable cracks, fissures, laminations or shattered edges.

19. Identification

Each specimen shall be marked so that it may be identified with the pipe used in the crushing strength test from which the specimen was taken. The marking shall be applied so that the pigment used shall not cover more than 1 percent of the total superficial area of the specimen.

20. Number of Tests

One specimen shall be tested of each pipe broken in crushing strength test.

21. Weighing Apparatus

The balance used shall be sensitive to 0.5 g. when loaded with 1 kg. and weighing shall be read to the nearest 1 g. When other than metric weights are used, the same degree of accuracy shall be obtained.

22. Procedure

(a) Drying—Preparatory to the absorption test, the specimen shall be brought to constant weight in a drier or oven at a temperature of not less than 110 degrees C. (230 degrees F.)

(b) Immersion—After reaching constant weight, the specimen shall be placed with other similar specimens in a suitable wire receptacle, packed tightly enough to prevent jostling, covered with distilled water or rainwater, raised to the boiling point and boiled for five hours, and then cooled in water to a final temperature of 15 to 25 degrees C. (59 to 77 degrees F.)

(c) Reweighing—The specimen shall be allowed to drain for one minute, and after the superficial moisture has been removed by towel or blotting paper, the specimen shall be placed upon the balance and weighed.

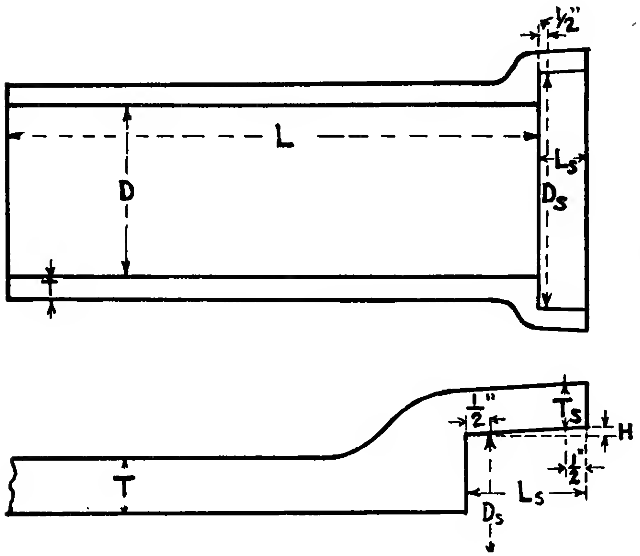


Fig. 3.—Applications of Dimensions Given in Table 2.

23. Calculation and Reporting of Results

The absorption shall be calculated as percentage of the initial dry weight. The results shall be reported separately for each individual specimen, together with the mean for all the specimens from the same shipment of pipe.

24. Acceptance or Rejection on Results of Test

(a) Failure of 20 percent of the specimens to meet the requirements of crushing strength and/or absorption tests shall result in rejection of all the pipe in the shipment or delivery, corresponding to the sizes thus failing to comply; except that in the event of 20 percent of the specimens in any size failing to meet the requirements the manufacturer or seller may, with the consent of the purchaser, furnish for test, without charge, additional specimens from the same shipment. In case more than 80 percent of the specimens tested, including those first tested, shall show substantial conformance for each of the various tests performed, then the entire shipment or delivery for this size shall be accepted; otherwise it shall be rejected.

(b) However, in case of failure of pipe to meet the requirements under the specified method, and the accuracy of the testing machine is questioned, a retest at the request of the manufacturer shall be made upon a machine whose accuracy is known or the machine originally used shall be recalibrated before the retest is made.

(c) In addition to the requirements in Paragraph (a) failure of 10 percent or more of the individual specimens tested to develop 75 percent of the average crushing strength requirements shall be cause for the rejection of the shipment, but the manufacturer or seller may cull the pipe and submit the balance of the shipment for retest, and if the shipment then conforms to all of the requirements of these specifications it shall be accepted.

SIZES, DIMENSIONS AND PERMISSIBLE VARIATIONS

25. Sizes and Dimensions

Pipes shall be furnished of the sizes, internal diameter and with the dimensions given in Table 2.

26. Permissible Variations

The permissible variations from the dimensions given in Table 2 shall not exceed those specified in Table 3. Where the average diameter in the spigot is larger than the nominal size, the average diameter at the inside of the socket shall be increased by the same amount. Where the thickness of the barrel is increased beyond that given in Table 2, in order to meet the specified requirements of strength, the diameter at the inside of the socket shall be increased by double the increase in thickness of the barrel. Pipes intended to be straight shall have a maximum ordinate as measured from the concave side of the pipe not to exceed ⅛ inch per foot of length.

WORKMANSHIP AND FINISH

27. Absence of Defects

Pipes shall be substantially free from fractures, large or deep cracks and blisters, laminations and surface roughness.

28. Salt Glaze

The glaze shall consist of a continuous layer of salt glaze substantially free from large blisters or large pimples. No blisters shall exceed 3 inches in diameter and no blisters or pimples shall project more than ⅛ inch above the surrounding surface of the pipe for sizes up to and including 18 inches internal diameter. For sizes over 18 inches internal diameter no blisters shall exceed in diameter more than 2 inches per foot of the internal diameter of the pipe, nor project above the surrounding surface of the pipe more than ⅛ inch per foot of the internal diameter of the pipe.

Not more than 10 percent of the inner surface of any pipe barrel shall be bare of glaze except the socket, where it may be entirely absent. Glazing shall not be required on the outer surface of the barrel at the spigot end for a distance from the end of the pipe equal to the specified depth of socket. There shall be no well defined network of crazing lines or hair cracks.

TABLE 2

DIMENSIONS OF CLAY CULVERT PIPE[a]

Internal Diameter (D) Inches	*Laying Length (L) Ft.*	*Inside Diam. at ½ Inch Above Base of Socket (D_s) In.*[bc]	*Depth of Socket (L_s) In.*	*Minimum Taper of Socket ($H:L_s$)*	*Thickness of Barrel (T) In.*	*Thickness of Socket (T_s)*
12	3	15⅝	2¾	1:20	1¼	The thickness of the socket ½ inch from its outer end shall be not less than three-fourths of the specified thickness of the barrel of the pipe.
15	3	19¼	2¾	1:20	1½	
18	3	23	3	1:20	1⅞	
21	3	26⅞	3¼	1:20	2¼	
24	3	30⅜	3⅜	1:20	2½	
27	3	34⅛	3½	1:20	2¾	
30	3	37⅝	3½	1:20	3	
33	3	41¼	4	1:20	3¼	
36	3	44¾	4	1:20	3½	

[a] Applications of dimensions given in this table are shown in Fig. 3.
[b] When pipes are furnished having an increase in thickness over that given in last column, the diameter of socket shall be increased by an amount equal to twice the increase of thickness of barrel.
[c] When the pipes furnished have an average diameter larger than the nominal size, the inside diameter of the socket shall be greater by the same amount than the values given in the third column.

TABLE 3

PERMISSIBLE VARIATIONS IN DIMENSIONS OF CLAY CULVERT PIPE

Nominal Size Internal Diameter, in.	*Limits of Permissible Variation in:* Length, inches per ft. (—)	*Lengths of Two Opposite Sides, inches per foot of length*	*Internal Diameter inches* Spigot (+ or —)	Socket (+ or —)	*Depth of Socket in. (—)*	*Thickness of Barrel in. (—)*
12	¼	3/16	5/16	⅜	¼	⅛
15	¼	3/16	5/16	⅜	¼	⅛
18	¼	3/16	7/16	½	¼	⅛
21	¼	3/16	½	9/16	¼	⅛
24	⅜	¼	9/16	⅝	¼	3/16
27	⅜	¼	⅝	11/16	¼	3/16
30	⅜	¼	⅝	11/16	¼	3/16
33	⅜	¼	11/16	¾	¼	¼
36	⅜	¼	¾	13/16	¼	¼

Note—The minus sign (—) alone indicates that the plus variation is not limited, the plus and minus sign (+ or —) indicates variation in both excess and deficiency in dimensions.

29. Finish of Ends

The ends of the pipes shall be square with their longitudinal axes, except as provided in Table 3.

MARKING, INSPECTION AND REJECTION

30. Marking

Each length of pipe shall bear the initials or name of the person, company or corporation by whom manufactured and the location of the factory. The markings shall be indented on the exterior of the pipe near the socket and shall be plainly legible for purposes of identification.

31. Inspection

All pipes shall be subject to inspection at the factory, site of project or other point of delivery by a competent inspector employed by the purchaser. The purposes of the inspection shall be to cull and reject pipes which, independent of the physical tests herein specified, fail to conform to the requirements of these specifications.

32. Rejection

Pipes shall be subject to rejection on account of the following:

(a) Variations in any dimension exceeding the permissible variations given in Table 3.

(b) Fractures or cracks passing through the shell or socket except a single crack at the spigot end of the pipe not exceeding 75 percent of the depth of the socket, or a single fracture in the socket not exceeding 3 inches measured around the circumference, nor 2 inches lengthwise.

(c) Chips or fractures on the interior of the pipe exceeding 2 inches in length, 1 inch in width, and of a depth more than one-quarter of the thickness of the shell.

(d) Blisters which are broken or which exceed the dimensions specified in Section 28.

(e) Fire cracks or hair cracks sufficient to impair the strength, durability or serviceability of the pipe.

(f) Variation of more than 1/8 inch per linear foot in alinement of a pipe intended to be straight.

(g) Glaze which does not conform with these specifications as specified in Section 28.

33. Marking of Rejected Specimens

All pipes accepted may be plainly marked by the inspector. Rejected pipes shall not be marked so as to be defaced or to impair their value, but shall be replaced by the manufacturer or seller with pipes which meet the requirements of these specifications, without additional cost to the purchaser.

Report on Assignment 3 (b)

Pipe Line Crossings—Specifications, for Non-Inflammable Substances Under Pressure

W. C. Swartout (chairman, subcommittee), F. W. Capp, J. A. Given, Paul McKay, G. W. Payne, L. H. Roden, E. M. Smith.

In 1933, the Association adopted Specifications for Pipe Line Crossings Under Railway Tracks. These are inclusive specifications for pipe lines carrying all substances and were worked out in collaboration with Committee 20 of this Association and the American Petroleum Institute after a protracted series of conferences.

It is believed that these specifications have been found satisfactory and workable, but they are too rigorous for pipe lines carrying non-inflammable substances, hence the assignment for this year's work "Pipe line crossings—Specifications, for non-inflammable substances under pressure."

Your committee has prepared such specifications which are offered as information this year for the purpose of inviting criticisms and suggestions with the thought of submitting them, with any revisions deemed desirable, at the 1942 convention for adoption and inclusion in the Manual. Before these specifications can be adopted and included in the Manual, it will be necessary to adopt a revision of the Specifications for Pipe Line Crossings Under Railway Tracks Carrying Inflammable Substances referred to above.

The committee recommends that the first paragraph of Specifications for Pipe Line Crossings under Railway Tracks, A. For Inflammable Substances, (page 1–25 of Manual), be revised by deleting the last clause of the first sentence reading "or any substance which from its nature or pressure might cause damage if escaping on or in vicinity of railway property" as shown below. This revision is necessary in order that separate specifications may be submitted to cover Pipe Line Crossings under Railway Tracks, B. For Non-Inflammable Substances.

Present Form

Pipe lines included under these specifications are those installed to carry oil, gas, gasoline or other inflammable or highly volatile substance, under pressure, or any substance which from its nature or pressure might cause damage if escaping on or in vicinity of railway property. Gas transmission and distribution lines in city streets, carrying less than 45 pounds pressure, are not to be considered as coming under these specifications.

Proposed Form

Pipe lines included under these specifications are those installed to carry oil, gas, gasoline or other inflammable or highly volatile substance, under pressure. Gas transmission and distribution lines in city streets, carrying less than 45 pounds pressure, are not to be considered as coming under these specifications.

It is further recommended that each paragraph of these specifications be given a heading as shown in skeleton form below:

1. **Scope**

   Pipe lines included under these, etc.

2. **Installation**

   Pipe lines under railway tracks, etc.

3. **Carrier Pipe**

   Carrier line pipe inside, etc.

4. **Casing Pipe**

   Casing pipe and joints may, etc.

5. **Seals**

   Where ends of casing are below ground, etc.

6. **Depth of Casing**

   Where practicable the depth from, etc.

7. **Length of Casing**

   Casing shall extend at least, etc.

8. Shut-Off Valves

Where warranted by special local conditions, etc.

9. Location

Pipe lines shall, where practicable, etc.

10. Topography

Crossings under railway tracks, etc.

11. Approval of Plans

Plans for proposed crossing, etc.

Your committee submits the following specifications as information and invites comments and criticisms. It is proposed, as stated above, to submit these to the 1942 convention for inclusion in the Manual.

309. Pipe Line Crossings—Specifications

B. FOR NON-INFLAMMABLE SUBSTANCES

1. Scope

Pipe lines included under these specifications are those installed to carry steam, water or any non-inflammable substance which from its nature or pressure might cause damage if escaping on or in the vicinity of railway property.

2. Installation

Pipe lines under railway track shall be encased in a larger pipe or conduit installed as indicated in Fig. 1.

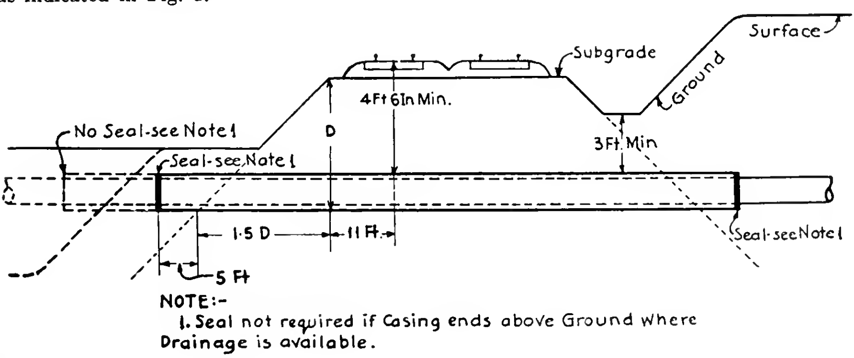


Fig. 1.

3. Carrier Pipe

Carrier line pipe inside the casing under the railway track and right-of-way shall be of approved construction.

4. Casing Pipe

Casing pipe and joints may be of any approved conduit construction and shall be capable of withstanding the load of railway roadbed, track and traffic; also shall be so constructed as to prevent leakage of any matter from the casing or conduit throughout its length under the track and railway right-of-way except at the ends of the casing or conduit where the ends are left open. The casing shall be so installed as to prevent the formation of a waterway under the railway.

Casing shall be installed with even bearing throughout its length and shall slope to one end.

The inside diameter of the casing shall be at least 2 inches greater than the largest outside diameter of the carrier pipe, joints or couplings.

5. Seals

Where the ends of the casing are below ground they shall be suitably protected against the entrance of foreign material, which might prevent ready removal of the carrier pipe.

Where the ends of the casing are at or above ground surface and above high water level they may be left open, provided drainage is afforded in such a manner that leakage will be conducted away from the roadbed and structures.

6. Depth of Casing

The top of the carrier pipe shall be below the frost line, and at its closest point shall not be less than 4½ feet below base of railway rail. On other portions of the railway right-of-way where the casing is not directly beneath any track the depth from the surface of the ground and from the bottom of ditches to the top of the casing, shall be not less than 3 feet. Where it is not practicable to secure the above depths, special construction shall be used.

7. Length

Casing shall extend each side from the center line of the outside track, measured at right angles, a minimum distance of 11 feet + 5 feet + 1.5D (Where D equals the depth of the bottom of the casing below subgrade). See Fig. 1. If additional tracks are constructed in the future, the casing shall be correspondingly extended.

8. Shut-Off Valves

Where warranted by special local conditions, and when mutually agreed to by the railroad company and the owner of the pipe line, accessible emergency shut-off valves shall be installed within effective distance at each side of the crossing.

9. Approval of Plans

Plans for a proposed crossing shall be submitted to and approved by the Chief Engineer or authorized representative of the railway before installation is begun and the execution of the work on the railway right-of-way, including the supporting of the track, shall be subject to his inspection and direction.

Report on Assignment 4 (a)

Formation of the Roadway—Settlement; Shrinkage, Subsidence

Paul Chipman (chairman, subcommittee), F. W. Alexander, E. J. Beugler, Clifton Brannon, Herbert Ensz, Albert Haertlein, G. E. Ladd, Raymond Swenk.

In order to supplement the substance of present Manual material relating to shrinkage and subsidence by adding the conclusions reported last year as information, the committee recommends that material under "C. Shrinkage and Subsidence", pages 1–35 and 1–36, be withdrawn and that it be replaced by new material under the caption "C. Settlement of Embankments."

Present Form

C. SHRINKAGE AND SUBSIDENCE

1. *General*

(a) *In determining the allowance for shrinkage to be made in a fill, it should be remembered primarily that it is easier to add to the height of a fill that settles than to lower the track if the settlement does not amount to as much as that anticipated in the original allowance. Therefore, unless the shrinkage of a material is well known in the conditions under which the fill is made, it is best to be well on the safe side; i.e., little or no allowance should be made in height; the extra material, when possible, being deposited where it will be conveniently available for raising the track, as required. The allowance in width should be from about 5 percent to 20 percent of the height of the fill, depending on the material and conditions.*

(b) *The material used for fill varies in shrinkage from sound, non-disintegrating rock, or gravel, which is least, to certain swelling clays, which give the greatest shrinkage both in compactibility and erosion at the slopes. While vegetable loam has a large percentage of actual shrinkage, it so quickly produces a protection cover of vegetation that the shrinkage due to erosion is usually small. Where frozen material must be used in making a fill, heavy settlement must be expected, and this is to be avoided where possible.*

(c) *The material and contour of the ground supporting the fill is also a matter of considerable importance. This is especially so where unstable material is encountered.*

(d) *The method of making the fill should also be carefully considered. When the tracks are being raised under traffic, the vertical shrinkage will be largely taken care of in the course of the work. When the fill is made by teams or such means as to reasonably tamp and compact the fill in thin layers, as it is made, the same is true. Where, however, the fill is made by trestle and without puddling or other method of compacting, the settlement is apt to be considerable.*

2. *Allowance for Shrinkage and Subsidence in Estimating*

(a) *Shrinkage:*

(1) *Figure a shrinkage of 10 percent of quantities measured in excavation on earth removed from excavation to embankment.*

(2) *Ascertain local conditions and results and use them as a guide in estimating swell of rock, considering nature of formation and method of handling.*

(b) *Subsidence:*

(1) *Some subsidence occurs under all embankments built on any ground except rock. It is very light in sand and gravel. The percentage of subsidence is in general greater under small fills than under large ones.*

(2) *Subsidence is due to compression or displacement of the strata of earth under the embankment.*

(3) *Subsidence must always be anticipated in swamps, marshes and bogs, and any land on which there is standing water.*

(4) *Serious subsidence is local and it is impossible to fix any rule as a guide in estimating or anticipating same.*

PROPOSED FORM

C. SETTLEMENT OF EMBANKMENTS

SHRINKAGE

The shrinkage of an embankment after construction depends almost entirely on two factors. One is the material of which it is made, the other the methods used in making it.

Kind of Material

Embankments made of rock which does not disintegrate or of gravel have practically no shrinkage, and shrinkage of clean sand is small. For other materials, the method of placement is the controlling factor. Aside from this factor, shrinkage in general increases with the amount of clay or organic matter, or both, in the soil mixture, being greatest in certain clays which swell extensively in the process of excavation.

Construction Methods

Future shrinkage of compactable soils can be eliminated by rolling, combined with regulation of the moisture content to approach the optimum as determined by tests. In fills made by dumping from above, as in filling bridges, widening banks, or end dumping of trucks, the natural shrinkage is not greatly reduced by the construction process, and additional compaction at such places is desirable and economical. Fills made with heavy hauling equipment, with teams and scrapers, or by lifting track under traffic are quite compact and have little shrinkage. Additional compaction by sprinkling and rolling is desirable where the soil is dry or where heavy or fast traffic is to be carried.

Allowance for Shrinkage

It is easier to add to the height of a fill that settles than to lower the track. No vertical allowance for future settlement should therefore be made unless it can be estimated from past behavior of the same material under similar conditions; but additional width to the extent of about three times the maximum probable shrinkage should be provided.

Shrinkage from Cut to Fill

The foregoing relates to shrinkage after construction. Shrinkage during construction from volume in excavation to volume in embankment likewise varies with the kind of material and method of construction but an average figure of 10 percent for earth will usually be close enough for estimating quantities and distribution of earthwork. For swell of rock the behavior of similar material under similar conditions should be ascertained if possible.

SUBSIDENCE

1. Some subsidence occurs under all embankments built on any ground except rock. It is very light in sand and gravel. The percentage of subsidence is in general greater under small fills than under larger ones.

2. Subsidence is due to compression or displacement of the earth under the embankment.

3. Subsidence must always be anticipated in swamps, marshes and bogs and any land on which there is standing water.

4. Where any considerable amount of subsidence is anticipated, particularly subsidence due to displacement, adequate depth tests should be taken and a study of the material made, in order to determine the method of treatment and to make an estimate of the amount of filling material required.

5. Good construction practice will avoid future subsidence by carrying the fill to solid ground by:

(a) Setting the partly made fill by means of explosives or jetting.
(b) Excavating a short section of the soft material and replacing it with suitable material dumped over the end of the advancing fill.
(c) A combination of these methods.

6. Railroad embankments subject to continuing subsidence should be studied to determine whether their stabilization would be economically justified.

Report on Assignment 4 (b)

Placing Material in Embankments

Consider Preparation of Receiving Surface; Compaction by Layers; Spreading Travel of Equipment, Rolling, Jetting, Moisture Content, Density Requirements

Paul Chipman (chairman, subcommittee), F. W. Alexander, E. J. Beugler, Clifton Brannon, Herbert Ensz, Albert Haertlein, G. E. Ladd, Raymond Swenk.

Highway Practice

Special compaction of embankments has in recent years become the standard practice of a number of state highway departments and has been used in railroad construction to a limited but growing extent. Specifications for such work all require that material be spread in level layers of uniform thickness, usually six or eight inches, and rolled with either a tamping (sheepsfoot) roller or a ten-ton or heavier self-propelled roller; although in some specifications only the former is permitted. Requirements as to the amount of rolling vary in different specifications. The minimum number of trips may be specified, rolling until no further compaction takes place, or rolling to the satisfaction of the engineer; but the tendency is toward requiring 90 percent or more of the maximum density at the optimum moisture content as determined by tests of the material.

In these tests, which were devised by R. R. Proctor, field engineer, Bureau of Waterworks and Supply of Los Angeles, Calif., the moisture content most favorable to compaction is determined by measuring resistance to penetration at different moisture contents, and the density of compacted soil at the optimum moisture content is ascertained. These tests and the apparatus for making them have been standardized and the latter may be purchased in the market. Further description may be found in the references given in the bibliography included in this report. The "Soils Manual" issued by the State Highway Commission of Kansas, is especially complete in regard to the theory and application of these tests.

The foregoing relates to compactable materials. Rock, gravel and clean sand do not compact under rolling; but spreading in layers is a general requirement, two feet being a thickness commonly used. The practice of settling embankments by jetting or ponding, or both, has been used to some extent by certain highway departments. It has now been largely superseded by mechanical compaction where the materials admit, but is still used to some extent for clean sand and sandy gravel.

If all shrinkage of a fill is to be prevented, it is not consistent to place it on loose soil. Specifications, therefore, usually require that under fills which are to be compacted, the surface be plowed and then compacted in the same manner as the fill itself.

Applicability to Railroad Embankments

The extent to which such methods are applicable to railroad construction is a subject that merits discussion. A small amount of unequal settlement under a concrete highway produces a roughness of surface that can be corrected only at considerable expense; but in a railroad fill, such irregularities are eliminated by surfacing the track. This being accomplished, the slight dip below the original grade line which might result from shrinkage of a fill made with modern equipment, but without rolling or sprinkling, would have no appreciable effect on cost of operation or riding comfort.

The sole disadvantage of the practice is its initial cost. This is made up of two parts, the cost of additional compaction and the cost of additional material required to make the more compact embankment. The latter is relatively small, and for higher fills is practically offset by not having to widen them to provide a base for future lifts necessitated by shrinkage.

The cost of sprinkling is the variable element. For earth dams, where impermeability is essential, a close approach to the optimum moisture content is desirable; but a degree of compaction that will prevent appreciable shrinkage can be attained at the moisture content usually found in compactable soils when freshly excavated. In most localities, the necessity for adding water in compacting railroad fills would be exceptional.

There is quite a range in the cost of such work reported by a number of state highway departments, also the Missouri Pacific Lines, as shown below:

		Averages 1937 *Cents*	1938 *Cents*	1939 *Cents*
Illinois	No definite figure, but mechanical compaction costs less than the water soaking formerly used, which cost 3 cents to 4 cents per cubic yard.			
Kansas	Rolling and tamping	3.4	2.1	1.8
	Class A Compaction		2.9	3.8
	Class B "		2.0	2.2
Missouri	Average 4 cents in 1939, not including water.			
Ohio	Think compaction has not increased cost.			
North Carolina	2 cents to 4 cents.			
Minnesota	1 cent to 2 cents, not including water, which might vary from nothing up to 5 cents or more for very dry soil.			
Missouri Pacific Lines	2 cents or less, not including water.			

In some of these states, the only basis for measuring this cost is a comparison of grading prices before and after the specifications were changed to provide for compaction. This accounts for the Ohio opinion and the indefiniteness of others. In Kansas the case is clear cut, as compaction is a separate item in bids and contracts. As grading contractors do more of this work, the price will possibly be lower, but at present 2 cents per cubic yard is as low a figure as should be used for estimates and comparisons.

In grading operations of any considerable extent, the material is now hauled in heavy units of equipment that are very effective agents of consolidation, if the material be spread in layers and concentration of equipment travel is avoided. Comparatively little grading by such methods has been done on railroads, and only a fraction of that so done has been further compacted by rolling, either with or without regulation of the moisture content. No definite figures are therefore available as to the saving in maintenance expense that results from thorough compaction. It is known that, while maintenance expense due to shrinkage of fills made with heavy hauling equipment is small, such expense may be entirely eliminated by thorough compaction, as such treatment definitely does away with future shrinkage. Compaction has no effect upon subsidence, which is the usual cause of serious settlement and is dealt with in a previous report by this committee.

What effect thorough compaction of the subgrade would have on the formation of water pockets can only be surmised, as no evidence exists. Probably no amount of compaction would prevent the depression that is formed under each rail by the heavier tamping that is done there. Water pockets start from these depressions which, although they may not grow so fast or get so deep in a more compact subgrade, would also not drain as readily.

In most cases compactable soil when freshly excavated contains enough moisture to consolidate effectively under the rolling of heavy equipment or the trampling of animals. However, there are many sections where at times this is not true, and the material as excavated is too dry to compact properly. In such cases, sprinkling and rolling is necessary to obtain a satisfactory compaction.

In situations where compactable material is not subject to the rolling of heavy hauling equipment, such as in filling bridges and trestles, widening banks, or backfilling behind abutments, or retaining walls, spreading in layers and special compaction is necessary if settlement is to be avoided. Layers should be sloped away from abutments and walls, as tests prove that the initial thrust is reduced thereby.

There are points of fixed elevation such as bridges, tunnels, and crossings, where the original grade line must be maintained. If shrinkage could be made good at such points in a single ballast lift, the cost would generally be less than compaction of the entire fill. But shrinkage takes place gradually and many surfacings over a term of years, with perhaps light applications of ballast, are usually required, at correspondingly greater expense.

It is difficult to so route equipment travel that the edges of a layer will receive as thorough compaction as other portions. Rolling of the edges is desirable, especially for high fills, even if not practiced elsewhere.

In some states this process is applied to all state highways; in others, to all except secondary roads that are not to receive a rigid surface. Its justification on railroads depends largely upon the nature and extent of the traffic. Under heavy or fast traffic, surfacing to take up settlement must be done more frequently and at greater cost than if traffic is light or slow.

Where the new fill is to carry fast or heavy traffic from the start, as in the case of a change of line, special compaction may well be justified as an insurance against excessive expense for lifting and surfacing track and possible slowing up of traffic. Further experience will make possible a more definite appraisal of its benefits.

Bibliography

Compaction of Embankments

Engineering News–Record, Vol. 111, Aug. 31, Sept. 7, 21, 28, 1933; R. R. Proctor.

Engineering News–Record, Vol. 114, Apr. 18, 1935; Pages 565, 566.

Soils Manual for the Control and Inspection of Earthwork. State Highway Commission of Kansas.

Revision of the Grading Specifications

(page 1–37 of Manual)

Provision for sprinkling or rolling or both, in cases where such treatment is desirable, calls for the revision of Sections 33 and 34 of the Specifications for the Formation of the Roadway.

Formation in layers is such an important factor in obtaining a compact fill that it should be required, except where otherwise directed. Such direction would be given in the case of end dumping by wheeled scrapers, or by trucks on a fill across soft ground, or, in some cases, where an incompactable material such as rock, gravel or clean sand is used.

Uniform spreading of equipment travel is also an important factor in building a compact fill, and should be required, unless otherwise directed. In other words, formation in layers and spreading travel of equipment should be the rule, instead of the exception, as Section 33 in its present form would imply.

The committee recommends that Sections 33 and 34 of the Specifications for the Formation of the Roadway be withdrawn and that they be replaced by new Sections 33 and 34.

Present Form

33. *Formation in Layers*

When directed, embankments shall be built in horizontal layers of .... (........) inches in thickness. The layers must be the full width of the embankment, without depressions between slopes, built to the true slope, and not widened with loose material from the top. The most suitable material shall be reserved for finishing the surface. Large stones shall not be permitted within a depth of .... (........) feet below subgrade.

Proposed Form

33. Formation in Layers

Unless otherwise directed, embankments of earth shall be built in horizontal layers of not more than twelve inches in thickness. Where the layers are to be rolled, their thickness shall not exceed .... (........) inches and they shall, if directed, be harrowed with a spring tooth or disc harrow. The layers must be the full width of the embankment, without depressions between slopes, built to true slope and not widened with loose material from the top. Layers shall be compacted as evenly and as densely as possible by distributing the hauling over the entire area of fill already placed. The most suitable material shall be reserved for finishing the surface. Large stones shall not be permitted within a depth of .... (........) feet below subgrade.

Present Form

34. *Rolling*

When directed, embankments placed in layers shall be thoroughly compacted by rolling each layer with a roller weighing not less than .... (........)

pounds per lineal inch. Additional payment for such compaction shall be made by the cubic yard, measured in excavation.

PROPOSED FORM

34. Moisture Content, Rolling

If the moisture content of material used for filling is insufficient to permit compaction to the density required by the Company, the Contractor shall furnish water and apply it to the fill by suitable means of distribution and in the amount directed, and shall mix it with the soil by harrowing. Such work shall be paid for on a force account basis, unless otherwise provided in the contract.

Where directed, embankments placed in layers shall be thoroughly compacted by rolling each layer with a self-propelled roller of the three-wheel type weighing not less than 300 pounds per linear inch of width of the rear wheels, or with a tamping roller weighing, when fully loaded, not less than 100 pounds per square inch of tamping area. Tamping rollers used shall have tamping feet which project 7 inches or more from the surface of the roller and are not less than 6 inches apart, and shall be equipped with a cleaning device. Rolling shall continue until no further compaction results, unless otherwise directed. Payment for rolling fills shall be per cubic yard of material rolled, measured in excavation, and shall be in addition to the price for excavation.

Where the material in an embankment is to be rolled, the natural soil on which the embankment will rest shall be plowed to a depth of .... (........) inches and sprinkled, harrowed and rolled in the same manner as the embankment. Payment for furnishing and applying water shall be on a force account basis, unless otherwise provided in the contract; and for plowing, harrowing and rolling shall be on a square yard basis.

Report on Assignment 7

Tunnels—Lighting

W. S. Moore (chairman, subcommittee), F. W. Alexander, H. F. Brown, F. W. Hillman, G. B. Wall, Jr.

Your committee reported on this subject at the 1940 convention, which report was offered as information in the Proceedings.

Further investigation has convinced the committee that the best lighting possible in tunnels is none too good. Track must be maintained to a higher standard there than anywhere else due to the limited clearances frequently found in older tunnels. Ample lights are also necessary for proper inspection of tunnel lining, and drainage conditions frequently require serious attention. Good lighting will increase the efficiency of the workmen and reduce the hazard of personal injuries.

Ordinary hand lanterns, banjo torches and carbide lights give insufficient light or are too low to do much good and some of them create objectionable fumes and smoke. They are expensive, as it is often necessary to assign some of the workmen to hold them up or move them frequently.

Of the 941 tunnels on which the committee obtained information last year, less than 7 percent have any form of permanent electric wiring for lights, either in conduit or in cable or open wiring. Corrosion and the maintenance cost of this type of construction are excessive.

The following is therefore recommended for adoption and inclusion in the Manual:

704. LIGHTING

Portable lighting plants with gasoline engine driven generators producing 110-volt current are economical and satisfactory for lighting tunnels. These may be secured in units that deliver as low as 650 watts and weigh only 70 pounds. These portable plants, placed in track ditches or along tunnel walls will easily clear passing trains. Lights used with them may be mounted on adjustable tripods which can be raised or lowered, or on wooden rods about 6 feet long, with pointed steel shoes so that they may be set up in the track above the workmen.

Two 300-watt flood lights with suitable extension cords plugged into the portable plants will produce ample illumination for all ordinary tunnel work.

Report on Assignment 8 (a)

Corrosion-Resisting Fence Wire

Collaborating with Appropriate Subcommittees of Committee A-5 on Corrosion of Iron and Steel, ASTM

A. R. Jones (chairman, subcommittee), F. W. Hillman, P. J. McCarthy, W. C. Pruett, P. H. Winchester.

Your committee is collaborating with and receiving reports of the exposure tests of farm field fence, unfabricated wire, wire strand, barbed wire and chain link fencing of ASTM Committee A–5 on Corrosion of Iron and Steel. The first report of the Wire Inspection Committee on Field Tests, published in the ASTM Proceedings for 1939, Vol. 42, page 156, indicated the following trends:

> Ordinary zinc coated wires do not show significant losses of strength until after rusting of base metal has started.
>
> Heaviest corrosion is in severe industrial atmosphere, next in sea coast exposure, next in moderate industrial atmosphere and least in rural exposures.
>
> Copper-bearing uncoated wires, copper content 0.22 percent to 0.25 percent, are corroding less rapidly than the low copper content, 0.05 percent to 0.08 percent, where exposed to severe industrial atmosphere.
>
> Thus far there is no clear cut indication that the lighter gage uncoated wires are being penetrated more rapidly than the heavy uncoated wires.
>
> There is a tendency for the wires of lighter gages to lose coating somewhat faster than the wires in heavier gages.

This report is presented as information.

Report on Assignment 8 (b)

Wood Fence Posts, Specifications, Etc.

A. R. Jones (chairman, subcommittee), F. W. Hillman, P. J. McCarthy, W. C. Pruett, P. H. Winchester.

Your committee has collected a number of specifications for wood fence posts now in use, and after a thorough study of these, offers the following specifications as information and invites comments and criticisms prior to offering them for inclusion in the Manual at the 1942 convention.

SPECIFICATIONS FOR WOOD FENCE POSTS

MATERIAL

1. Kinds of Wood

Before manufacturing posts, producers shall ascertain which of the following kinds of wood suitable for fence posts will be accepted.

Class U designates the kinds of wood that may be used untreated and Class T designates the kinds of wood which should receive preservative treatment.

Class U		*Class T*	
Black Locust	*Black Walnut*	*Ashes*	*Hackberries*
Cypress	*Heart Yellow Pine*	*Beech*	*Maple*
Catalpa	*Larches*	*Birch*	*Red Oak*
Cedar	*Red Mulberry*	*Black Gum*	*Sap Yellow Pine*
Chestnut	*Redwood*	*Cherry*	*Sycamores*
Douglas Fir	*White Oak*	*Elm*	*Sap Fir*
		Hickories	

PHYSICAL REQUIREMENTS

2. Defects*

Posts shall be free from the following defects: Decay, excessive crook, wane on rectangular posts, holes in top of post, numerous holes, large knots, large shakes and splits.

3. Defects Allowable*

In round cedar posts, pipe or stump rot up to 0.75 inches in diameter in butt end.

Peck in cypress up to limitation of holes.

Crook that does not exceed 3 inches measured between the longitudinal axis and a straight line from the center of one end to the center of the other end.

Wane on rectangular posts not exceeding one-fourth of the dimension of the faces.

Holes other than in top of post not exceeding 1 inch diameter and 3 inches deep.

Numerous holes that are not damaging in effect.

Knots in round posts whose average diameter is less than one-third the diameter of post.

Knots in rectangular posts whose average diameter is less than 0.25 the width of surface in which the knot appears.

Numerous knots that are not damaging in effect.

Large shakes in rectangular posts whose maximum dimension between parallel lines does not exceed 0.25 of the minimum thickness of post.

In round posts shakes not damaging in effect.

Splits not damaging in effect.

---

* For definition of terms please see "Definitions of Maximum Defects and Blemishes" Manual page 7–74.

DESIGN

4. General

Before manufacturing posts, producers shall ascertain which sizes will be acceptable and whether posts are to be round, rectangular, halved or quartered.

5. Dimensions

All posts shall be in accordance with the designs and dimensions shown in the table.

Design and Dimensions of Fence Posts

Design	*Dimensions*			
	Intermediate or Line Posts		*End, Corner, Anchor and Gate Posts*	
	At Small End	*Length*	*At Small End*	*Length*
Round	4 in. diameter	7 ft.	8 in. diameter	8 ft.
	5 in. diameter	8 ft.		
Rectangular	4 in. by 4 in.	7 ft.	8 in. by 8 in.	8 ft.
	5 in. by 5 in.	8 ft.		
Halved	19 in. perimeter	7 ft.		
	21 in. perimeter	8 ft.		
Quartered	19 in. perimeter	7 ft.		
	21 in. perimeter	8 ft.		

MANUFACTURE

6. General Requirements

All posts shall be straight, well manufactured, of natural taper, free from projections and cut square at ends unless small end is roofed. Inner skin must be removed and roofing or gaining of treated posts shall be done before treatment.

INSPECTION

7. Place

Posts shall be inspected at points of shipment or destination, in suitable and convenient places satisfactory to the railroad. Posts will be inspected at points other than the railroad property whenever in the judgment of the railroad there is sufficient number to warrant it; but the shipper shall provide accommodations for the inspector at the expense of the railroad, while away from rail or steamship lines, and transport him from and to a railroad station or steamer landing.

8. Manner

Inspectors will make a reasonably close inspection of each post, which shall be judged independently, without regard for decisions on others in the same lot. Posts too soiled for ready examination will be rejected. Posts shall be turned over as inspected.

WORKMANSHIP

9. Tolerances

Posts shall not be more than 1 inch shorter nor 3 inches longer than the lengths specified.

Posts shall not be more than ¼ inch smaller nor more than 1 inch larger than the diameters, widths and perimeters specified.

DELIVERY

10. Separated as Specified

Posts shall be separated according to the kind of wood, shape and size or as may be required in the order for them.

PRESERVATIVE TREATMENT

11. Specifications

Posts requiring treatment shall be treated in accordance with the AREA Specifications for the Preservative Treatment of Wood.

Report on Assignment 8 (c)

Electrified Fences

Collaborating with Committee 3—Overhead Transmission Line and Catenary Construction of the Electrical Section, Engineering Division, AAR

A. R. Jones (chairman, subcommittee), F. W. Hillman, P. J. McCarthy, W. C. Pruett, P. H. Winchester.

Modern effective electric fences are usually single strand barbed wires that are supported on insulators and so supplied with electricity that any animal touching them will receive a shock strong enough to turn the animal, but the shock must not be strong enough to be dangerous. As there is usually only one strand of wire supported on light posts spaced 3 rods apart and as the pull of the fence is not excessive so that end post bracing is simple, electric fences cost very little in materials or labor as compared with woven wire or regular barbed wire fences.

Electricity is regulated and supplied to electric fences through devices known as electric fence controllers which may operate on (1) battery current only, or on (2) central station alternating current only, or (3) either on battery current, or on alternating current that is so modified in the controller as to be a substitute for battery current.

An alternating current of 25 milliamperes is considered the amount of current necessary to flow from the fence through the animal if all the perverse animals in a herd are to be turned from the fence with reasonable certainty. Such current is effective if it comes from the fence in brief shocks with an interval between of sufficient duration to allow an animal to release itself from the fence. Off periods of at least 0.9 second and shock periods of not over 0.1 second, coming not more frequently than once a second are generally considered standard for alternating current controllers. Such controllers are required to be made so that there is no reasonable probability that the interrupting mechanism will fail to function or that the insulation will break down and connect the power line directly to the fence.

There are now three codes or sets of rules setting forth how electric fences may operate and how they should be constructed for safety. The code first issued is that of the Industrial Commission of Wisconsin, the second the Electric Fence section of the National Electric Safety Code which is sponsored by the U. S. Bureau of Standards; the third is the Standard for Electric Fence Controllers by Underwriters Laboratories Inc. sponsored by the National Board of Fire Underwriters.

The following are quotations in part from General Orders on Electric Fences dated October 6, 1938 and issued and published by the Industrial Commission of Wisconsin.

> An electric fence is a barrier to animals or fowls consisting of an electrified conductor and an energizing and controlling device.
>
> An electrified conductor may be wire, ribbon, tape, rod, tube, plate, mesh or any other form suitable for its purpose, but may be referred to simply as fence wire.
>
> The energizing and controlling device is the device or combination of devices by which the fence is electrified and may be referred to simply as the controller.
>
> A battery controller is one for which the power source is a battery or batteries limited to less than 15 volts.
>
> An alternating current controller is one for which the power source is alternating current at voltages normally supplied by electric distributing agencies.
>
> All controllers and converters which are sold or installed in Wisconsin after October 6, 1938 shall comply with the requirements of these orders and be approved by the Industrial Commission of Wisconsin.
>
> Controllers supplied by a primary source of power in excess of 15 volts and which do not provide separation by insulation between the primary source of electric energy and the fence, and those of the continuous vibration type delivering more than 5 miliamperes Y.M.S. or 25 miliamperes peak shall be prohibited after October 6, 1938.
>
> Electric fences, when installed along public highways, or as property line fence, shall be identified by approved signs clamped to the wire or fastened to the posts at intervals of not more than 200 feet.

Electric fences are increasing in use for farm fencing. Their application to the right-of-way would require determination in each state as to meeting requirements for legal right-of-way fence. Policing is necessary to keep vegetation cleared as a possible cause of short circuits. This type of fencing along the right-of-way would lend itself to claims for injury to persons and to stock.

The committee is of the opinion that the electric fence is not suitable for general use as a right-of-way fence.

The report is presented as information.

Report on Assignment 9 (a)

Design of Signs

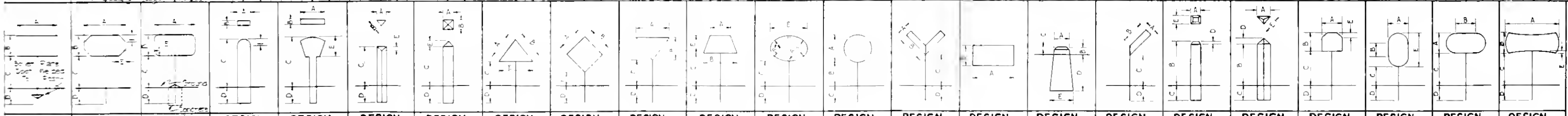
L. J. Drumeller (chairman, subcommittee), Clifton Brannon, G. H. Burnette, F. L. Guy, O. N. Lackey, A. H. Woerner.

For the purpose of developing information regarding current practice in the design of signs, a questionnaire was sent to 28 representative railroads in the United States and Canada having a total of 191,768 miles of road. From the data received in the replies, your committee has prepared the tabulation appearing on the folded insert, which shows the materials of construction and the dimensions of the various types of signs used on these railroads for the purposes indicated in Manual pages 1–87 and 1–88 under the heading "901. Roadway Signs Required."

NAME OF ROAD CANVASSED	MILEAGE	LAND MONUMENTS	NO TRESPASS	MILE POSTS	ALINEMENT	GRADE	CITY LIMIT	COUNTY LINE	STATE LINE	VALUATION SECTION	MAINTENANCE LIMIT	BRIDGE OR CULVERT	SECTION LIMIT	SNOW PLOW	FLANGER	SPEED CONTROL	STATION WHISTLE	HIGHWAY X-ING WHISTLE	APPROACH TO RWY X-ING AT GRADE	YARD LIMIT	APPROACH TO DRAWBRIDGE	JUNCTION WHISTLE	INFLAMMABLE STORAGE	UNDERGROUND PASSAGE OF INFLAMMABLES	HIGH VOLTAGE
A.T.&S.F.	3475	Scrap Rail	[illegible]	[illegible]	Scrap Rail				[illegible]			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]		
A.C.L.	5108	Scrap Rail		[illegible]				[illegible]	[illegible]							[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
B.&M.	1953	[illegible]	[illegible]	[illegible]					[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
Canadian Pacific	[illegible]	[illegible]	[illegible]	[illegible]								[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
C.&N.W.	8383	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]					[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
C.B.&Q.	8950	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			
Canadian National	23400	[illegible]	[illegible]	[illegible]					[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
Central of Georgia	1927		[illegible]	[illegible]				[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
C.R.I.&P.	7342		[illegible]	[illegible]									[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		
[illegible]	* 9352	[illegible]	[illegible]	[illegible]	6' 26" 16" 1" 2"	6' 3¼"	[illegible]		[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]		
[illegible]	999		[illegible]	[illegible]					[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
[illegible]	2563	Scrap Rail	[illegible]	[illegible]	Scrap Rail							[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
Great Northern	8072		[illegible]	[illegible]	6' 10" 8" 16"				[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
Illinois Central	6825	[illegible]		[illegible]	5½ (4'6") 2' 5½						[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
Lehigh Valley	1282		[illegible]	[illegible]	4' 2' 10' 26" -			[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]	[illegible]	[illegible]
L.&N.	4925		[illegible]	[illegible]			[illegible]									[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		
Missouri Pacific	[illegible]		[illegible]	[illegible]	3' 2'							[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
M.K.T. Lines	3188	[illegible]	[illegible]	[illegible]	Scrap Rail		[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
Northern Pacific	6722	[illegible]	[illegible]	[illegible]	4' 10' 6' 36"			[illegible]				[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Norfolk Southern	805	[illegible]	[illegible]	[illegible]	[illegible]						[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
[illegible]	1884		[illegible]	[illegible]								[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
[illegible]	12450	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		
[illegible]	[illegible]		[illegible]	[illegible]				[illegible]	[illegible]				[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Pennsylvania	9920	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
P.&L.E.	233	[illegible]	[illegible]	[illegible]		4½ Var			[illegible]				[illegible]			[illegible]			[illegible]						
Reading	1401		[illegible]								[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]		[illegible]					
Southern	7924	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
Southern Pacific	** 3058	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

* Includes [illegible] Plans and [illegible] Designs and Mileage

** [illegible] Mileage [illegible] Mexico



DESIGN NO.1 — DESIGN NO.2 — DESIGN NO.3 — DESIGN NO.4 — DESIGN NO.5 — DESIGN NO.6 — DESIGN NO.7 — DESIGN NO.8 — DESIGN NO.9 — DESIGN NO.10 — DESIGN NO.11 — DESIGN NO.12 — DESIGN NO.13 — DESIGN NO.14 — DESIGN NO.15 — DESIGN NO.16 — DESIGN NO.17 — DESIGN NO.18 — DESIGN NO.19 — DESIGN NO.20 — DESIGN NO.21 — DESIGN NO.22 — DESIGN NO.23

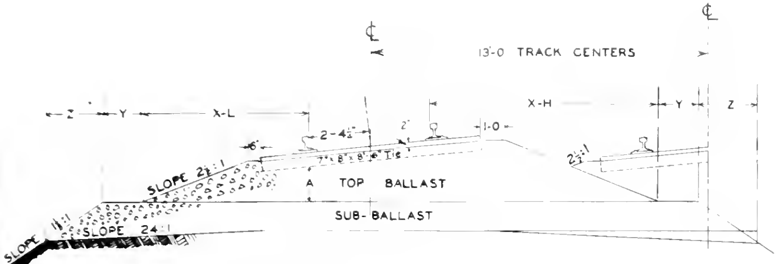
AMERICAN RAILWAY ENGINEERING ASSOCIATION

COMMITTEE I SUB-COMMITTEE 9

DESIGN OF SIGNS

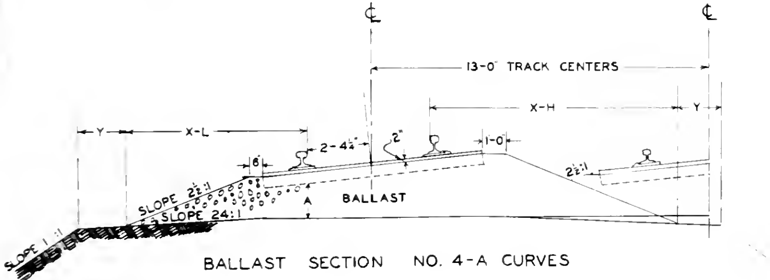
Legend
(m) Metal
(c) Concrete
(w) Wood

MARCH 1941



BALLAST SECTION NO. 3-A CURVES

MATERIALS: PREPARED GRAVEL 0-20% CRUSHED PARTICLES AND PIT RUN GRAVEL



BALLAST SECTION NO. 4-A CURVES

MATERIALS: PREPARED GRAVEL 0-20% CRUSHED PARTICLES AND PIT RUN GRAVEL

TABLE OF VARIABLES AND QUANTITIES PER 100 FEET SINGLE TRACK- FOR SECTION 3-A CURVES.

SECTON ✱	A	SUPERELEVATION 1"			2"			3"			4"			5"			6"		
		X-L	X-H	Cu.Yds.	X-L	X-H	Cu.Yds.	X-L	X-H	Cu.Yds.	X-L	X-H	Cu.Yds.	X-L	X-H	Cu.Yds.	X-L	X-H	Cu.Yds.
3-A a-b	16"	6-8	7'-7"	104	6'-7"	7'-10"	108	6-6"	8'-2"	113	6'-5"	8'-5"	116	6'-4"	8'-9"	120	6'-3"	9'-0"	123
3-A c-d-e-f	14"	6-3	7-2	92	6-2	7-5	95	6-1	7-9	100	6-0"	8-0"	104	5'-11"	8-4	108	5-10"	8-7"	112
3-A g-i	12	5-10	6-9	78	5-9	7-0	81	5'-8"	7'-4"	86	5'-7"	7-7	89	5-6"	7-11"	93	5-5"	8-2"	98
3-A h-j-k-n	10"	5 5	6-4"	68	5-4	6-7	7,1	5'-3"	6'-11"	74	5'-2"	7'-2"	77	5'-1"	7-6"	81	5-0"	7'-9	85
3-A l-o	8"	5'-0"	5-11"	55	4'-11"	6'-2"	59	4'-10"	6'-6"	62	4'-9"	6-9"	66	4'-8"	7-1"	69	4'-7"	7-4"	73
3-A m-p	6	4-7"	5-6"	44	4'-6"	5-9	47	4'-5	6'-1"	51	4-4	6'-4	53	4-3	6'-8"	57	4'-2"	6'-11"	60

TABLE OF VARIABLES AND QUANTITIES PER 100 FEET SINGLE TRACK-FOR SECTION 4-A CURVES

SECTION ✱	A	SUPERELEVATION 1"			2"			3"			4"			5"			6"		
		X-L	X-H	Cu.Yds	X-L	X-H	Cu.Yds	X-L	X-H	Cu.Yds	X-L	X-H	Cu.Yds	X-L	X-H	Cu.Yds	X-L	X-H	Cu.Yds
4-A a	24"	9'-0"	10'-0"	170	8'-11"	10'-3"	173	8'-10"	10'-7"	178	8'-9"	10'-11"	184	8'-8"	11'-3"	190	8'-7"	11'-7"	196
4-A b	22"	8'-7"	9'-6"	155	8'-6"	9'-10"	159	8-5"	10'-2"	163	8-4"	10'-6"	169	8'-3"	10'-10"	173	8'-1"	11'-2"	178
4-A c	20"	8'-1"	9-0"	139	8-0	9'-4	143	7-11"	9'-8"	147	7'-10"	10'-0"	151	7'-9"	10'-4"	157	7'-8"	10'-8"	162
4-A d-e	18"	7-8	8-7	123	7-7"	8'-11"	127	7'-6"	9'-3"	133	7'-4"	9'-7	136	7'-3"	9'-10"	140	7'-2"	10'-2"	146
4-A f	16"	7'-2"	8'-1"	109	7'-1"	8-5"	112	7-0"	8'-9"	116	6-11"	9'-1"	121	6'-10"	9'-5	125	6'-9"	9'-9"	130
4-A g-h	14"	6-9"	7'-8"	96	6'-8"	8-0"	100	6-6"	8-3"	102	6-5"	8-7"	106	6'-4"	8'-11"	111	6'-3"	9-3"	115
4-A i	12"	6-3"	7'-2"	81	6'-2"	7'-6"	85	6-0"	7'-10"	89	5'-11"	8-2"	93	5-10"	8-6"	97	5'-9"	8'-10"	101
4-A j-k	10"	5'-9"	6-8"	69	5-8"	7'-0"	72	5-7"	7'-4"	76	5'-6"	7'-8"	81	5'-5"	8-0"	84	5'-4"	8'-4"	88
4-A l	8"	5-4"	6'-3"	57	5'-3"	6'-7"	60	5'-2"	6'-11"	64	5'-1"	7'-3"	68	4'-11"	7'-7"	72	4'-10"	7'-10"	75
4-A m	6"	4'-10"	5-9"	47	4'-9"	6'-1"	51	4'-8"	6-5"	54	4'-7"	6-9"	57	4'-6"	7'-1"	59	4'-5"	7-5"	63

✱ SUB-LETTERS GIVEN IN SECTION COLUMN INDICATE CORRESPONDING SECTIONS FOR TANGENT TRACK - SEE MANUAL, PAGE 2-18.

NOTES

1. DEPTH OF SECTION TO USE WILL DEPEND ON CONDITIONS PECULIAR TO EACH RAILROAD OR LOCATION.
2. UNDER CERTAIN CONDITIONS IT MAY BE NECESSARY TO USE A DEPTH IN EXCESS OF MAXIMUM SHOWN IN TABLES.
3. ROADBED TO BE WIDENED ON HIGH SIDE WHEN NECESSARY TO PROVIDE MINIMUM OF 18 INCHES FOR Y.
4. QUANTITIES COMPUTED ON BASIS OF 3200 TIES PER MILE AND 15% ALLOWANCE FOR SHRINKAGE.
5. VARIABLES AND QUANTITIES FOR SUPERELEVATION UP TO 3 INCHES ARE SHOWN AS INFORMATION.

A. R. E. A.
BALLAST SECTIONS
SINGLE AND MULTIPLE TRACK-CURVES
(FOR SUPERELEVATION IN EXCESS OF 3 INCHES)

In view of the great diversity of signs now in use, as disclosed by this tabulation, your committee is of the opinion that the development of recommended designs of signs for these various purposes is not practical. For example, of the 28 roads canvassed, there are 10, each of which uses a different shape for the speed control sign.

In the opinion of the committee, individual railroads should give consideration to the economies to be effected by a reduction in the number of shapes of signs, so that a sign for one purpose could be used for another simply by changing the legend. For example, a "No Trespass" sign, which has been eliminated at one point could be reused at some other location as a "City Limit", "County Line", "State Line", or other sign, by having it relettered. However, it is desirable that the signs for the various purposes listed under Item "D. Transportation" on Manual page 1–88 should each have a distinctive shape that can be easily recognized at a distance, so that appropriate action thereon is not dependent upon an ability to read the legend.

The tabulation prepared from information in the replies to the questionnaire is presented not only for the purpose of showing the various types and shapes of signs actually in use on the railways canvassed, but also with the thought that it would be found useful in the design of signs on various roads to the end that there may eventually be some semblance of uniformity in the shape and dimensions of each kind of roadway sign.

This report is offered as information.

Report on Assignment 10 (a)

Ballast Section Design

A. D. Kennedy (chairman, subcommittee), A. P. Crosley, R. L. Dyke, F. L. Guy, T. P. Polson, G. B. Wall, Jr.

The committee has prepared two ballast section plans designed for curves: Section No. 3a—Curves and No. 4a—Curves, for prepared gravel, under 20 percent crushed particles and for pit run gravel.

These sections are recommended for superelevations in excess of three inches, and are presented for adoption and inclusion in the Manual.

Report on Assignment 10 (c)

Investigate the Use of Asphalt in Ballast

J. M. Podmore (chairman, subcommittee), J. A. Given, P. J. McCarthy, J. A. Noble, Stanton Walker, C. S. Wicker.

In the early fall of 1939 a test section of emulsified asphalt coated stone ballast track was completed at Bryan, Ohio. This test section is 600 ft. long and is located on tangent in the east bound high speed track at the station platform. A complete account of the method of constructing this test section of track, the amount and kind of material used, and the force employed was given by your committee in its report to the last convention, Proceedings for 1940, Vol. 41, page 545.

After the completion of the test section, no work was done and no expense incurred until minor repairs were made on August 16, 17 and 18, 1940. At that time a foreman and three laborers worked 2½ days, or 20 hours each; a total of 80 hours. The work performed consisted of removing between five and six wheelbarrows of dirt, cinders, sand, coal and other foreign material from the top of the asphalt ballasted track and the ties.

It was found that the asphalt seal coat was shattered in a few places between the ties, and this was removed and replaced with new material. There was some creeping of track that was causing the bond between the edges of the ties and the seal coat to open and show cracks. These cracks were filled with a mixture of sand and asphalt. There was one joint low, which was dug out and retamped after which the carpet coat was replaced. The work described above required 1½ cu. yd. of sand and 330 gal. of asphalt.

The track is in good line and surface and has maintained this condition since it was installed. The water sheds off quickly after a storm and there is no foul or muddy track.

As it will require more time to determine the merits of this experiment, this report is submitted as one of progress, with the suggestion that a further report be made on the service behavior of this test at some later date.

Report on Assignment 10 (d)

Adherence to Stone Ballast Specifications, Particularly Size

A. D. Kennedy (chairman, subcommittee), A. P. Crosley, R. L. Dyke, F. L. Guy, T. P. Polson, G. B. Wall, Jr.

For the purpose of obtaining information on the extent of the use of the stone ballast specifications, the following questionnaire was addressed to the chief maintenance officers of the principal railroads on June 12, 1940:

Attention Chief Maintenance Officers:

One of the subjects assigned to the Roadway and Ballast committee of the AREA for this year is to determine the extent of adherence on the part of the various railroads to the AREA stone specifications, particularly size.

The sizes of stone now specified are as follows:

Designation	*Normal Size, Square Opening*	*Approximate Size, Round Opening*
2–A	1″ to 2″	1¼″ to 2½″
3–A	½″ to 1″	⅝″ to 1¼″
3–B	¾″ to 1½″	⅞″ to 1¾″
23–B	¾″ to 2½″	⅞″ to 3″

Will you please indicate to what extent the above gradations are followed by your road in purchasing ballast from commercial plants.

Further in this same direction, since the advent of higher speed schedules, which call for more exactness in surfacing track, the trend is toward the use of smaller sized ballast, especially for spot work; some roads are using ballast not to exceed one inch in size.

In view of the foregoing, do you think the AREA ballast specifications should provide a ballast gradation smaller than now shown? If so, please indicate your preference for any of the following designations, which are included in the latest recommendations of the National Bureau of Standards:

Designation	*Normal Size, Square Opening*	*Approximate Size, Round Opening*
57	1"–No. 4	1¼"–¼"
6	¾"–⅜"	⅞"–½"
67	¾"–No. 4	⅞"–¼"

In response to the foregoing questionnaire, replies were received from 35 railroads, representing 214,000 route miles in Canada and the United States. A compilation of the data furnished indicates that 77 percent of the roads use crushed stone for ballast and 23 percent use gravel or special materials. The replies show that of the roads using crushed stone, 53 percent adhere to the present AREA specifications in so far as gradation is concerned, and 60 percent of the replies indicate that a smaller size gradation than now specified should be added, a decided preference being shown for Bureau of Standards gradation No. 57.

The table of gradation now appearing in Section 301 of the specifications conforms with the Bureau of Standards Simplified Practice Recommendation R 163–36 issued in 1936. However, the bureau's recommendation R 163–39 issued in 1939 supersedes R 163–36, and embraces changes in gradations and in the designating numbers. The revised recommendation R 163–39 has been accepted by a majority of producers and users of coarse aggregates and ballast.

The table of gradation now in the Manual, which conforms to Bureau of Standards recommendation R 163–36, is given in Table 1, while the gradation conforming with the bureau's recommendation R 163–39 is given in Table 2:

Table 1. Present Form

Designation	*Nominal Size, Square Openings*	*Approximate Size, Round Openings*	*Amounts Finer than Each Sieve (Square Opening) Percents by Weight* 3"	2½"	2"	1½"	1"	¾"	½"
2A	1–2 "	1¼–2½"	...	100	90–100	35–70	0–15	0–5	....
3A	½–1 "	⅝–1¼"	...	...	...	100	90–100	....	0–15
3B	¾–1½"	⅞–1¾"	...	...	100	90–100	20–55	0–15	....
23B	¾–2½"	⅞–3 "	100	90–100	...	25–60	...	0–10	....

Table 2. Proposed Form

Size No.	*Nominal Size, Square Opening*	*Approximate Size, Round Opening*	*Amounts Finer than Each Sieve (Square Opening Laboratory Sieve) Percents by Weight* 3"	2½"	2"	1½"	1"	¾"	½"	⅜"	No. 4	No. 8
24	2½"– ¾"	3 "– ⅞"	100	90–100	...	25–60	...	0–10	0–5	....	....	...
3	2 "–1 "	2⅜"–1¼"	...	100	95–100	35–70	0–15	.....	0–5	....	....	...
4	1½"– ¾"	1¾"– ⅞"	...	...	100	90–100	20–55	0–15	.....	0–5	....	...
5	1 "– ⅜"	....	...	...	...	100	90–100	40–75	15–35	0–15	0–5	...
57	1 "–No. 4	1¼"– ¼"	...	...	...	100	90–100	.....	25–60	....	0–10	0–5

Note: Size numbers and gradations in size adopted from National Bureau of Standards' Simplified Practice Recommendation R 163–39.

Aside from the addition of Size No. 57 in Table 2, the major differences between Table 1 and Table 2 are in the arrangement, and that the tolerances allowed in Table 1 are subjected to further restrictions. For example, size 3–B in Table 1 corresponds with size No. 4 in Table 2, except that the limit of 15 percent placed on material finer than ½-in. provided in Table 1, has been replaced by the requirement that only 5 percent is permitted to pass a sieve with ⅜-in. square openings.

Your committee recommends that the gradation table now in the Manual under Section 301, of the Specifications for Ballast (shown above as Table 1), be withdrawn and replaced with gradation Table No. 2.

Report of Committee 5—Track

W. G. Arn, *Chairman*,
Lem Adams
L. L. Adams
C. W. Baldridge
A. L. Bartlett
W. H. Bettis
W. H. B. Bevan
F. J. Bishop
L. H. Bond
C. W. Breed
E. W. Caruthers
Armstrong Chinn
H. R. Clarke
O. U. Cook
E. D. Cowlin
H. Q. Day
L. W. Deslauriers
J. A. Ellis
H. F. Fifield
J. W. Fulmer
F. S. Hales
H. H. Harman
N. M. Hench
F. W. Hillman
E. T. Howson
A. F. Huber
W. G. Hulbert
C. T. Jackson
F. J. Jerome
A. A. Johnson
J. H. Kelly
J. de N. Macomb
G. M. Magee
E. E. Martin
L. I. Martin
F. H. Masters
K. R. McLennan
R. E. Miller
W. A. Murray
A. E. Perlman, *Vice-Chairman*,
J. B. Myers
G. A. Peabody
S. H. Poore
J. A. Reed
O. C. Rehfuss
C. J. Rist
W. L. Roller
I. H. Schram
J. F. Shaffer
G. L. Sitton
G. J. Slibeck
G. M. Strachan
C. R. Strattman
Hermann von Schrenk
H. N. West
R. P. Winton
J. G. Wishart
M. J. T. Zeeman
Committee

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

Progress report, embracing a number of recommended revisions .... page 576

For other revisions see Assignments 3, 4(a), 10, 12 and 13.

2. Fastenings for continuous welded rail, collaborating with Committee 4—Rail.

Progress report—submitted as information .... page 580

3. Plans and specifications for track tools and recommended limits of wear, collaborating with Committees 1—Roadway and Ballast, and 22—Economics of Railway Labor.

Progress report, including recommendations for revision of the Manual .. page 584

4 (a). Plans for switches, frogs, crossings, spring and slip switches, collaborating with Signal Section.

Progress report, including plans submitted for adoption .... page 595

For plans previously published during year, see Bulletin 418, page 209, and Bulletin 419, page 139 and Part 2 of the same bulletin.

4 (b). Track construction in paved streets, collaborating with Committee 9—Highways.

No report.

5. Corrosion of rail and fastenings in tunnels, collaborating with Committee 4—Rail.

Final report—submitted as information .... page 605

6. Design of tie plates for RE rail sections as developed, collaborating with Committees 3—Ties, and 4—Rail.

No report.

7. Practicability of using "reflex" units for switch lamps and targets, collaborating with Committee 10—Signals and Interlocking.

Progress report—submitted as information .... page 606

Bulletin 423, February, 1941.

8. Welding of manganese castings in special trackwork, collaborating with Committee 27—Maintenance of Way Work Equipment.

No report.

9. Bolt tension necessary for proper supporting of rail joints.

Progress report—submitted as information .... page 608

10. Lubrication of rail on curves, collaborating with Committee 16—Economics of Railway Location and Operation.

Progress report with recommendation for inclusion in the Manual ...... page 626

11. Prevention of damage due to brine drippings on track and structures, collaborating with Mechanical Division, AAR.

Progress report—submitted as information .... page 628

12. Specifications for laying rails, designed to set up requirements for good workmanship.

Final report—with recommendation for inclusion in the Manual ...... page 633

13. Spirals for high speed operation, collaborating with Committee 16—Economics of Railway Location and Operation.

Final report with final recommendation for inclusion in the Manual .... page 636

The Committee on Track,

W. G. Arn, *Chairman.*

Report on Assignment 1

Revision of Manual

M. J. T. Zeeman (chairman, subcommittee), L. L. Adams, W. H. B. Bevan, C. W. Breed, J. A. Ellis, E. T. Howson, A. A. Johnson, J. de N. Macomb, J. B. Myers, I. H. Schram, J. G. Wishart.

The committee submits the following revisions:

Page 5–2

Paragraph 401 (e). Delete this sentence and in lieu thereof insert the following:

(e) Tie plates shall be paid for on the basis of actual weight as applied to the entire order, except that payment shall not be made for any weight in excess of 3 percent over the weight calculated from the specified dimensions.

The reason for this change is to state more clearly that payments are made on the basis of actual weights, whether under or over, but that not more than 3 percent overweight will be paid for.

Page 5–14.2

Paragraph 401 (f). Delete this sentence and in lieu thereof insert the following:

(f) Tie plates shall be paid for on the basis of actual weight as applied to the entire order, except that payment shall not be made for any weight in excess of 3 percent over the weight calculated from the specified dimensions.

The reason for this change is to state more clearly that payments are made on the basis of actual weights, whether under or over, but that not more than 3 percent overweight will be paid for.

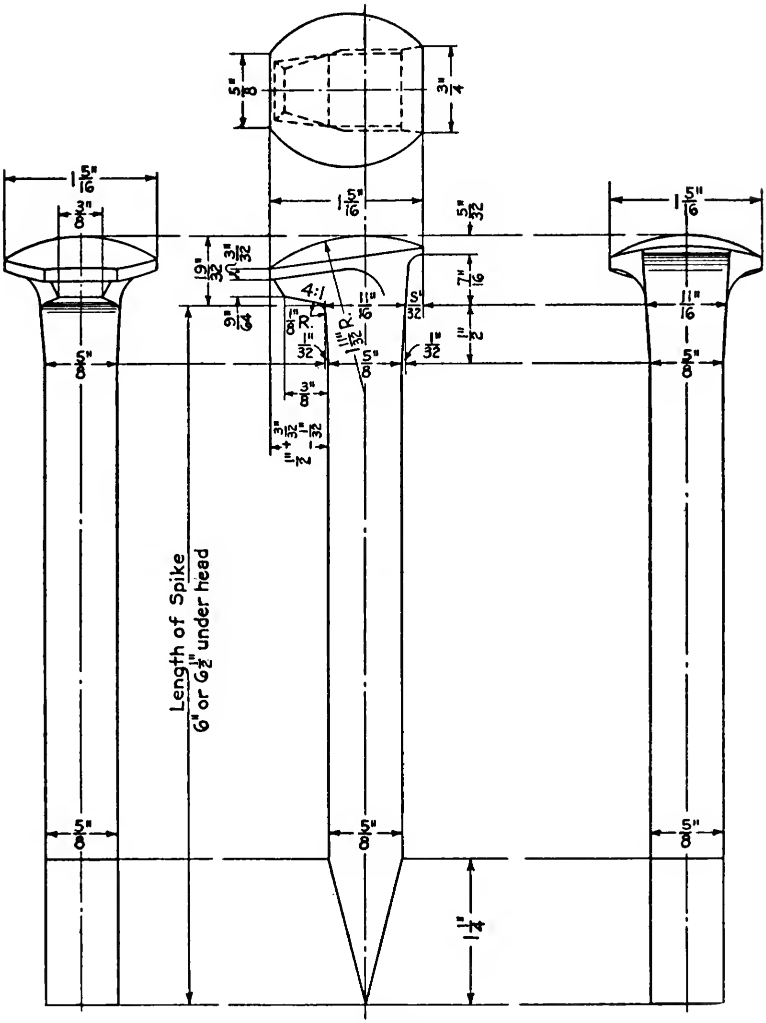


Fig. 509.

Page 5–16.2

Delete the drawing on this page, retaining the heading "Design of Cut Track Spike," also the title "For Use at Rail Joints and Alternate Design for General Use," and insert the new design of spike, to be identified as Fig. 509.

The reason for this change is to overcome manufacturing difficulties encountered with the design now in the Manual. While the specifications on page 5–16 permit a variation of 3/32 in. over and 1/32 in. under the specified dimensions of the head of the spike, some objection has been raised when all of this over tolerance comes at the toe of the spike head, which makes the toe distance greater than 9/16 in. By retaining the specification tolerances and reducing the head width and length from 1⅜ in. to

1-5/16 in., which also reduces the toe distance from 9/16 in. to ½ in., the manufacturers will be able to produce a satisfactory spike. Fig. 509 shows that it will be acceptable if the entire permissible head tolerance occurs at the toe of the spike head.

Page 5–34

Under "Speeds of Trains Through Level Turnouts" delete the text and the table and in lieu thereof insert the following text and two tables, retaining the present heading:

The following tables show speeds through level turnouts giving riding conditions equivalent to those obtained in traversing a curve elevated 3 inches less than that required for equilibrium; when the center of gravity of equipment is 84 inches above the rail, the resultant of forces will intersect the plane of top of rail approximately 6 inches outside the center line of the track.

Speeds through turnouts with either straight or curved switch points are calculated from formula $E = 0.00066\ D\ S^2 - 3$, (See Manual page 5–42) where D equals the degree of curvature of the closure curve or the switch curve, whichever is sharper; for turnouts with straight switch points, D for the switch point curve is the degree of curvature of a curve having a central angle equal to the switch angle and a chord length equal to the length of the switch points.

Turnouts With Straight Switch Points (AREA)

Turnout Number	*Length of Switch Points*	*Speed In Miles Per Hour*
5	11′–0″	12
6	11′–0″	14
7	16′–6″	16
8	16′–6″	19
9	16′–6″	21
10	16′–6″	21
11	22′–0″	27
12	22′–0″	28
14	22′–0″	28
15	30′–0″	37
16	30′–0″	38
18	30′–0″	38
20	30′–0″	38

Turnouts With Curved Switch Points (AREA)

Turnout Number	*Length of Switch Points*	*Speed In Miles Per Hour*
5	11′–0″	12
6	11′–0″	14
7	19′–6″	17
8	19′–6″	20
9	19′–6″	23
10	19′–6″	25
11	19′–6″	25
12	30′–0″	30
14	30′–0″	35
15	30′–0″	39
16	30′–0″	41
18	39′–0″	46
20	39′–0″	50

This change is desirable because the AREA track plans now include both straight and curved switches as recommended practice, and a speed table for curved switches should be added. The lengths of switch points for each turnout shown in the proposed tables are AREA recommended lengths.

Page 5–35

Delete Fig. 511, diagram of Speed of Trains Through Level Turnouts, as the essential data shown therein are incorporated in the text and tables presented next above.

Page 5–45

Delete the heading "Proper Methods of Tamping," and the entire text, and in lieu thereof insert the following:

TAMPING

1. General

(a) The distances shown below for tamping inside and outside of the rail are recommended for heavy or fast traffic, but these distances may vary to some extent, depending on the kind of traffic.

(b) The term "power tamper" used as a tamping tool includes any tamping machine, whether operated mechanically, pneumatically or electrically.

(c) Uniformity of cross level in tamping is the prime requisite for good riding track.

2. Tamping Tools

(a) For broken stone, crushed and washed gravel or slag ballast, use a tamping pick, tamping bar, ballast fork or power tamper. The power tamper should have a tamping bar with a tamping end similar to a tamping pick face.

(b) For gravel, volcanic cinders, chats or chert ballast, use a shovel, tamping pick, tamping bar or power tamper. For heavy traffic, a tamping pick, tamping bar or power tamper should be used. The power tamper should have a tamping bar with a tamping end of sufficient area. For light traffic, shovel tamping is sufficient.

(c) For engine cinders ballast, use a shovel only, for out-of-face or spot tamping.

3. Methods of Tamping

In surfacing out of face, for a raise of 3 inches or more, track with 8-foot crossties should be tamped from 12 inches inside of the rail to the end of the tie, and track with 9-foot crossties should be tamped from 18 inches inside of the rail to the end of the tie. For a raise of less than 3 inches, the tamping distances inside the rail should be decreased to 10 inches and 16 inches, respectively. Ties should also be tamped on the outside of the ends. Tamping should not be permitted at the center of the tie, between the above stated tamping limits, but this center area should be filled lightly with a ballast fork. Both ends of the ties should be tamped simultaneously and tamping inside and outside of the rail should be done at the same time. Thorough tamping of ballast under the rail seat should be required.

Regardless of the kind of ballast or the kind of power tamper used, two tamping bars should always be worked opposite each other on the same tie. It is recommended that power tampers be started from a nearly vertical position and used directly against the sides of the tie to be tamped, and work downward past the bottom corner, after which the tools may be tipped down to force the ballast directly under the tie.

The track should be raised on jacks to true surface and the ties tamped to a tight bearing against the raised rail, but without disturbing the surface.

For spot tamping, tamping picks, tamping bars or power tampers should be used. The track should be promptly filled in and finished in accordance with the standard section.

This change is offered for the purpose of setting up recommended practices that conform with modern methods.

On Page Containing Table of Contents

Below the two items under "See Portfolio of Trackwork Plans for the following" insert "Data for Gages and Flangeways in Curved Track."

Report on Assignment 2

Fastenings for Continuous Welded Rail

Collaborating With Committee 4—Rail

G. M. Magee (chairman, subcommittee), Lem Adams, L. L. Adams, C. W. Baldridge, A. L. Bartlett, W. H. B. Bevan, F. J. Bishop, O. U. Cook, E. D. Cowlin, J. A. Ellis, H. F. Fifield, F. S. Hales, H. H. Harman, N. M. Hench, E. T. Howson, J. de N. Macomb, E. E. Martin, W. A. Murray, J. B. Myers, J. A. Reed, G. J. Slibeck, C. R. Strattman, R. P. Winton.

The subcommittee has collaborated with a subcommittee of Committee 4—Rail, in preparing a questionnaire to secure information on various installations of welded rail and reports of failures occurring in the welds. This information may be found in the report on Assignment 6 of the Rail committee and has much of interest bearing on this assignment.

In previous reports, the subcommittee presented descriptions of installations of continuous welded rail on the Delaware & Hudson, the Bessemer & Lake Erie, and the Central of Georgia, together with reports of the service performance of these installations. The officers of these railways have furnished supplemental service reports this year to bring this information up to date. In addition, a description is given this year of a test installation of continuous welded rail on the Great Northern Railway in which the type of rail fastening used is different from those used in the three installations mentioned above. The reports follow:

Delaware & Hudson Installations

(M & L Rail Clips and Screw Spike Tie Plate Fastenings)

We have experienced no difficulty with this track further than that outlined in Volume 40, page 558 of the Proceedings, with the exception that in July, 1940, the welded rail installed at Windsor, N. Y., kicked out of line adjacent to where it connects with joint bar track.

Early this spring we experienced some creepage of the joint bar track in a direction toward the welded rail, and it is believed that the difficulty experienced with the welded rail kicking out of line was due to this joint bar track bunching against the end of the welded rail.

Bessemer & Lake Erie Installation—River Valley, Pa.

(GEO Rail Clips and Tie-Plate Construction)

Our last report was dated September 19, 1938, and since that time we have had no trouble whatever with the mile of welded track, except for one broken joint—no difficulty, whatever, as to buckling, excessive movement, failure or slippage through any of the fastenings. We have continued current records of track movements which show nothing of interest.

On January 3, 1940, our section foreman discovered a broken rail, joint No. 174, east side of track, in the low rail of a 5-deg. 43-min. curve. The temperature when the break was discovered was 8 deg. F., and the rail at the break had opened up ½ in. Without any difficulty, a section of rail 38 in. long was cut out, and a new section put in and fastened with angle bars. It was not until June that the Metal & Thermit Corporation was in a position to replace the short section put in in January. At that time we inserted a new piece of rail, 39 ft. long, and two welds were made, this being done between trains. The parent metal in the rail, adjacent to the break, was across the top and either side of a weld, and it is our opinion that this metal had been damaged in the preheating process at the time the original weld was made. Both the Metal & Thermit Corporation and we are of the opinion that methods have been developed to control the preheating operation, which should minimize, or prevent, the danger of damaging the parent metal in the preheating process.

We estimate the total tonnage, including weight of equipment, over the welded rail since it was installed in November, 1935, at 65,000,000 tons, up to August 1, 1940.

Practically no maintenance work, other than inspection and the replacing of the one broken rail, mentioned above, has been necessary since our last report. The track remains in first class line and surface and is giving very satisfactory performance.

Central of Georgia Railway Installation—Lovejoy, Ga.

(Cut Spike Rail Fastening, Cut Spike Tie-Plate Fastening, Rail Anchors)

A complete report on this installation was given in Vol. 40, page 549, including measurements of temperature stresses and rail movements due to temperature and traffic. The subcommittee suggested that it would afford valuable information to increase the number of rail anchors and repeat these measurements.

Mr. R. R. Cummins, general manager, Central of Georgia, advises that 12 rail anchors per panel have been applied to this track, and the measurements resumed on July 30, 1940. Data will be furnished the subcommittee after the rail has gone through a year's cycle of high and low temperatures.

No difficulties in maintenance of the installation were reported.

Great Northern Railway

(M & L Rail Clips, Cut Spike Tie-Plate Fastening)

In August 1937 we laid a total of 5,667.8 track feet of 110-lb. rail with welded joints and M & L fastenings just east of our station at Rexford, Mont. The east 759.4 ft. of this rail is on tangent, then there is a 3-deg. curve for 531 ft., and then tangent for 4,377.4 ft.

Before any work was done in connection with the rail the track was given a lift with washed gravel ballast from our washing plant at Warland. The instruc-

View of the Welded Rail on the Great Northern at Rexford

tions called for at least 12 in. of ballast below the bottoms of the ties and provided for 19 ft. between ballast lines and a 12-½ ft. width of ballast level with the tops of ties.

The rail was furnished by the Bethlehem Steel Company from its Lackawanna plant in 39-ft. lengths, undrilled, and controlled cooled, of Great Northern standard 110-lb. section. The rail was distributed on the north side of the track, the nearest rail being 4-½ ft. from the track and the distance between rails 2-½ ft. The ends were supported on two ties.

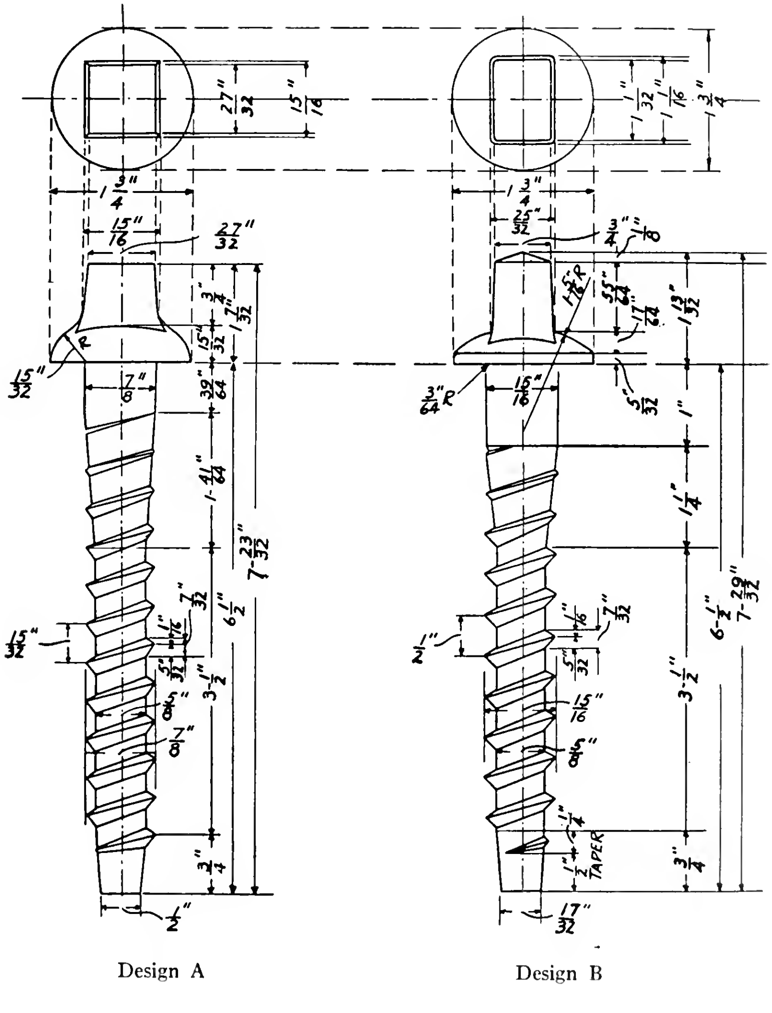
The weld was of the Thermit process, the work being done under the supervision of the Metal & Thermit Corporation. The welding was started on August 10 and completed on August 21.

New double-shoulder tie plates 8-½ x 12 in., according to the Great Northern standard plan, were used with M & L clips. The tie plates were fastened to the ties in the outside holes with cut spikes.

Screw Spikes for Holding Down Tie Plates, Independent of the Rail Fastenings

Your subcommittee was asked to submit a recommended design of screw spike which could be used for securing the tie plate to the tie independently of the rail fastening. Investigation showed that most railways using screw spikes for this purpose had purchased spikes according to Designs A or B in the accompanying drawing, except that some of the roads using Design A have lengthened the cylindrical portion of the shank under the head. The principal differences in the two designs are in the shape of the head, the diameter of the shank, depth of thread, length of the straight portion of the shank under the head, and the taper. These differences, in the opinion of the subcommittee, did not justify the adoption of a new design and it was thought one of these designs should be recommended.

Accordingly, a questionnaire was addressed to various manufacturers of screw spikes which, together with abstracts of the replies, is included in the accompanying tabulation.



Design A Design B

The shape of the head in design "B" insures longer life of the chucks used in applying the screw spikes and also affords a better grip during the life of the spike as the head is reduced by corrosion. Also, the greater depth of thread affords a considerable increase in the holding power of Design B compared to Design A. These advantages would seem to offset the objections expressed by certain of the manufacturers.

Questionnaire Sent to Screw Spike Manufacturers and Abstracted Replies

Question	Manufacturer			
	A	B	C	D
1. Is there any difference in the cost of manufacturing Designs A and B?	Square head on Design A costs less to manufacture	Square head on Design A costs less. Should have 9/16" point.	Design A costs less	Prefer design B. No difference in cost
2. Can you roll Design B from 15/16 in. stock to 5/8 in. diameter at the root of the threads?	Yes	Yes	Yes	Yes
3. Can the length between the underside of the head and the thread be varied to suit the purchaser and without extra cost?	Thinks one length should be made standard.	Length can be varied, but at extra cost.	Length can be varied to 1/2 in. minimum.	Yes
4. Is the base price for designs A and B the same?	No	Suggest Design A be made standard and Design B a special alternate.	Yes, but if design B is made standard a higher price for screw spikes will probably result.	Yes
5. To what railroads have you sold screw spikes for holding down tie plates within the past five years?	Chesapeake and Ohio; Erie	Pennsylvania; Delaware & Hudson; Erie; Chesapeake & Ohio.	Illinois Central; Duluth, Missabe, & Iron Range; Missouri Pacific; Pere Marquette; Chesapeake & Ohio; Southern Pacific; Milwaukee Road.	Bessemer and Lake Erie; Chesapeake & Ohio; New York Central

H

A hole of 11/16 in. diameter should be pre-bored in hardwood ties for insertion of the spike. In softwood ties, the hole should be of ⅝ in. diameter. Care should be taken to locate the hole in the center of the tie plate hole and also to avoid overdriving the screw spike and stripping the wood threads formed by the screw spike threads.

This report is submitted as information.

Report on Assignment 3

Plans and Specifications for Track Tools and Recommended Limits of Wear

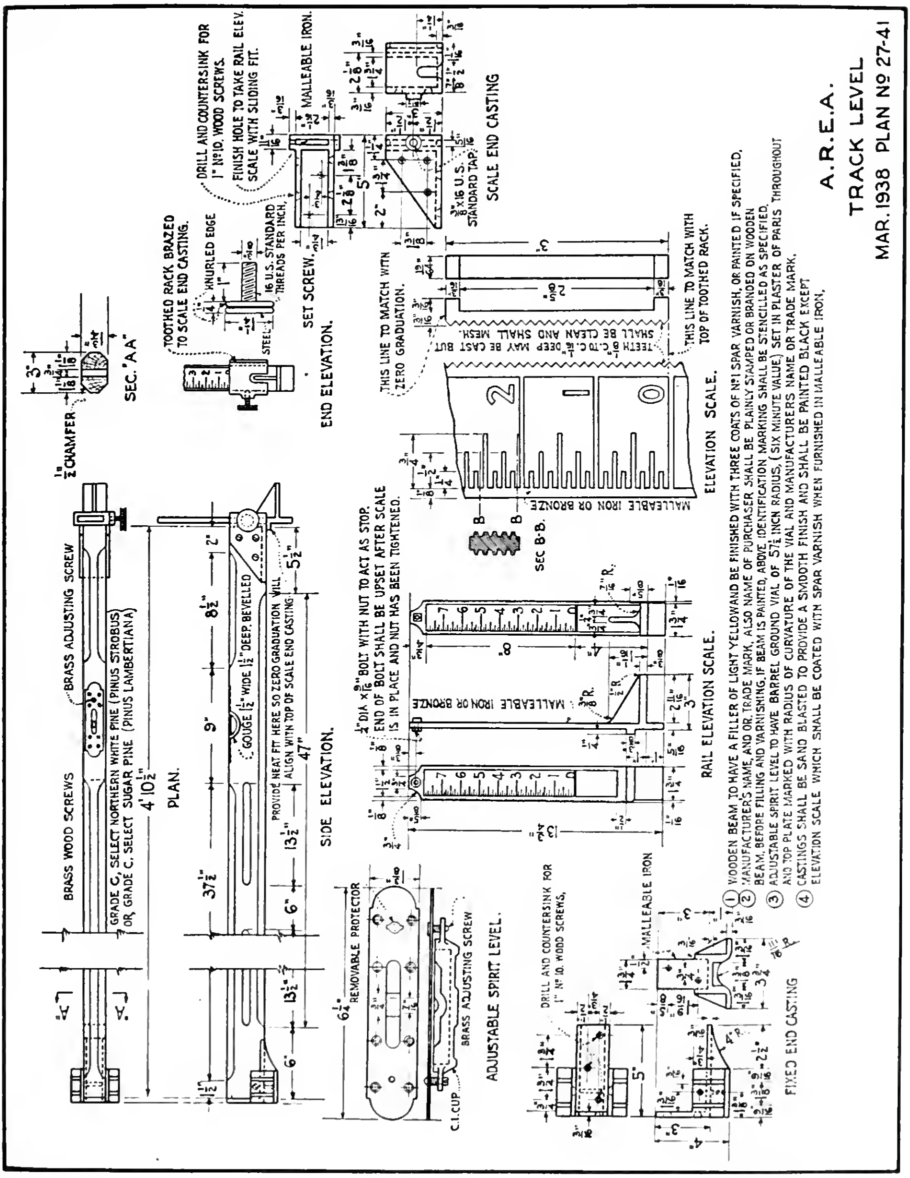
Collaborating with Committee 1—Roadway and Ballast and Committee 22—Economics of Railway Labor

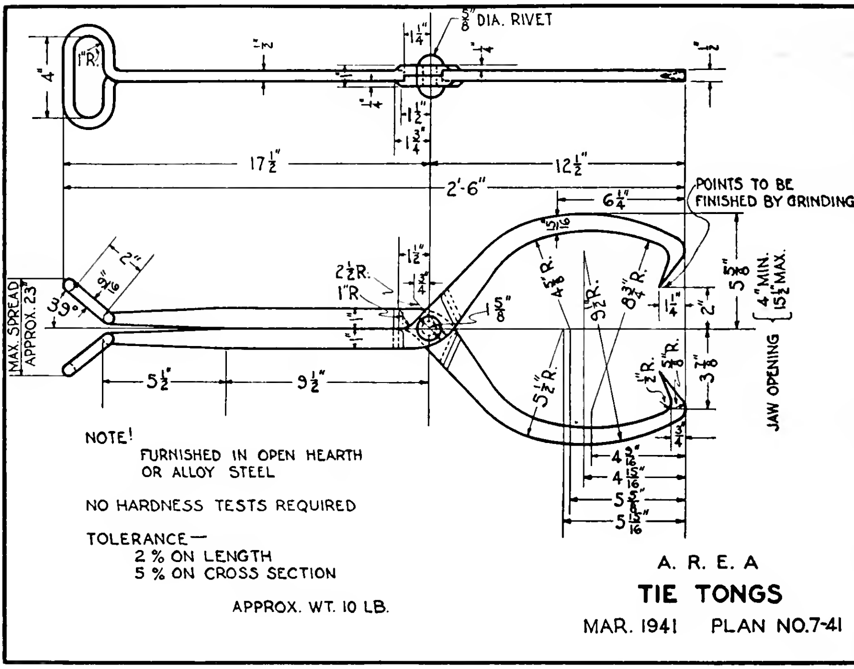
W. L. Roller (chairman, subcommittee), W. H. B. Bevan, E. W. Caruthers, L. W. Deslauriers, J. A. Ellis, J. W. Fulmer, F. S. Hales, E. T. Howson, F. J. Jerome, J. H. Kelly, E. E. Martin, J. B. Myers, C. J. Rist, I. H. Schram, J. F. Shaffer, G. M. Strachan.

The committee submits the following revisions to the Manual:

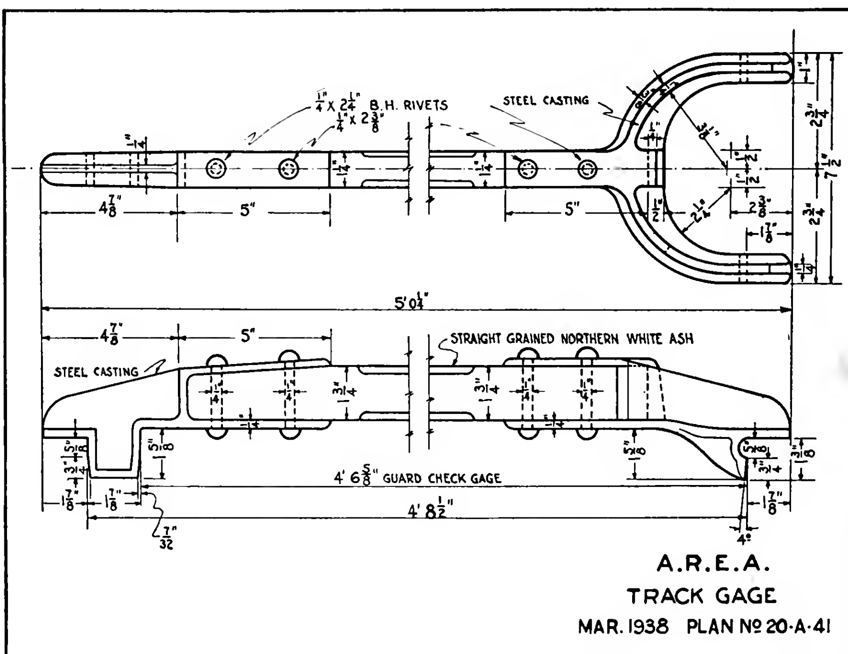
Plan No. 7—Tie Tongs, appears in the Manual, page 5–57, Fig. 519. These tongs were found to be too light in construction to render satisfactory service in the handling of cross and switch ties now in use, being too flexible and prone to become worn around the rivet. Plan No. 7–41 has been prepared, which is of sturdier design and reinforced around the rivet, and it is offered for adoption and publication in the Manual in place of Plan No. 7.

Plan No. 27–41—Track Level, has been revised to show some corrections on dimensions of the fixed end casting to agree with over all dimension. It is offered for publica-


A.R.E.A.
TRACK LEVEL
MAR. 1938 PLAN No 27-41
PLAN.
SIDE ELEVATION.
END ELEVATION.
SEC. "AA"
SET SCREW.
SCALE END CASTING
RAIL ELEVATION SCALE.
ELEVATION SCALE.
SEC B-B.
ADJUSTABLE SPIRIT LEVEL.
FIXED END CASTING
BRASS WOOD SCREWS
BRASS ADJUSTING SCREW
GRADE C, SELECT NORTHERN WHITE PINE (PINUS STROBUS) OR GRADE C, SELECT SUGAR PINE (PINUS LAMBERTIANA)
TOOTHED RACK BRAZED TO SCALE END CASTING.
KNURLED EDGE
16 U.S. STANDARD THREADS PER INCH.
DRILL AND COUNTERSINK FOR 1" No 10. WOOD SCREWS.
FINISH HOLE TO TAKE RAIL ELEV. SCALE WITH SLIDING FIT.
MALLEABLE IRON.
PROVIDE NEAT FIT HERE SO ZERO GRADUATION WILL ALIGN WITH TOP OF SCALE END CASTING.
THIS LINE TO MATCH WITH ZERO GRADUATION.
TEETH CAST BUT SHALL BE CLEAN AND SHALL MESH.
THIS LINE TO MATCH WITH TOP OF TOOTHED RACK.
MALLEABLE IRON OR BRONZE
END OF BOLT SHALL BE UPSET AFTER SCALE IS IN PLACE AND NUT HAS BEEN TIGHTENED.
REMOVABLE PROTECTOR
C.I. CUP
(1) WOODEN BEAM TO HAVE A FILLER OF LIGHT YELLOW AND BE FINISHED WITH THREE COATS OF No 1 SPAR VARNISH, OR PAINTED IF SPECIFIED.
(2) MANUFACTURER'S NAME, AND OR TRADE MARK, ALSO NAME OF PURCHASER SHALL BE PLAINLY STAMPED OR BRANDED ON WOODEN BEAM, BEFORE FILLING AND VARNISHING. IF BEAM IS PAINTED, ABOVE IDENTIFICATION MARKING SHALL BE STENCILLED AS SPECIFIED.
(3) ADJUSTABLE SPIRIT LEVEL TO HAVE BARREL GROUND VIAL OF INCH RADIUS, (SIX MINUTE VALUE) SET IN PLASTER OF PARIS THROUGHOUT AND TOP PLATE MARKED WITH RADIUS OF CURVATURE OF THE VIAL AND MANUFACTURERS NAME OR TRADE MARK.
(4) CASTINGS SHALL BE SAND BLASTED TO PROVIDE A SMOOTH FINISH AND SHALL BE PAINTED BLACK EXCEPT ELEVATION SCALE WHICH SHALL BE COATED WITH SPAR VARNISH WHEN FURNISHED IN MALLEABLE IRON.



5/8" DIA. RIVET
POINTS TO BE FINISHED BY GRINDING
MAX. SPREAD APPROX. 23"
JAW OPENING 4" MIN. 15 1/2" MAX.
NOTE!
FURNISHED IN OPEN HEARTH OR ALLOY STEEL
NO HARDNESS TESTS REQUIRED
TOLERANCE—
2 % ON LENGTH
5 % ON CROSS SECTION
APPROX. WT. 10 LB.
A. R. E. A
TIE TONGS
MAR. 1941 PLAN NO.7-41



1/4" x 2 1/4" B.H. RIVETS
1/4" x 2 3/8"
STEEL CASTING
STRAIGHT GRAINED NORTHERN WHITE ASH
STEEL CASTING
4' 6 5/8" GUARD CHECK GAGE
4' 8 1/2"
5' 0 1/4"
A.R.E.A.
TRACK GAGE
MAR. 1938 PLAN № 20-A-41

tion in the Manual in place of Plan No. 27–40, now appearing in the Manual on page 5–68.

Last year the committee submitted as information, Plan No. 20A–40—Wood Connected Track Gage, as shown on page 562 of Volume 41, Proceedings for 1940. This plan has been revised to provide better clearance over guard rail and as to type of wood in the beam. It is now submitted as revised for adoption and publication in the Manual as Plan No. 20A–41.

Recommended Limits of Wear of Track Tools

Last March the committee was given the added assignment of Recommended Limits of Wear of Track Tools (for Reclamation purposes) and submits the following progress report—

It was assumed in pursuing the study of Limits of Wear for Track Tools, that a definite recommendation is desired for each particular tool which would indicate the minimum limit of reclaimed tools. Only tools which are otherwise sound and serviceable without flaw or physical defect should be considered for reclamation and the minimum recommended sizes of reclaimed tools are indicated in dashed lines on original plans.

The committee recommends the reclamation of the tools listed below (now included in the Manual) either by grinding or by forging as specified in each case and to the outline (minimum) indicated in dashed lines on plans. It is understood in making these recommendations that the tool is to be reshaped, using only the native or original metal and no new metal is to be applied by welding to restore the tool to desired contour. The original physical properties are to be unimpaired.

Tools showing checks, cracks or other physical defects, which might impair their usefulness or safety, are not to be repaired.

Tools recommended for reclamation may be repaired and reconditioned for re-use from time to time and until the minimum limit is reached. When worn beyond these limits, tools should be scrapped.

Tools to be reclaimed must be in such condition that after preparation for re-issue, their minimum size shall not be less than as outlined in dashed lines on plans Nos. 1, 2, 3, 5, 12, 12A, 13, 14, 15, 16, 17, 18, 19, and 21, as included as a part of this report.

Plan No. 1.—Clay Pick. To be reclaimed by forging and/or grinding. Tool should be kept in good balance by keeping ends approximately equal in length and weight. Original contour should be maintained at or near the eye.

Plan No. 2.—Tamping Pick. To be reclaimed by forging and/or grinding. Tool should be kept in good balance by keeping ends approximately equal in length and weight. Original contour should be maintained at or near the eye.

Plan No. 3.—Spike Maul, Design No. 1. If made of open hearth steel, reclaim by forging; if alloy, by grinding.

Plan No. 3.—Spike Maul, Design No. 2. If made of open hearth steel, reclaim by forging; if alloy, by grinding.

Plan No. 5.—Lining Bar.

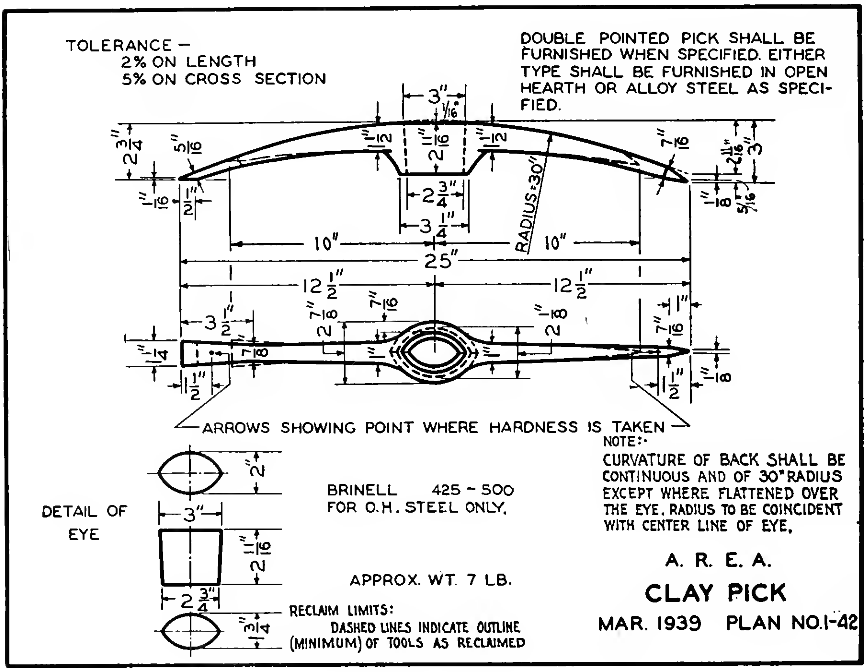
Plan No. 12.—Track Adze. As this is an alloy tool, it should be reclaimed by grinding only.

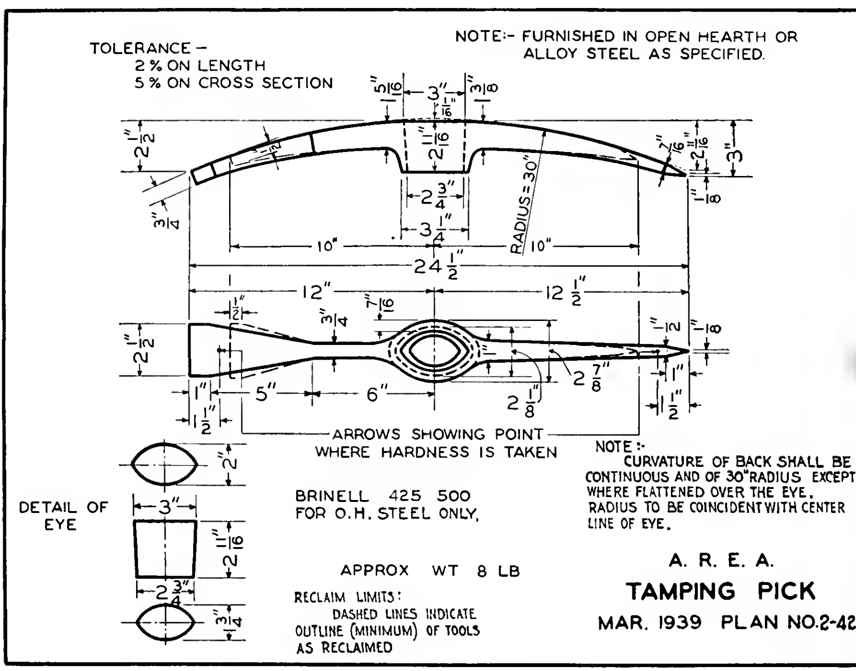
Plan No. 12A.—Carpenter Adze. As this is an alloy tool, it should be reclaimed by grinding only.

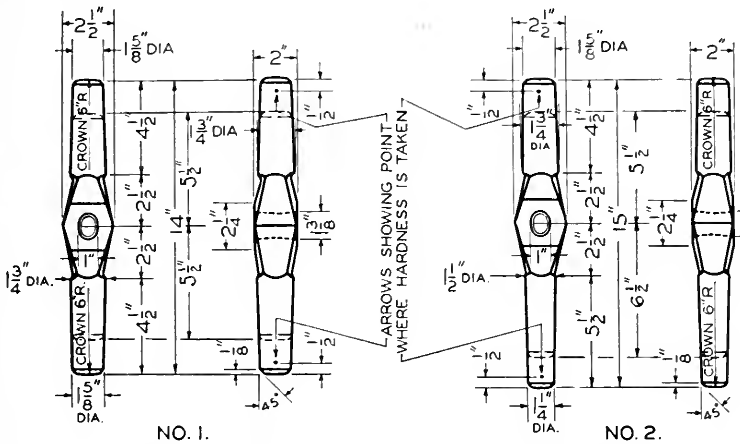
Plan No. 13.—Double Face Sledge.

Plan No. 14.—Tamping Bar, Chisel End. Reclaim by forging to limits shown.

Plan No. 15.—Tamping Bar, Spear End. Reclaim by forging to limits shown.


TOLERANCE –
2% ON LENGTH
5% ON CROSS SECTION
DOUBLE POINTED PICK SHALL BE FURNISHED WHEN SPECIFIED. EITHER TYPE SHALL BE FURNISHED IN OPEN HEARTH OR ALLOY STEEL AS SPECIFIED.
RADIUS = 30"
ARROWS SHOWING POINT WHERE HARDNESS IS TAKEN
DETAIL OF EYE
BRINELL 425 – 500
FOR O.H. STEEL ONLY.
APPROX. WT. 7 LB.
RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED
NOTE:-
CURVATURE OF BACK SHALL BE CONTINUOUS AND OF 30" RADIUS EXCEPT WHERE FLATTENED OVER THE EYE. RADIUS TO BE COINCIDENT WITH CENTER LINE OF EYE.
A. R. E. A.
CLAY PICK
MAR. 1939 PLAN NO. 1-42


TOLERANCE –
2% ON LENGTH
5% ON CROSS SECTION
NOTE:- FURNISHED IN OPEN HEARTH OR ALLOY STEEL AS SPECIFIED.
RADIUS = 30"
ARROWS SHOWING POINT WHERE HARDNESS IS TAKEN
DETAIL OF EYE
BRINELL 425 500
FOR O.H. STEEL ONLY.
APPROX WT 8 LB
RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED
NOTE:-
CURVATURE OF BACK SHALL BE CONTINUOUS AND OF 30" RADIUS EXCEPT WHERE FLATTENED OVER THE EYE. RADIUS TO BE COINCIDENT WITH CENTER LINE OF EYE.
A. R. E. A.
TAMPING PICK
MAR. 1939 PLAN NO. 2-42



BRINELL 425-500

EYE TAPERED TO CENTER
4° ON LONG DIAMETER
3° ON SHORT DIAMETER.

TOLERANCE –
2% ON LENGTH
5% ON CROSS SECTION.

FURNISHED IN OPEN HEARTH OR ALLOY STEEL AS SPECIFIED.

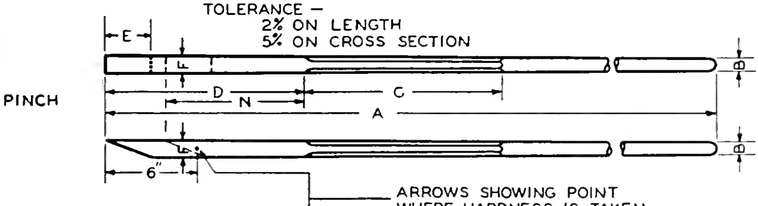
RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED.

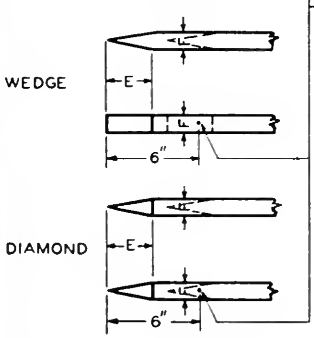
A. R. E. A.

SPIKE MAULS

MAR. 1936 PLAN NO. 3-42

TOLERANCE –
2% ON LENGTH
5% ON CROSS SECTION





SCHEDULE OF DIMENSIONS							
APPROX. WEIGHT	A	B	C	D	E	F	N
18 LB	5'-0"	¾"	14"	14"	3"	1¼"	10"
20 "	5'-3"	¾"	14"	14"	3"	1¼"	10"
26 "	5'-6"	⅞"	14"	14"	3"	1½"	10"

ORDER SHALL SPECIFY TYPE OF POINT AND LENGTH OF BAR

BRINELL 300 - 375

RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED.

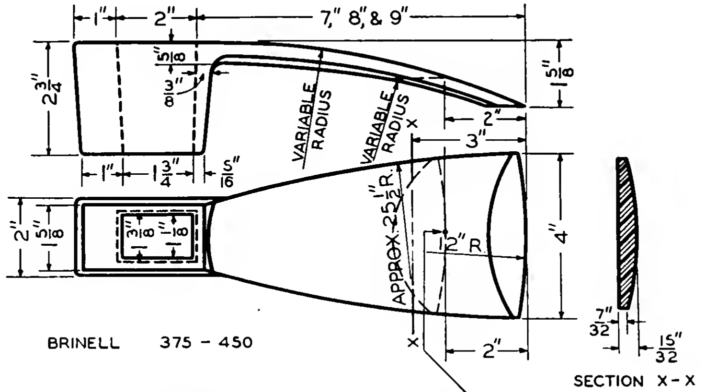
A. R. E. A.

LINING BAR

MAR. 1936 PLAN NO. 5.

TOLERANCE –
2% ON LENGTH
5% ON CROSS SECTION

FURNISHED IN OPEN HEARTH OR ALLOY STEEL AS SPECIFIED.



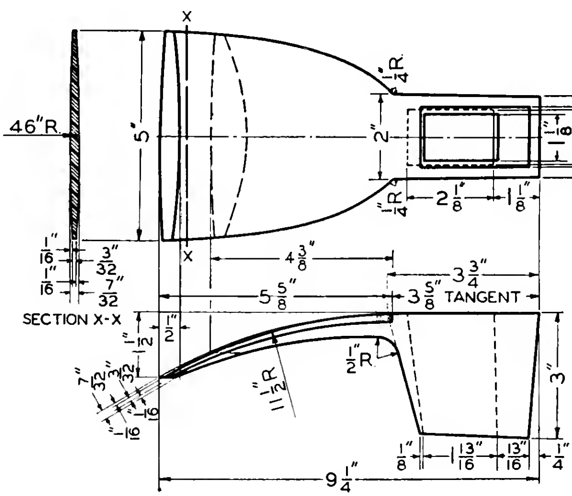
APPROX. WT.
- 7"-BIT 5 LB.
- 8"-BIT 5½ LB.
- 9"-BIT 6 LB.

RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED

A. R. E. A.

TRACK ADZE

MAR. 1936 PLAN NO. 12



RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED.

TOLERANCE –
2% ON LENGTH
5% ON CROSS SECTION

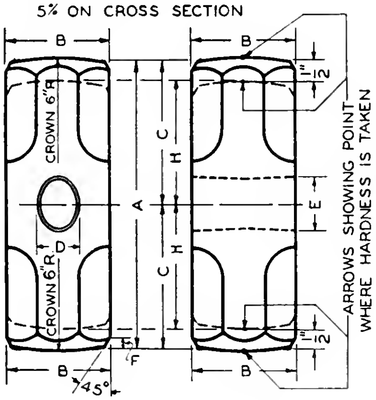
FURNISHED IN OPEN HEARTH OR ALLOY STEEL AS SPECIFIED

A. R. E. A.

CARPENTERS ADZE

MAR. 1935 PLAN NO. 12-A-42

TOLERANCE —
2% ON LENGTH
5% ON CROSS SECTION



BRINELL 425 – 500

FURNISHED IN OPEN HEARTH OR ALLOY STEEL AS SPECIFIED

SCHEDULE OF DIMENSIONS IN INCHES							
APPROX. WEIGHT	A	B	C	D	E	F	H
6 LB.	6	$2\frac{1}{8}$	3	1	$1\frac{3}{8}$	$\frac{3}{16}$	$2\frac{3}{4}$
8 LB.	$6\frac{1}{2}$	$2\frac{1}{4}$	$3\frac{1}{4}$	1	$1\frac{3}{8}$	$\frac{3}{16}$	$2\frac{3}{4}$
10 LB	7	$2\frac{1}{2}$	$3\frac{1}{2}$	1	$1\frac{3}{8}$	$\frac{1}{4}$	3
12 LB	$7\frac{1}{2}$	$2\frac{5}{8}$	$3\frac{3}{4}$	1	$1\frac{3}{8}$	$\frac{1}{4}$	$3\frac{1}{4}$
14 LB.	8	$2\frac{3}{4}$	4	1	$1\frac{3}{8}$	$\frac{1}{4}$	$3\frac{1}{2}$
16 LB	$8\frac{1}{4}$	$2\frac{7}{8}$	$4\frac{1}{8}$	1	$1\frac{3}{8}$	$\frac{1}{4}$	$3\frac{5}{8}$

RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOL AS RECLAIMED.

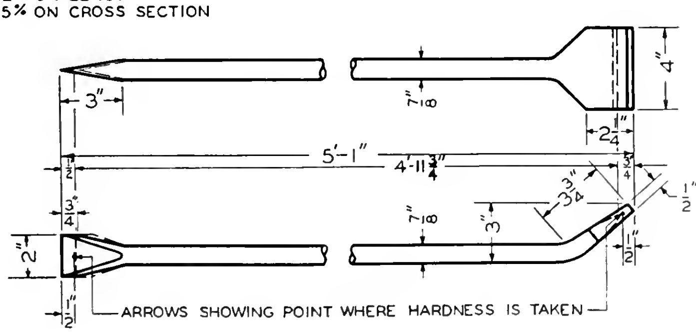
EYE TAPERED TO CENTER
4° ON LONG DIAMETER
3° ON SHORT DIAMETER

A. R. E. A.

DOUBLE FACED SLEDGE

MAR. 1936 PLAN NO. 13-42

TOLERANCE —
2% ON LENGTH
5% ON CROSS SECTION



BRINELL 425 – 500

APPROX WT 13 LB

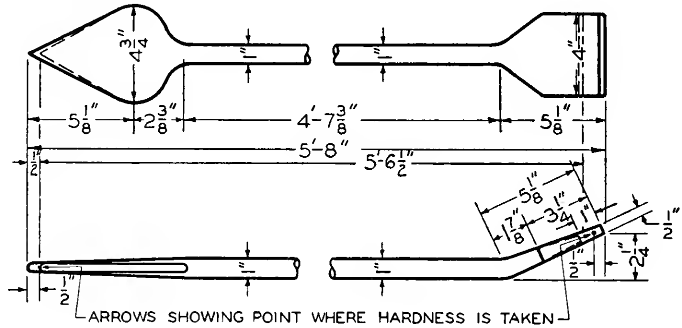
RECLAIM LIMITS
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED

A R E A

CHISEL END TAMPING BAR

MAR. 1936 PLAN NO 14-42

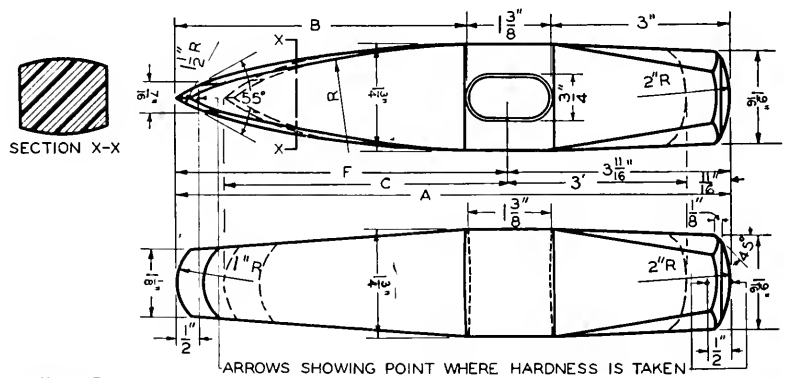
TOLERANCE—
2% ON LENGTH
5% ON CROSS SECTION



BRINELL 425 - 500
APPROX WT 15 LB

RECLAIM LIMITS
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED

A R E A
SPEAR END TAMPING BAR
MAR 1936 PLAN NO 15-42



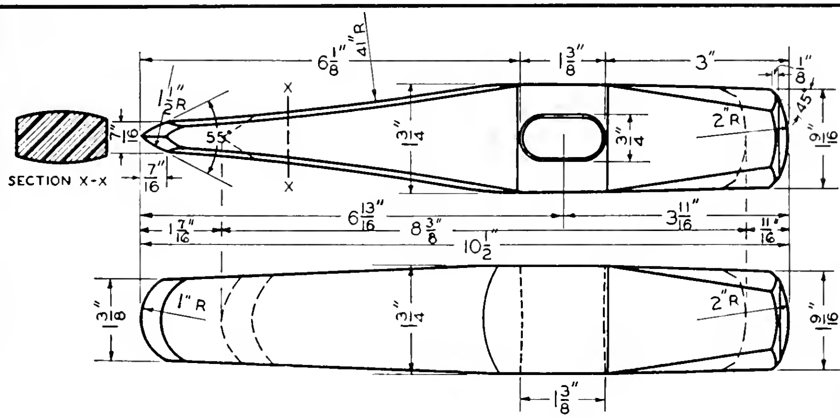
TOLERANCE—
2% ON LENGTH, 5% ON CROSS SECTION.
EYE TAPERED TO CENTER
4° ON LONG DIAMETER
3° ON SHORT DIAMETER.
FURNISHED IN OPEN HEARTH, OR ALLOY STEEL AS SPECIFIED.

BRINELL {POINT 477-532, HEAD 286-340} FOR O. H. STEEL ONLY

APPROX. WT.	A	B	F	R	C
$5\frac{1}{4}$ LBS.	$9\frac{1}{4}''$	$4\frac{7}{8}''$	$5\frac{9}{16}''$	$18\frac{7}{8}''$	$5''$
$6\frac{1}{4}$ LBS.	$10\frac{1}{2}''$	$6\frac{1}{8}''$	$6\frac{13}{16}''$	$33\frac{1}{4}''$	$5\frac{1}{8}''$

RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED

A. R. E. A.
TRACK CHISEL
DESIGN NO. 1.
MAR. 1939 PLAN NO 16-42

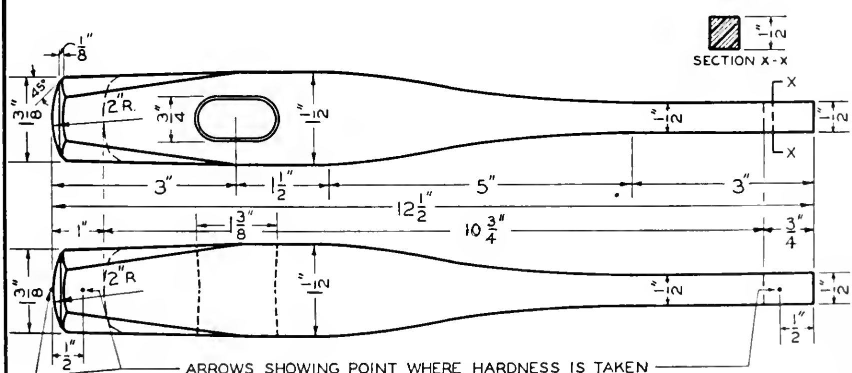


THIS DESIGN FURNISHED IN ALLOY STEEL ONLY
APPROX WEIGHT 5½ LB.

TOLERANCE —
2% ON LENGTH, 5% ON CROSS SECTION
EYE TAPERED TO CENTER
4° ON LONG DIAMETER
3° ON SHORT DIAMETER

RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED.

A. R. E. A.
TRACK CHISEL
DESIGN NO. 2.
MAR. 1939 PLAN NO. 17-42



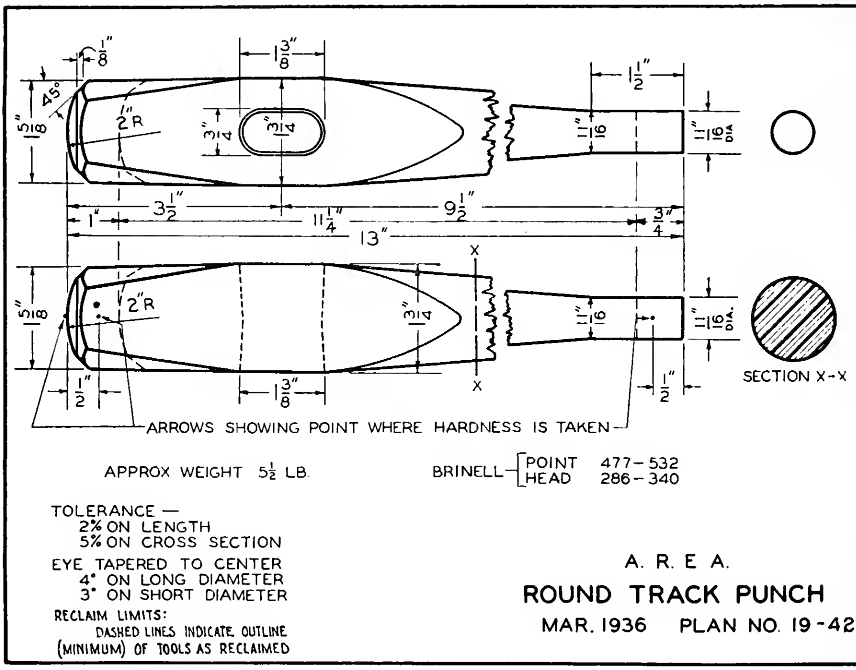
BRINELL — POINT — 477-532
HEAD — 286-340

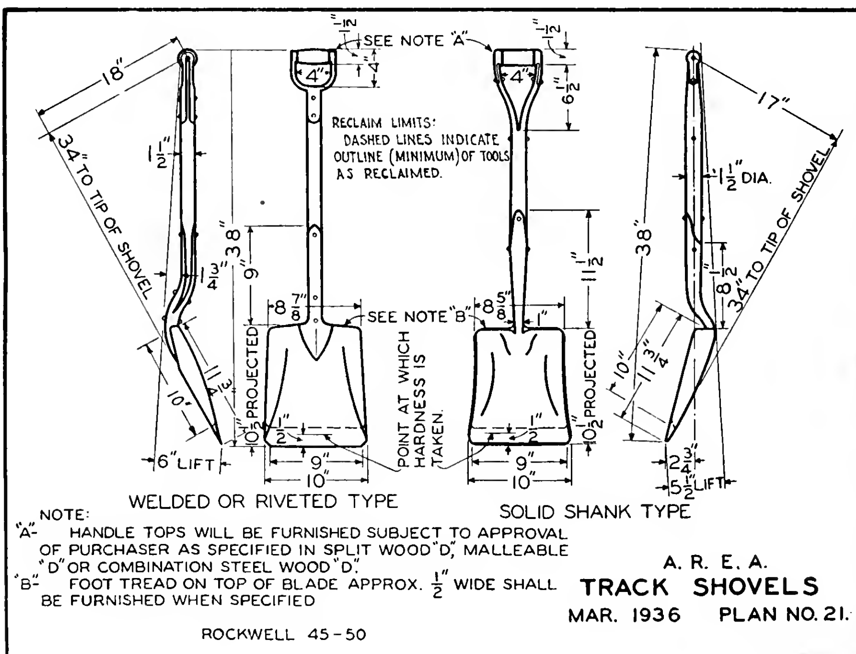
APPROX WEIGHT 4 LB

TOLERANCE —
2% ON LENGTH
5% ON CROSS SECTION
EYE TAPERED TO CENTER
4° ON LONG DIAMETER
3° ON SHORT DIAMETER

RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE (MINIMUM) OF TOOLS AS RECLAIMED.

A. R. E. A.
TIE PLUG PUNCH
MAR. 1936 PLAN NO. 18-42


ARROWS SHOWING POINT WHERE HARDNESS IS TAKEN
SECTION X-X
APPROX WEIGHT 5½ LB.
BRINELL POINT 477-532
HEAD 286-340
TOLERANCE —
2% ON LENGTH
5% ON CROSS SECTION
EYE TAPERED TO CENTER
4° ON LONG DIAMETER
3° ON SHORT DIAMETER
RECLAIM LIMITS:
DASHED LINES INDICATE OUTLINE
(MINIMUM) OF TOOLS AS RECLAIMED
A. R. E. A.
ROUND TRACK PUNCH
MAR. 1936 PLAN NO. 19-42


SEE NOTE "A"
RECLAIM LIMITS:
DASHED LINES INDICATE
OUTLINE (MINIMUM) OF TOOLS
AS RECLAIMED.
34" TO TIP OF SHOVEL
SEE NOTE "B"
POINT AT WHICH
HARDNESS IS
TAKEN.
6" LIFT
5½" LIFT
1½" DIA.
WELDED OR RIVETED TYPE
SOLID SHANK TYPE
NOTE:
"A"- HANDLE TOPS WILL BE FURNISHED SUBJECT TO APPROVAL
OF PURCHASER AS SPECIFIED IN SPLIT WOOD "D", MALLEABLE
"D" OR COMBINATION STEEL WOOD "D".
"B"- FOOT TREAD ON TOP OF BLADE APPROX. ½" WIDE SHALL
BE FURNISHED WHEN SPECIFIED
ROCKWELL 45-50
A. R. E. A.
TRACK SHOVELS
MAR. 1936 PLAN NO. 21.

Plan No. 16.—Track Chisel, Design No. 1. Reclaim by forging if open hearth and by grinding if alloy.

Plan No. 17.—Track Chisel, Design No. 2. By grinding only.

Plan No. 18.—Tie Plug Punch. Reclaim by forging.

Plan No. 19.—Round Punch. Reclaim by forging.

Plan No. 21.—Track Shovel. Length of blade 10 in., economical wear limit.

The report on Recommended Limits of Wear of Track Tools is a progress report. The committee recommends the subject be continued.

Report on Assignment 4 (a)

Plans for Switches, Frogs, Crossings, Spring and Slip Switches

Collaborating with Signal Section

E. W. Caruthers (chairman, subcommittee), L. L. Adams, W. H. Bettis, L. H. Bond, C. W. Breed, E. D. Cowlin, H. Q. Day, L. W. Deslauriers, J. A. Ellis, J. W. Fulmer, N. M. Hench, F. W. Hillman, A. F. Huber, W. G. Hulbert, C. T. Jackson, A. A. Johnson, L. I. Martin, F. H. Masters, K. R. McLennan, R. E. Miller, W. A. Murray, J. B. Myers, G. A. Peabody, S. H. Poore, J. A. Reed, O. C. Rehfuss, C. J. Rist, I. H. Schram, G. L. Sitton, G. J. Slibeck, C. R. Strattman, H. N. West, R. P. Winton, J. G. Wishart, M. J. T. Zeeman.

As stated in the report of the committee appearing in Proceedings, Vol. 41, page 565, a review is being made of all of the trackwork plans and specifications which have been approved by the Association as recommended practice. Following the acceptance by the Association of the key plans presented with the above mentioned report, work has progressed on the remaining plans of the various series, in line with the details accepted in the approved key plans.

To place the information in the hands of the association at the earliest date possible, groups of plans embraced in this report were published in Bulletin 418, June-July, 1940, page 209, and Bulletin 419, September-October, 1940, page 139 and Part II.

To serve as a temporary index, the following list shows the status of all of the old plans as well as a complete list of the reissued plans. Plans adopted in 1940 are identified by suffix "–40", those now offered for adoption by the suffix "–41", and these which are to be reissued without revisions requiring convention approval are designated by a suffix indicating the year of adoption. There is also a list of plans to be withdrawn.

All details with which the use of signal material is involved have been developed in collaboration with the Signal Section of the AAR.

The Standardization committee of the Manganese Track Society has continued its valuable assistance in the preparation of these plans and specifications and also contributed all of the necessary drafting work.

Conclusions

The committee offers for adoption as recommended practice and publication in the Manual the plans with the suffix "–41" in the following list:

Plan No.	Title	Remarks
SWITCHES		
111–41	16′ 6″ Straight Split Switch with Uniform Risers.	Revision of Plan No. 111–40.
112–41	16′ 6″ Straight Split Switch with Graduated Risers.	Revision of Plan No. 112–40.
113–41	11′ 0″ Straight Split Switch with Uniform Risers.	Supersedes Plan No. 103, revised 1938.
114–41	11′ 0″ Straight Split Switch with Graduated Risers.	Supersedes Plan No. 104, revised 1938.
115–41	22′ 0″ Straight Split Switch with Uniform Risers.	Supersedes Plan No. 105, revised 1938.
116–41	22′ 0″ Straight Split Switch with Graduated Risers.	Supersedes Plan No. 106, revised 1938.
117–41	30′ 0″ Straight Split Switch with Uniform Risers.	Supersedes Plan No. 107, revised 1938.
118–41	30′ 0″ Straight Split Switch with Graduated Risers.	Supersedes Plan No. 108, revised 1938.
121–41	11′ 0″ Curved Split Switch with Uniform Risers.	Supersedes Plan No. 121, adopted 1939.
123–41	19′ 6″ Curved Split Switch with Uniform Risers.	Supersedes Plan No. 123, adopted 1938.
125–41	30′ 0″ Curved Split Switch with Uniform Risers.	Supersedes Plan No. 125, adopted 1938.
127–41	39′ 0″ Curved Split Switch with Uniform Risers.	Supersedes Plan No. 127, adopted 1937.
209–41	Numerical and Classified Index of Detail Numbers Covering Switch Fittings.	Supersedes Plan No. 209, adopted 1938.
213–41	11′ 0″ Split Switch Point Derail.	Supersedes Plan No. 213, revised 1934.
221–40	Details for Switch Points.	Supersedes in part Plans Nos. 101 and 108 inc., 201 and 204 revised 1934, Plan No. 215 adopted 1937, and Plan No. 140 adopted 1938.
222–41	Switch Rods and Clips.	Revision of Plan 222-40.
223–40	Switch Plates and Rigid Rail Braces.	Supersedes in part Plans Nos. 201, 202, 205, 206, 207.
224–40	Switch Plates and Adjustable Rail Braces.	Supersedes in part Plan No. 240, revised 1935 and Plan No. 215, adopted 1937.
241–41	Details and Typical Applications of Twin Tie Plates.	Replaces Plan No. 325, revised 1934, withdrawn 1940.
SWITCH STANDS		
251–41	Switch Stands and Appurtenances.	Supersedes Plans Nos. 251 to 254 incl., revised 1934.

The plans published during the year, which are now offered for adoption, appear in bulletins as follows:

Bulletin 418 June–July, 1940	*Bulletin 419 September–October, 1940*		*Bulletin 423 February, 1941*
111–41	121–41	704–41	209–41
112–41	123–41	705–41	213–41
113–41	125–41	706–41	251–41
114–41	127–41	708–41	320–41
115–41	222–41	710–41	322–41
116–41	600–41	755–41	323–41
117–41	611–41	757–41	324–41
118–41	612–41	761–41	401–41
241–41	613–41	910–41	405–41
	614–41	911–41	640–41
	615–41	912–41	670–41
	702–41	920–41	700–41
	703–41	921–41	768–41
			774–41
			775–41

Plan No.	*Title*	*Remarks*
255–34	Plan and Specifications for Switch Lock.	Reissue of Plan No. 255, revised 1934.
Bolted Rigid Frogs		
320–41	Data and Sections—Bolted Rigid Frogs.	Supersedes Plan 320, revised 1938.
322–41	No. 4, No. 5 and No. 6 Bolted Rigid Frogs.	Supersedes in part Plan No. 301–3 and Plan No. 309, revised 1934.
323–41	No. 7, No. 8 and No. 9 Bolted Rigid Frogs.	Supersedes in part Plan No. 301–3, revised 1934.
324–41	No. 10, No. 11 and No. 12 Bolted Rigid Frogs.	Supersedes Plan 304–6, revised 1934.
Spring Rail Frogs		
401–41	No. 10 Spring Rail Frog	Supersedes Plan No. 401 and Plan No. 404, revised 1934.
405–41	No. 10 Spring Rail Frog Short Spring Rail Type.	Supersedes Plan No. 405, adopted 1939.
Guard Rails		
502–40	Setting for Guard Rails; Tee-Rail Design.	Supersedes Plan No. 502, revised 1934.
503–40	Guard Rails; Tee-Rail Design with Planed Flares and Canted Plates.	Companion plan to Plan No. 504-40, but showing canted instead of flat plates.
504–40	Guard Rails; Tee-Rail Design with Planed Flares and Flat Plates.	Supersedes Plan No. 504, revised 1934.
505–40	Specifications for Guard-Rail Clamps.	Revision of Plan No. 505, adopted 1934.
510–40	Manganese Steel One-Piece Guard Rails.	Revision of Plan No. 510, as revised 1934.
590–40	Diagram Illustrating Preferred Names of Parts for Guard Rails.	Revision of Plan No. 590 as revised 1934.
Rail Bound and Solid Manganese Frogs		
600–41	Data and Sections for Rail Bound Manganese Steel Frogs.	Supersedes Plans Nos. 600, revised 1938, and 600-A, revised 1934.
600B–34	Standard Manganese Steel Frog Point and Flangeway Layout.	Reissue of Plan 600-B, adopted 1934.
611–41	No. 4 and No. 5 Rail Bound Manganese Steel Frogs.	Supersedes Plan No. 608, revised 1937.
612–41	No. 6, No. 7 and No. 8 Rail Bound Manganese Steel Frogs.	Supersedes Plan No. 601-3, revised 1937.
613–41	No. 9, No. 10, and No. 11 Rail Bound Manganese Steel Frogs.	Supersedes Plans Nos. 609, revised 1937, and 604–5, revised 1937.
614–41	No. 12, No. 14, and No. 15 Rail Bound Manganese Steel Frogs.	Supersedes Plans Nos. 609, revised 1937, and 610, revised 1937.
615–41	No. 16, No. 18, and No. 20 Rail Bound Manganese Steel Frogs.	Supersedes Plans Nos. 606–7, revised 1937, and 610, revised 1937.
640–41	Solid Manganese Steel Self Guarded Frogs.	Supersedes Plan No. 640, revised 1938.
670–41	Solid Manganese Steel Frogs.	Supersedes Plan 670, revised 1938.
700-41	Applications of AREA Crossing Designs and Recommended Practices.	Supersedes Plan No. 700, revised 1934.

Plan No.	Title	Remarks
Bolted Rail Crossings		
701–40	Bolted Rail Crossings, Angles 90° to 50° incl. Three-Rail Design.	Supersedes Plan No. 701, revised 1934.
702–41	Bolted Rail Crossings, Angles 90° to 50° incl. Two-Rail Design.	Supersedes Plan No. 702, revised 1934.
703–41	Bolted Rail Crossings, Angles Below 50° to 35° incl. Three Rail Design.	Supersedes Plan No. 703, revised 1934.
704–41	Bolted Rail Crossings, Angles Below 50° to 35° incl. Two-Rail Design.	Supersedes Plan No. 704, revised 1934.
705–41	Bolted Rail Crossings, Angles Below 35° to 25°. incl. Three-Rail Design.	Supersedes Plan No. 705, revised 1934.
706–41	Bolted Rail Crossings, Angles Below 35° to 25° incl. Two-Rail Design.	Supersedes Plan No. 706, revised 1934.
708–41	Bolted Rail Crossings, Angles Below 25° and Above 14° 15′.	Supersedes Plans Nos. 707 and 708, revised 1934.
710–41	Bolted Rail Crossings, Angles 14° 15′ to 8° 10′ incl.	Supersedes Plans Nos. 709 and 710, revised 1934.
Manganese Insert Crossings		
751–40	Design and Dimensions of Manganese Steel Inserts for Crossings, of Angles from 14° 15′ to 45° 0′.	Supersedes Plan No. 751, revised 1934.
755–41	Manganese Steel Insert Crossings, Angles 45° to 35°, incl.	Supersedes Plan No. 755, revised 1934.
757–41	Manganese Steel Insert Crossings, of Angles below 35° to 25°, incl.	Supersedes Plan No. 757, revised 1934.
761–41	Manganese Steel Insert Crossings, of Angles below 25° and above 14° 15′.	Supersedes Plan No. 761, revised 1935.
768–41	Manganese Steel Insert Crossings, Angles 14° 15′ to 8° 10′, incl.	Supersedes Plans Nos. 753, revised 1934, and 768, revised 1935.
Solid Manganese Crossings		
771–40	Solid Manganese Steel Crossings, Angles 90° to 60°, incl.	Supersedes Plan No. 771, revised 1934.
772–40	Solid Manganese Steel Crossings, Angles below 60° to 40°, incl.	Supersedes Plan No. 772, revised 1934.
773–40	Solid Manganese Steel Crossings, Angles 40° to 25°, incl.	Supersedes Plan No. 773, revised 1934.
774–41	Crossings with Solid Manganese Steel Frogs and Interior Rolled Closure Rails, Angles below 25° and above 14° 15′, Single-Rail Construction.	Supersedes Plan No. 774, revised 1939.
775–41	Crossings with Solid Manganese Steel Frogs and Interior Rolled Closure Rails, Angles 14° 15′ to 8° 10′, incl., Single-Rail Construction.	Supersedes Plan 775, revised 1939.

Plan No.	Title	Remarks
776–40	Solid Manganese Steel Crossings, Steam Railroad over Electric Railway, Angles 90° to 60°, incl.	Supersedes Plan No. 776, revised 1934.
777–40	Solid Manganese Steel Crossings, Steam Railroad over Electric Railway. Angles below 60° to 40°, incl.	Supersedes Plan No. 777, revised 1934.
780–40	Solid Manganese Steel Crossings for 7″ and 9″ Girder Rails, Angles 90° to 60°, incl., for Steam Railroad over Electric Railway and for Steam Railroad Tracks both ways.	Supersedes Plan No. 780, revised 1934.
781–40	Solid Manganese Steel Crossings for 7″ and 9″ Girder Rails, Angles below 60° to 40°, incl., for Steam Railroad over Electric Railway and for Steam Railroad Tracks both ways.	Supersedes Plan No. 781, revised 1934.
790–34	Data for Gages and Flangeways at Frogs and Crossings.	Reissue of Plan No. 790, revised 1934.
791–34	Data for Gages and Flangeways in Curved Track.	Reissue of Plan No. 791, revised 1934.
792–34	Data for Gages and Flangeways in Curved Track.	Reissue of Plan No. 792, revised 1934.
793–40	Data Sheet for AAR Standard Wheel Flanges, Treads and Gages.	Supersedes Plan No. 793, revised 1935.

Turnout and Crossover Data

910–41	Turnout and Crossover Data for Straight Split Switches.	Supersedes Plan No. 900, revised 1934.
911–41	Location of Joints for Turnouts with Straight Split Switches.	Supersedes in part Plans Nos. 901 to 908 incl., revised 1934.
912–41	Bills of Timber for Turnouts and Crossovers.	Supersedes in part Plans Nos. 901 to 908 incl., revised 1934.
920–41	Turnout and Crossover Data for Curved Split Switches.	Supersedes Plan No. 920, adopted 1938.
921–41	Location of Joints for Turnouts with Curved Split Switches.	Supersedes Plans Nos. 124-A, 124-B, 126-A, 126-B, adopted 1938, 128, revised 1938.

Track Construction for Paved Streets

980–34	Alinement Details for Turnouts, Tongue-Switch Construction	Reissue of Plan 980, revised 1934.
982–34	200-ft. Radius Tongue Switch and Mate, Solid Manganese Steel, for 7″ and 9″ Girder Rails.	Reissue of Plan No. 982, revised 1934.
983–35	Solid Manganese Steel Frogs for 7″ and 9″ Girder Rails.	Reissue of Plan No. 983, revised 1934.
984–35	Nos. 4 and 5 Frogs, Iron Bound Manganese Steel Center, for 7″ and 9″ Girder Rail.	Reissue of Plan No. 984, revised 1934.

Plan No.	Title	Remarks
985–35	Nos. 6 and 8 Frogs, Iron Bound Manganese Steel Center, for 7″ and 9″ Girder Rails.	Reissue of Plan No. 985, revised 1934.
986–35	No. 10 Frog, Iron Bound Manganese Steel Center, for 7″ and 9″ Girder Rails.	Reissue of Plan 986, revised 1934.
987–34	Straight Double Tongue Switches, For Engine Wheel Base not over 14′ 6″, Solid Manganese Steel, 7″ and 9″ Girder Rails.	Reissue of Plan No. 987, revised 1934.
988–34	Straight Double Tongue Switches, For Engine Wheel Base over 14′ 6″, but not Exceeding 19′ 0″, Solid Manganese Steel, 7″ and 9″ Girder Rails.	Reissue of Plan No. 988, revised 1934.

Data for Rail Sections, Etc.

1001–40*	Data for Tee-Rail Sections.	Revision of Plan No. 1001 as revised 1934.
1002–40*	Girder Rail Sections.	Revision of Plan No. 1002 as revised 1934.
1003–40*	Data Sheet for AREA Girder Grooved Rails, Girder Guard Rails and Plain Girder Rails.	Revision of Plan No. 1003 as revised 1934.
1004–40*	Data for Head-Free Rail Sections.	Revision of Plan No. 1004 as revised 1934.
1005–40	Beveling of Rail Ends for Special Trackwork.	Supersedes data in Appendix A, Section 36A, adopted 1938.

In view of the issuance of the plans listed above, the committee recommends withdrawal of the following plans from the Portfolio:

103 Revised 1938	11′ 0″ Split Switch with Uniform Risers.	Superseded by Plan No. 113-41.
104 Revised 1938	11′ 0″ Split Switch with Graduated Risers.	Superseded by Plan No. 114-41.
105 Revised 1938	22′ 0″ Split Switch with Uniform Risers.	Superseded by Plan No. 115–41.
106 Revised 1938	22′ 0″ Split Switch with Graduated Risers.	Superseded by Plan No. 116–41.
107 Revised 1938	30′ 0″ Split Switch with Uniform Risers.	Superseded by Plan No. 117–41.
108 Revised 1938	30′ 0″ Split Switch with Graduated Risers.	Superseded by Plan No. 118–41.
111–40	16′ 6″ Straight Split Switch with Uniform Risers.	Superseded by Plan No. 111–41.
112–40	16′ 6″ Straight Split Switch with Graduated Risers.	Superseded by Plan No. 112–41.
121 Adopted 1939	11′ 0″ Curved Split Switch with Uniform Risers.	Superseded by Plan No. 121–41.
123 Adopted 1938	19′ 6″ Curved Split Switch with Uniform Risers.	Superseded by Plan No. 123–41.
124A Adopted 1938	Location of Joints for No. 7 and No. 8 Turnouts with 19′ 6″ Curved Switches.	Superseded by Plan No. 921–41.

* These drawings are sheets of information rather than recommended practice.

Plan No.	*Title*	*Remarks*
124B Adopted 1938	Location of Joints for No. 9, No. 10 and No. 11 Turnouts with 19′ 6″ Curve Switches.	Superseded by Plan No. 921–41.
125 Adopted 1938	30′ 0″ Curved Split Switch with Uniform Risers.	Superseded by Plan No. 125–41.
126A Adopted 1938	Location of Joints for No. 12 and No. 14 Turnouts with 30′ 0″ Curved Switches.	Superseded by Plan No. 921–41.
126B Adopted 1938	Location of Joints for No. 15 and No. 16 Turnouts with 30′ 0″ Curved Switches.	Superseded by Plan No. 921–41.
127 Adopted 1937	39′ 0″ Curved Split Switch with Uniform Risers.	Superseded by Plan No. 127–41.
128 Revised 1938	Location of Joints for No. 18 and No. 20 Turnouts with 39′ 0″ Curved Switches.	Superseded by Plan No. 921–41.
140 Adopted 1938	Method of Beveling Heel End and Round Stock Rail Side of Split Switch Points.	Superseded by Plan No. 221–40.
201 Revised 1934	Split Switch Fixtures for Medium Weight Rails.	Superseded by Plans Nos. 221–40, 222–41, 223–40.
202 Revised 1934	Split Switch Fixtures for Medium Weight Rails.	Superseded by Plans Nos. 221–40, 222–41, 223–40.
203 Revised 1934	Split Switch Fixtures for Medium Weight Rails, Heel and Turnout Plates for 16′ 6″ and 11′ 0″ Split Switches.	Superseded by Plans Nos. 111–41, 113–41, 223–40.
204 Revised 1934	Split Switch Fixtures for Medium Weight Rails, Heel and Turnout Plates for 22′ 0″ and 30′ 0″ Split Switches.	Superseded by Plans Nos. 115–41, 117–41, 223–40.
205 Revised 1934	Split Switch Fixtures for Heavy Rails. (General)	Superseded by Plans Nos. 221–40, 222–41, 223–40.
206 Revised 1934	Split Switch Fixtures for Heavy Rails.	Superseded by Plans Nos. 222–41, 223–40.
207 Revised 1934	Split Switch Fixtures for Heavy Rails, Heel and Turnout Plates for 16′ 6″ and 11′ 0″ Split Switches.	Superseded by Plans Nos. 111–41, 113–41, 223–40.
208 Revised 1934	Split Switch Fixtures for Heavy Rails, Heel and Turnout Plates for 22′ 0″ and 30′ 0″ Split Switches.	Superseded by Plans Nos. 115–41, 117–41, 223–40.
209 Revised 1938	Numerical and Classified Index of Detail Numbers Covering Switch Fittings.	Superseded by Plan No. 209-41.
210 Revised 1934	Bills of Material for 11′ 0″ and 16′ 6″ Split Switches.	Superseded by Plans Nos. 111–41, 112–41, 113–41, 114–41.
211 Revised 1935	Bills of Material for 22′ 0″ and 30′ 0″ Split Switches.	Superseded by Plans Nos. 115–41, 116–41, 117–41, 118–41.
213 Revised 1934	Details for Split Switch Point Derail.	Superseded by Plan No. 213–41.
215 Adopted 1937	Split Switch Details for Heavy and Medium Weight Rails.	Superseded by Plans Nos. 221–40, 224–40.
222–40 Adopt'd 1940	Switch Rods and Clips.	Superseded by Plan No. 222–41.
240 Revised 1935	Specifications for Adjustable Rail Braces.	Superseded by Plan No. 224–40.
251 Revised 1934	Requisites, Including Connect-Rods for Switch Stands.	Superseded by Plan No. 251–41.

Plan No.	Title	Remarks
252 Revised 1934	Detail of Lamp Tips for Switch Stands.	Superseded by Plan No. 251–41.
253 Revised 1934	Detail of Switch Stand Target Shapes.	Superseded by Plan No. 251–41.
254 Revised 1934	Day Target Discs for Switch Lamps.	Superseded by Plan No. 251–41.
256 Revised 1934	No. 4 Frogs for Medium Weight Rails, Angle 14° 15′ 00″.	Withdrawn.
257 Revised 1934	No. 5 Frogs for Medium Weight Rails, Angle 11° 25′ 16″.	Withdrawn.
258 Revised 1938	No. 6 Frogs for Medium Weight Rails, Angle 9° 31′ 38″.	Withdrawn.
259 Revised 1938	No. 7 Frogs for Medium Weight Rails, Angle 8° 10′ 16″.	Withdrawn.
260 Revised 1938	No. 8 Frogs for Medium Weight Rails, Angle 7° 9′ 10″.	Withdrawn.
261 Revised 1938	No. 9 Frogs for Medium Weight Rails, Angle 6° 21′ 35″.	Withdrawn.
262 Revised 1938	No. 10 Frogs for Medium Weight Rails, Angle 5° 43′ 29″.	Withdrawn.
278 Revised 1938	No. 11 Frogs with Uniform Tie Spacing, For Heavy and Medium Weight Rails, Angle 5° 12′ 18″.	Withdrawn.
279 Revised 1938	No. 12 Frogs with Uniform Tie Spacing, for Heavy and Medium Weight Rails, Angle 4° 46′ 19″.	Withdrawn.
281 Revised 1938	No. 14 Frogs with Uniform Tie Spacing, for Heavy and Medium Weight Rails, Angle 4° 5′ 27″.	Withdrawn.
282 Revised 1938	No. 15 Frogs with Uniform Tie Spacing, for Heavy and Medium Weight Rails, Angle 3° 49′ 6″.	Withdrawn.
283 Revised 1938	No. 16 Frogs with Uniform Tie Spacing, for Heavy and Medium Weight Rails, Angle 3° 34′ 47″.	Withdrawn.
291 Revised 1938	No. 18 Frogs with Uniform Tie Spacing, for Heavy and Medium Weight Rails, Angle 3° 10′ 56″.	Withdrawn.
292 Revised 1938	No. 20 Frogs with Uniform Tie Spacing, for Heavy and Medium Weight Rails, Angle 2° 51′ 51″.	Withdrawn.
320 Revised 1938	Data and Sections, Bolted Rigid Frogs.	Superseded by Plan No. 320–41.
401 Revised 1934	No. 10 Spring Rail Frog.	Superseded by Plan No. 401–41.
404 Revised 1934	No. 10 Spring Rail Frog with Uniform Tie Spacing.	Superseded by Plan No. 401–41.
405 Adopted 1939	No. 10 Spring Rail Frog; Short Spring Rail Type.	Superseded by Plan No. 405–41.
600 Revised 1938	Data and Sections for Rail Bound Manganese Steel Frogs.	Superseded by Plan No. 600–41.
600A Revised 1934	Application of Wing Wheel Risers to Manganese Steel Frogs.	Superseded by various other plans.

Plan No.	*Title*	*Remarks*
601–3 Revised 1937	No. 6, No. 7 and No. 8 Rail Bound Manganese Steel Frogs, for Heavy and Medium Weight Rails.	Superseded by Plan No. 612–41.
604–5 Revised 1937	No. 10 and No. 11 Rail Bound Manganese Steel Frogs, for Heavy and Medium Weight Rails.	Superseded by Plan No. 613–41.
606–7 Revised 1937	No. 16 and No. 20 Rail Bound Manganese Steel Frogs, for Heavy and Medium Weight Rails.	Superseded by Plan No. 615–41.
608 Revised 1937	No. 4 and No. 5 Rail Bound Manganese Steel Frogs, for Heavy and Medium Weight Rails.	Superseded by Plan No. 611–41.
609 Revised 1937	No. 9, No. 12 and No. 14 Rail Bound Manganese Steel Frogs, for Heavy and Medium Weight Rails.	Superseded by Plans Nos. 613–41, 614–41.
610 Revised 1937	No. 15 and No. 18 Rail Bound Manganese Steel Frogs, for Heavy and Medium Weight Rails.	Superseded by Plans Nos. 614–41, 615–41.
640–40 Revised 1938	Data and Sections for Solid Manganese Steel Self Guarded Frogs.	Superseded by Plan No. 640–41.
670–40 Revised 1938	Data and Sections for Solid Manganese Steel Frogs.	Superseded by Plan No. 670–41.
700 Revised 1935	Crossing Designs and Recommended Practices.	Superseded by Plan No. 700–41.
700A Revised 1934	Data and Record Sheet for Ordering Crossings.	Superseded by Plan No. 700–41.
700A Example 1 Revised 1934	Data and Record Sheet for Ordering Crossings.	Superseded by Plan No. 700–41.
700A Example 2 Revised 1934	Data and Record Sheet for Ordering Crossings.	Superseded by Plan No. 700–41.
702 Revised 1934	Bolted Rail Crossings, Angles 90° to 50°, Incl., Two Rail Design.	Superseded by Plan No. 702–41.
703 Revised 1934	Bolted Rail Crossings, Angles below 50° to 35°, incl., Three rail Design.	Superseded by Plan No. 703–41.
704 Revised 1934	Bolted Rail Crossings, Angles Below 50° to 35°, incl., Two-Rail Design.	Superseded by Plan No. 704–41.
705 Revised 1934	Bolted Rail Crossings, Angles Below 35° to 25°, incl., Three-Rail Design.	Superseded by Plan No. 705–41.
706 Revised 1934	Bolted Rail Crossings, Angles Below 35° to 25°, incl., Two Rail Design.	Superseded by Plan No. 706–41.
707 Revised 1934	Bolted Rail Crossings, Angles Below 25° and Above 14° 15′, Single-Rail Design and Two-Rail Design, With Short Easer Rails.	Superseded by Plan No. 708–41.

Plan No.	*Title*	*Remarks*
708 Revised 1934	Bolted Rail Crossings, Angles Below 25° and Above 14° 15′, Single-Rail Design and Two-Rail Design.	Superseded by Plan No. 708–41.
709 Revised 1934	Bolted Rail Crossings, Angles 14° 15′ to 8°, incl., Single-Rail Design and Two-Rail Design with Short Easer Rails.	Superseded by Plan No. 710–41.
710 Revised 1934	Bolted Rail Crossings, Angles 14° 15′ to 8° 10′ incl., Single-Rail Design and Two-Rail Design.	Superseded by Plan No. 710–41.
716 Revised 1934	Bolted Rail Crossings, Steam Railroad over Electric Railway, Angles 90° to 50°, incl.	Withdrawn.
717 Revised 1934	Bolted Rail Crossings, Steam Railroad over Electric Railway, Angles Below 50° to 30°, incl.	Withdrawn.
753 Revised 1934	Manganese Steel Insert Crossings, Designs and Dimensions of Manganese Steel Inserts, for Angles 8° 10′ to 14° 15′, incl.	Superseded by Plan No. 768–41.
754 Revised 1934	Manganese Steel Insert Crossing, Angle Below 45° to 35°, incl.—Detail A, Three-Rail Design.	Withdrawn.
755 Revised 1934	Manganese Steel Insert Crossing, Angle Below 45° to 35°, incl.—Detail A, Two-Rail Design.	Superseded by Plan No. 755–41.
756 Revised 1934	Manganese Steel Insert Crossing, Angle Below 35° to 25°, incl.—Detail A, Three-Rail Design.	Withdrawn.
757 Revised 1934	Manganese Steel Insert Crossing, Angle Below 35° to 25°, incl.—Detail A, Two-Rail Design.	Superseded by Plan No. 757–41.
758 Revised 1934	Manganese Steel Insert Crossing, Angle Below 25° and Above 14° 15′—Detail A, Two-Rail Design, With Short Easer Rails.	Withdrawn.
759 Revised 1934	Manganese Steel Insert Crossing, Angle Below 25° and Above 14° 15′—Detail A, Two-Rail Design.	Withdrawn.
760 Revised 1935	Manganese Steel Insert Crossing, Angle Below 25° and Above 14° 15′—Detail A, Single-Rail Design, With Short Easer Rails.	Withdrawn.
761 Revised 1935	Manganese Steel Insert Crossing, Angle Below 25° and Above 14° 15′—Detail A, Single-Rail Design.	Superseded by Plan No. 761-41.
767 Revised 1935	Manganese Steel Insert Crossing, Angle 14° 15′ to 8° 10′, incl., Two-Rail Design.	Withdrawn.

Plan No.	*Title*	*Remarks*
768 Revised 1935	Manganese Steel Insert Crossing, Angle 14° 15′ to 8° 10′, incl., Single-Rail Design.	Superseded by Plan No. 768–41.
770 Revised 1934	Insulated Internal Joint for Crossings—Three-Rail Design, Angle 45° to 25°, incl.	Withdrawn.
774 Revised 1939	Crossing with Solid Manganese Steel Frogs and Interior Rolled Closure Rails. Angles below 25° 0′ and above 14° 15′. Single-Rail Construction.	Superseded by Plan No. 774–41.
775 Revised 1939	Crossing with Solid Manganese Steel Frogs and Interior Rolled Closure Rails. Angles 14° 15′ to 8° 10′, incl. Single-Rail construction.	Superseded by Plan No. 775–41.
900 Revised 1934	Tables of Turnout Leads and Other Turnout Data.	Superseded by Plan No. 910–41.
901 Revised 1934	Typical Layout, No. 6 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
902 Revised 1934	Typical Layout, No. 7 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
903 Revised 1934	Typical Layout, No. 8 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
904 Revised 1934	Typical Layout, No. 9 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
905 Revised 1934	Typical Layout, No. 10 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
906 Revised 1934	Typical Layout, No. 11 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
907 Revised 1934	Typical Layout, No. 16 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
908 Revised 1934	Typical Layout, No. 20 Turnout and Crossover.	Superseded by Plans Nos. 911–41, 912–41.
920 Adopted 1938	Turnout Data for Curved Switches.	Superseded by Plan No. 920–41.

Report on Assignment 5

Corrosion of Rail and Fastenings in Tunnels

Collaborating with Committee 4—Rail

A. E. Perlman (chairman, subcommittee), W. H. Bettis, O. U. Cook, L. W. Deslauriers, S. H. Poore, G. M. Strachan, Hermann von Schrenk.

The subcommittee has continued its study in the laboratory and the field to determine methods for the control of corrosion of rail and fastenings in tunnels. This year's study has been of various commercial alloys, zinc spray, galvanized products, and other resistant coatings.

The study leads to the following conclusions:

1. No practical, or economical corrosion resistant alloy has been found because the materials tested depend upon a protecting film of corrosion products for their resistance. This protecting film naturally cannot be maintained on the running surface of the rail.

The initial corrosion rates of all ferrous alloys, excepting the 18–8 stainless steel, are practically the same.

2. Zinc metal spray or galvanizing is the best means of protecting angle bars, bolts, spikes, etc., since zinc is not rapidly corroded by the tunnel gases.

3. Galvanic action of zinc, plated or sprayed on the sides of the rail head, is not sufficient to offer any noticeable protection to the running surface.

4. Neutralization of the corrosive elements in stack gases cannot be accomplished by practical means.

5. One means of increasing life of rail in tunnels would be to roll a special rail section with more metal in the head by increasing the height of the rail head. This would allow for more metal to be lost from the running surface before replacement is necessary. The remainder of the rail, and fastenings, could be sprayed with zinc or a similar coating to give protection.

6. The annual penetration of the running surface in the Moffat tunnel, where tests were conducted, is 0.08 of an inch per year.

7. The only solution to the problem of corrosion of the rail and fastenings in tunnels because of steam operation is to change to either electric or Diesel operation. With Diesel power, special control of the corrosion elements in the fuel oil is required.

This report is submitted as information with the recommendation that the subject be discontinued.

Report on Assignment 7

Practicability of Using Reflex Units for Switch Lamps and Targets

L. L. Adams (chairman, subcommittee), F. J. Bishop, J. F. Shaffer, I. H. Schram, G. L. Sitton, M. J. T. Zeeman.

Reports on this subject were made in 1933 and 1939. In 1933 only three railroads reporting had an appreciable number of units in service, while in 1939 this number had increased to thirteen. No questionnaire was sent out this year to determine if there had been any increase in this number, but information secured in an informal manner indicates that the use of reflex units for switch lamps and targets is being extended on roads that had them in use in 1939 and also the number of roads using them has increased. One road that reported 1,250 units in service in 1938 now reports 3,100. This road has also extended the use of reflex units to caution and resume speed signs for protecting slow orders at night.

There are certain states that have laws which might prohibit the use of reflex units for switch lamps. The following states have such laws:

Arkansas.—Statutes read: "Switch Lights: Any company, corporation or officer of court or any person or persons operating any line of railroad during the night time in this state shall be required to place and maintain sufficient lights during the night time on all its main line switches of the line of railroad so operated, and of the color green indicating main line and red to indicate side tracks. Act February 10, 1911.

Penalty: Any company, corporation or officer of court or any person or persons operating any railroad in this state, who shall violate any of the provisions of this act, shall be liable on conviction to a penalty of a fine of not less than twenty-five dollars nor more than one hundred dollars for each separate offense, which penalty shall be recovered in a civil action in the name of the state."

Colorado.—Any railroad, or railroad company, owning or operating within this state any line or branch of railroad connecting with any main line of railroad by means of a switch, shall provide such switch with a suitable light, such as is commonly used for such purpose, and shall keep the same lighted from sunset on each and every calendar day of the year, until sunrise of the following day.

Authority is vested in the Public Utilities Commission of the State of Colorado to permit or order substitution of reflex lenses for switch lights after a hearing on petition or on its own motion.

Indiana.—Requires maintenance of switch and derail lights.

Kansas.—It shall be the duty of any person, firm or corporation or receiver, owning or operating any railroad, in whole or in part, in the State of Kansas, to keep and maintain in good condition, switch lights on all main line switch stands, except where automatic block signals are used, where such automatic block signals are so located as to answer the purpose of switch lights, and to keep all lights controlling the movement of trains on the main line burning from sunset to sunrise: Provided, this act shall not apply to branch lines, where trains are not regularly operated at night, or in cases where the lights have been properly lighted, but have failed for causes beyond the control of the company and it has not had reasonable time to relight them.

Massachusetts.—Required to notify Public Service Commission of intention to install interlocking block or special signals.

Michigan.—From wording of act it is apparent that burning lights must be provided.

Missouri.—All common carriers, their officers, agents and employees, operating any railroad or part of railroad in this state, are hereby required on or before the 1st day of June 1915, to adopt, put in use and maintain lights between sunset and sunrise, on main line switches, and all lead switches in yards, where cars are switched in making up or breaking up of trains. Provided that this law shall not include branch lines where trains do not operate at night, or independent lines of less than 50 miles in length. Provided further, that the provisions of this section shall not apply to trailing point switches on double track.

Nebraska.—Every person, firm, corporation, lessee or receiver of any railroad engaged in the business of transportation in this state shall equip with proper lights all switch stands to each and every switch leading from all main tracks of any such road, on which trains generally are operated at night; except lines fully equipped with automatic block signals. The lights upon such switch stands shall be kept in good condition constantly, and shall be lighted and kept burning between the time of sundown and sunrise and at such other times, when by reason of excessively foggy weather the condition of such lights or signals would render it unsafe for the employees of such railroad company and for the general public.

South Dakota.—Switch lights required: Civil penalty. It shall be the duty of every railroad company operating any line of railway in this state to maintain good and sufficient switch lights on all switches connected with its main line, and to keep the same lighted from dark until daylight. Such lights shall be required only on such main line switches over which trains shall be operated between sunset and sunrise.

Other states do not have laws pertaining to switch lamps.

No additional information has developed that will change or modify the information as published in the Proceedings for 1939, Vol. 40, pages 566, 567.

This is a progress report, submitted as information.

Report on Assignment 9

Bolt Tension Necessary for Proper Supporting of Rail Joints

C. W. Breed (chairman, subcommittee), C. W. Baldridge, A. L. Bartlett, E. D. Cowlin, L. W. Deslauriers, H. F. Fifield, J. W. Fulmer, F. S. Hales, C. T. Jackson, J. de N. Macomb, G. M. Magee, E. E. Martin, W. A. Murray, S. H. Poore.

Your committee submits the following report of progress in the tension tests of bolts installed in the tracks of several railroads, as described in the Proceedings for 1939 and 1940, Vol. 40, page 565, and Vol. 41, page 574.

Chicago, Milwaukee, St. Paul & Pacific

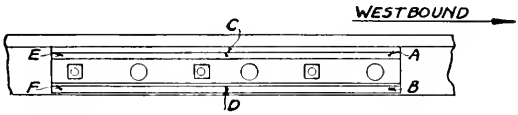
The test installation on the Milwaukee Railroad near Winona, Minn. was described in the committee report given in Vol. 40, page 570. This test section is approximately ¼ mile in length. The rail is 112-lb. RE section with 6-hole toeless joint bars and 1-in. track bolts without spring washers. The rail was laid new June 22, 1938. In the report last year, Vol. 41, page 582, information was given in Table 4 showing the loss in bolt tension between December 2, 1938 and June 30, 1939, a period of approximately 7 months. The bolts on the north rail were tightened to an average of 10,800 lb., and the

Table 1
BOLT TENSION MEASUREMENTS
C M St.P & P RR Test Installation

	NORTH RAIL			SOUTH RAIL		
	Average Bolt Tension Per Joint - Lbs.			Average Bolt Tension Per Joint - Lbs.		
Jt. No.	Applied 6-30-39	Remaining 6-12-40	Loss	Applied 6-29-39	Remaining 6-12-40	Loss
1	10,200	4,000	6,200	14,100	8,100	6,000
2	11,400	3,300	8,100	12,200	3,100	9,100
3	8,700	7,000	1,700	23,200	12,000	11,200
4	11,800	6,800	5,000	21,100	10,200	10,900
5	9,700	9,700	0	20,900	14,100	6,800
6	7,900	5,300	2,600	19,500	14,300	5,200
7	8,100	5,400	2,700	-	-	- *
8	10,300	7,900	2,400	17,500	11,200	6,300
9	9,500	6,400	3,100	18,900	11,600	7,300
10	9,300	6,800	2,500	16,600	11,600	5,000
11	10,300	7,700	2,600	16,800	9,100	7,700
12	7,700	4,300	3,400	13,400	9,800	3,600
13	12,100	7,900	4,200	14,800	6,700	8,100
14	8,300	4,500	3,800	15,600	11,100	4,500
15	11,500	8,000	3,500	13,600	6,700	6,900
16	8,500	3,300	5,200	13,800	6,400	7,400
17	9,900	7,400	2,500	17,000	11,000	6,000
18	10,500	4,400	6,100	14,900	8,800	6,100
19	10,800	3,700	7,100	18,100	10,600	7,500
20	11,500	5,800	5,700	18,600	8,900	9,700
21	11,400	4,100	7,300	17,400	6,700	10,700
22	10,800	7,400	3,400	14,200	6,700	7,500
23	9,800	7,000	2,800	15,700	5,400	10,300
24	10,800	5,800	5,000	14,300	9,100	5,200
25	8,900	5,700	3,200	16,300	9,800	6,500
26	13,200	7,600	5,600	13,600	8,400	5,200
27	13,200	10,100	3,100	14,500	5,100	9,400
28	9,500	4,900	4,600	15,700	5,000	10,700
29	10,500	4,800	5,700	16,700	7,400	9,300
30	8,500	6,800	1,700	19,200	8,300	10,900
31	10,100	7,400	2,700	16,900	11,100	5,800
32	10,200	7,100	3,100	15,300	11,000	4,300
33	10,700	8,400	2,300	19,100	10,200	8,900
34				16,000	8,600	7,400
Ave.	10,170	6,260	3,910	16,530	9,030	7,500
% Loss of Original Tension			38%			45%

*Crossing Plank

TABLE 2.



Average Change in Out-to-Out Distance of Joint Bars

C M St.P & P Test Installation

(From 12-2-38 to 6-12-40)

Location	NORTH RAIL Average Change Inches	SOUTH RAIL Average Change Inches
A	.018	.022
B	.022	.024
C	.013	.021
D	.015	.015
E	.008	.014
F	.012	.008
Average	.015	.017

Note: The average change is a decrease in out-to-out distance at the locations shown.

bolt tension had decreased to 6,400 lb. in the 7 months time. The bolts on the south rail were tightened to 17,200 lb. and decreased to 9,600 lb. in the same period.

In Table 1 similar information is given for the period June 30, 1939 to June 12, 1940, slightly less than one year. On June 30, 1939, the bolts on the north rail were tightened to an average of 10,200 lb. tension and at the end of one year, under regular traffic, the bolt tension had decreased to an average of 6,300 lb. The bolts on the south rail were tightened to an average of 16,500 lb. bolt tension and this tension decreased to 9,000 lb. in the same period.

The loss in bolt tension on both the north and south rail was about the same in the 12-months period as in the preceding period. The south rail with higher initial bolt tension, lost considerably more bolt tension during the test period than did the north rail with the lower bolt tension. However, even with this loss, at the end of the test period the remaining bolt tension on the south rail was some 50 percent higher than on the north rail.

Wear of Joint Bars and Rail Fishing Surface

Out-to-out measurements of joint bars were made by means of a joint caliper (See Vol. 40, page 570). Measurements were made on the top and bottom ribs of the bar near each end and at its middle. The location of these measurements is shown in the drawing. The out-to-out measurements were made December 2, 1938, on all joint bars included in the bolt tension tests. These measurements were repeated on June 12, 1940, and in Table 2 is given the average change in the out-to-out distance during this period. In this table the change in out-to-out distance is averaged for each location on the joint bar separately, and also for the north and south rail separately. The average change given is the average distance in inches by which the out-to-out measurements of the joint bars have decreased during the test period. It will be noted that the amount of this change in out-to-out distance is approximately the same on both the north and south rail. This indicates that in this test period of 19 months little difference in the amount of joint bar and rail fishing wear resulted from the difference in bolt tension. The measurements show more wear at the receiving end of the joint than at the leaving end.

Chicago, Burlington & Quincy

The bolt test installation on the Burlington near Western Springs, Ill., was described in the report of two years ago (Vol. 40, page 568). The test includes approximately 40 joints on the north rail and 40 joints on the south rail on the eastbound main track between Western Springs and Highlands. The rail in the test is 131-lb. rail with 6-hole toeless joint bars of both head free and head contact types, 1-in. heat-treated track bolts, and "Triflex" or "double-coil improved Hi Power" washers. The rail on this test was laid new in August, 1938 and the bolt tension obtained in the tightening was measured and described in the 1939 report. Since many of the bolts had been tightened beyond their elastic limit, and the bolt tension measurements depended upon the elastic elongation of the bolts, the bolts were loosened on October 5, 1938 and the permanent set was measured. The bolts on the south rail were then retightened to a bolt tension of approximately 15,000 lb. and those on the north rail to a bolt tension between 20,000 and 25,000 lb.

Loss of Bolt Tension Under Traffic

After the October 5, 1939, tightening of the bolts, the bolt tension was accurately measured and the bolts were left undisturbed. Measurements of bolt tensions were repeated on November 1, 1938; November 30, 1938; April 25, 1939; August 4, 1939, and April 24, 1940. On this last date it was thought that the bolt tension had decreased to where the bolts should be retightened. Before tightening, however, it was desired to check the "no load" lengths of the bolts. To do this without disturbing the fishing surface contacts of the joints, only three bolts of each joint were loosened at one time for "no load" readings. The bolts were then retightened, aiming for an average of 15,000-lb. bolt tension on the south rail and 25,000 lb. on the north rail. Bolt tension readings were taken immediately following the tightening and another series of readings was taken on October 16, 1940.

There are four different test sections on both north and south rails of approximately 10 joints each, in the following order from west to east:

Head free bars with "Hi Power" washers
Head free bars with "Triflex" washers
Head contact bars with "Hi Power" washers
Head contact bars with "Triflex" washers

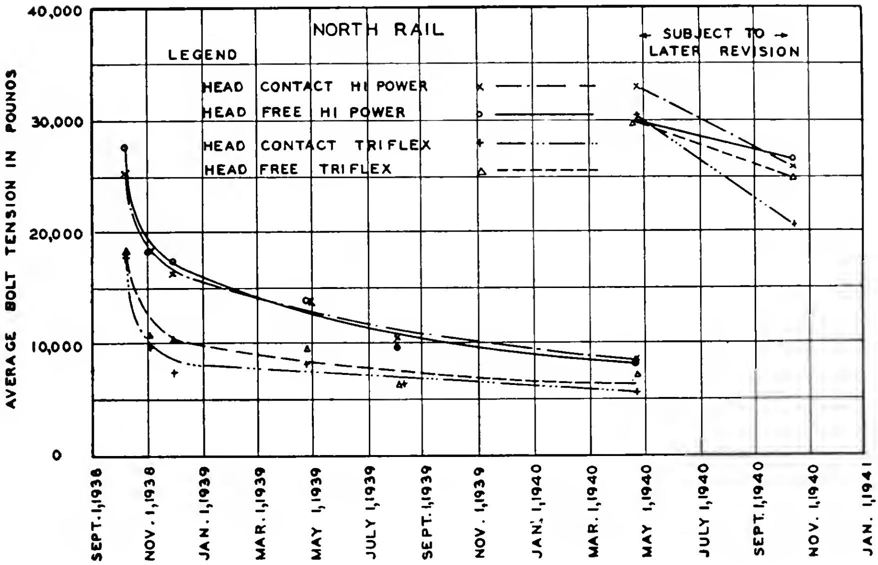
In Fig. 1 the average bolt tensions at the various dates of measurements are given for each separate test section on the north rail. The estimated trend of the bolt tension loss as indicated by these averages is also shown. It will be noted that the decrease in bolt tension was relatively rapid following the October 5, 1938, tightening for a period of about two months. The rate at which the bolt tension had decreased since then has been much less rapid. Corresponding data for the bolts on the south rail are shown in Fig. 2, and it will be noted that on this rail, also, the loss in bolt tension for the first two months after tightening was relatively much greater than it was subsequently.

FIG. I

LOSS OF BOLT TENSION UNDER TRAFFIC

ORIGINAL TIGHTENING OCT. 5,1938 RETIGHTENED APRIL 25, 1940

APPROXIMATE TRAFFIC DENSITY 15,000,000 G. T. PER YEAR



Generally the rate of bolt tension loss was greater with the "Hi Power" washers than with the "Triflex" springs. The rate of bolt tension loss was not greatly different for the head contact and head free types of bars. The bolt tension values shown in these two figures are somewhat different from those given in the committee report last year (Vol. 41, page 577, Fig. 2). This is due to the fact that the bolt tension values this year could be corrected for the permanent set of the bolts as determined from the April 24, 1940 readings. Also, for the north rail only those bolts were included in the averages last year which had an original tension on October 5, 1938 of approximately 25,000 lb. However, this so reduced the number of bolts in the test that it was thought preferable this year to include all the bolts in the test. This had the effect of lowering considerably the amount of the tension throughout for the Triflex springs, but the rate of bolt tension loss was very little affected.

Figures 1 and 2 show the average bolt tension as retightened on April 25, 1940 and as found on October 16, 1940. These values are subject to later correction for permanent set. Furthermore, the trend of bolt tension loss can be better estimated when more measured values are available. However, it does seem apparent that the rate of bolt tension loss in the six months' period following October 16, 1940 was not as great as in the six months' period following October 5, 1938.

It should be noted that the bolts in the north rail with the higher original tension on April 24, 1940, after 19 months' service had much higher remaining tension than did those of the south rail.

FIG. 2

LOSS OF BOLT TENSION UNDER TRAFFIC

ORIGINAL TIGHTENING OCT. 5, 1938 RETIGHTENED APRIL 25, 1940

APPROXIMATE TRAFFIC DENSITY 15,000,000 G. T. PER YEAR

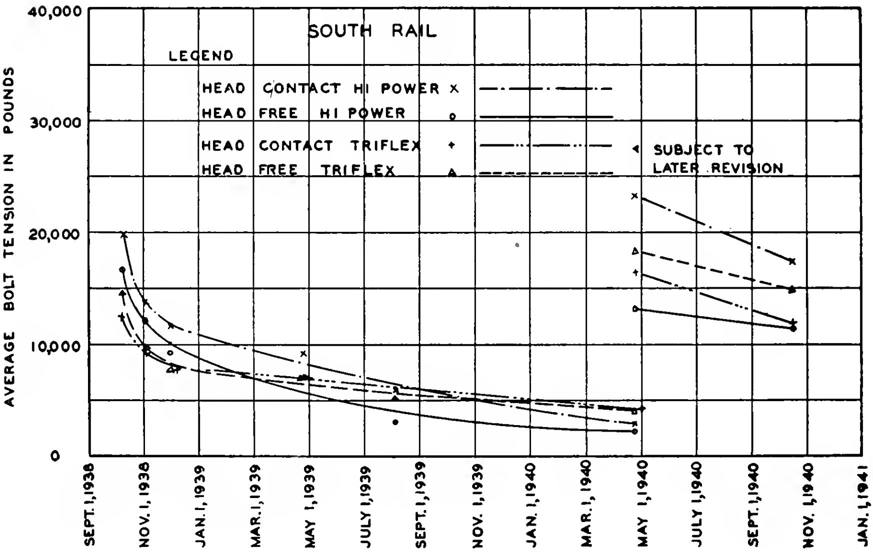


Table 3 shows the average loss in bolt tension per month on each of the various test sections during the 19 months' period from October 5, 1938 to April 4, 1940.

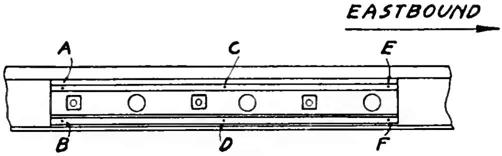
Table 3.—Average Loss in Bolt Tension from October 5, 1938 to April 24, 1940.

	Average Bolt Tension in Lb.				No. of	No. Bolts
				Loss Per	Bolts	Loose
South Rail	10–5–38	4–24–40	Loss	Month	in Test	4–24–40
Head free Triflex	14,730	4,090	10,640	570	60	6
Head free Hipower	16,710	2,190	14,520	780	58	20
Head contact Tri.	12,410	4,090	8,320	450	54	7
Head contract H.P.	19,880	2,820	17,060	910	60	17
North Rail						
Head free Triflex	18,400	7,050	11,350	610	58	4
Head free Hipower	27,560	8,040	19,520	1,047	53	3
Head contact Tri.	17,840	5,500	12,340	660	41	2
Head contact H.P.	25,030	8,530	16,500	880	60	5

Wear of Joint Bars

When the test was started accurate measurements were made of the out-to-out distances between the outer faces of the bars at each joint on both top and bottom ribs at each end and near the center of the bar. (See Fig. 3, page 570, Vol. 40). As wear occurs on the fishing surfaces of the joint and rail the bars are moved closer together

TABLE 4.



Average Change in Out-to-Out Distance of Joint Bars
C. B. & Q. R.R. Test Installation
(From October 5, 1938 to October 16, 1940)

Type of Joint & Spring Washer	Location on Joint						
North Rail:	A	B	C	D	E	F	Ave.
Headfree Hipower	- .009	- .053	- .031	- .079	- .022	- .063	- .043
Headfree Triflex	- .014	- .052	- .028	- .068	- .020	- .057	- .040
Head Contact H.P.	- .034	- .023	- .058	- .065	- .058	- .054	- .049
Head Contact Tri.	- .060	- .049	- .104	- .084	- .068	- .054	- .070
South Rail:							
Headfree Hipower	- .005	- .055	- .019	- .079	- .008	- .065	- .038
Headfree Triflex	.003	- .052	- .023	- .088	- .013	- .082	- .043
Head Contact H.P.	- .049	- .026	- .108	- .081	- .076	- .060	- .067
Head Contact Tri.	- .054	- .046	- .102	- .094	- .062	- .058	- .069

Note: All values shown are in inches. The " - " sign indicates the average change is a decrease in out-to-out distance.

by the bolt tension and a comparison of subsequent out-to-out measurements with the original measurement is an indication of the rate of joint bar wear. The purpose of making these measurements was to determine whether the amount of bolt tension had a major effect upon the rate of joint bar wear.

In Table 4 the average change in out-to-out distance of joint bars for the eight test sections is given separately for each position of measurement of the bar. It will be noted from this table that there was no appreciable difference in the rate of wear on the north and south rail even though the average bolt tension over the test period was considerably greater on the north rail. It will also be noted from this table that the head free bars generally show little inward movement at the top, which is to be expected due to the design of the bar, but the inward movement at the bottom of the bar is approximately the same as the average inward movement of the head contact type bars. Generally, somewhat more wear and inward movement is indicated at the center of the bar than at the ends. In general, the results for the four test sections for each type of bar are in good agreement, the only exception being that the head contact Hi Power on the north rail showed considerably less inward movement than the other three head contact test sections. There was considerable difference in the amount of out-to-out movement in individual joints in each test section and since only 10 joints were included in each test some variation is to be expected. It should be pointed out that the amount of out-to-out change in these joint bars in the two-year period is much greater than in the corresponding period on the Milwaukee and the D. & R. G. W. tests. The traffic density on the Burlington test is from three to five times as great as on these other two test installations, and this seems a probable explanation for the difference. It will be of interest to note whether the change in the out-to-out distance continues at the same rate in the future and, if so, to estimate the probable traffic period when the 3/16-in. clearances between joint bar and rail web will be exhausted by the inward movement of the joint bars resulting from fishing surface wear.

Denver & Rio Grande Western

The rail was laid for this test installation on the D. & R. G. W. single track main line near Glenwood Springs, Colo., on September 7, 1938 (See Vol. 40, page 568). The rail is 131 lb., with 4-hole toeless joint bars, 1⅛-in. heat-treated bolts, and National grooved spring washers. At the time the rail was laid, the bolts on the north rail were tightened with a Nordberg power wrench, and the bolts on the south rail were tightened by hand with a 48-in. wrench. Very high bolt tensions were obtained, particularly with the power wrench, and in many cases the elastic limit of the bolt was exceeded. Since the bolt tension measurements depend upon a true elastic elongation of the bolt it was not possible to determine the bolt tension originally applied in tightening until the bolts could be loosened and the permanent set measured. In the committee report last year, therefore, only the loss in tension at succeeding periods of measurement was reported.

Loss of Bolt Tension Under Traffic

It was decided that the bolt tension had been so decreased by traffic that the bolts should be retightened this year. Accordingly, measurements were taken on October 10, 1940, and the bolts were then all loosened and the permanent set was measured. From these and the preceding measurements, it was then possible to determine the bolt tension originally applied on September 7, 1938, and the bolt tension remaining at the successive periods of measurement up to October 10, 1940. This information is shown in Table 5. To conserve space, the average bolt tension is shown for the four bolts of each joint (except as otherwise noted), instead of for each individual bolt. One point to be noted in Table 5 is that the loss in bolt tension is not the same at each joint. On the north rail, although a wide variation in the bolt tension was applied to individual bolts with the power wrench, as will be discussed later, nevertheless the average bolt tension applied per joint was reasonably uniform. However, at the time of the measurements on October 10, 1940, the average bolt tension per joint was relatively quite different at individual joints. A comparison with the joint gap measurements (Table 7, Vol. 41, p. 586) indicates that generally those joints showing the greatest loss in bolt tension also showed the greatest expansion movement, as indicated by the joint gap openings in cold weather.

In Fig. 3 the average bolt tension for the north and south rail has been plotted with respect to time after the original tightening. The bolts were not touched from September 7, 1938 to October 10, 1940, so the reduction in bolt tension resulted from service conditions only. Smooth curves have been drawn to coincide as nearly as possible with the measured values for each rail. The rate of bolt tension loss was relatively great for the first two months after tightening and much smaller thereafter.

Uniformity of Tightening

At the time of the original tightening of the bolts on September 7, 1938, it was desired to gain information on the variation in bolt tension obtained in tightening. Since many of the bolts were tightened beyond their elastic limit, as previously stated, it was not possible at that time to show this variation for bolt tensions above 30,000 lb. per sq. in. (See Vol. 40, pages 573, 574). It became possible, however, to show this information after the permanent set was measured on October 10, 1940, and Fig. 4 has

FIG. 3

D. & R. G. W. R. R.

LOSS OF BOLT TENSION UNDER TRAFFIC

RAIL LAID AND BOLTS TIGHTENED SEPT. 7, 1938 NO SUBSEQUENT TIGHTENING

APPROXIMATE TRAFFIC DENSITY 3,000,000 G. T. PER YEAR

EXCLUSIVE OF LOCOMOTIVES AND PASSENGER TRAINS

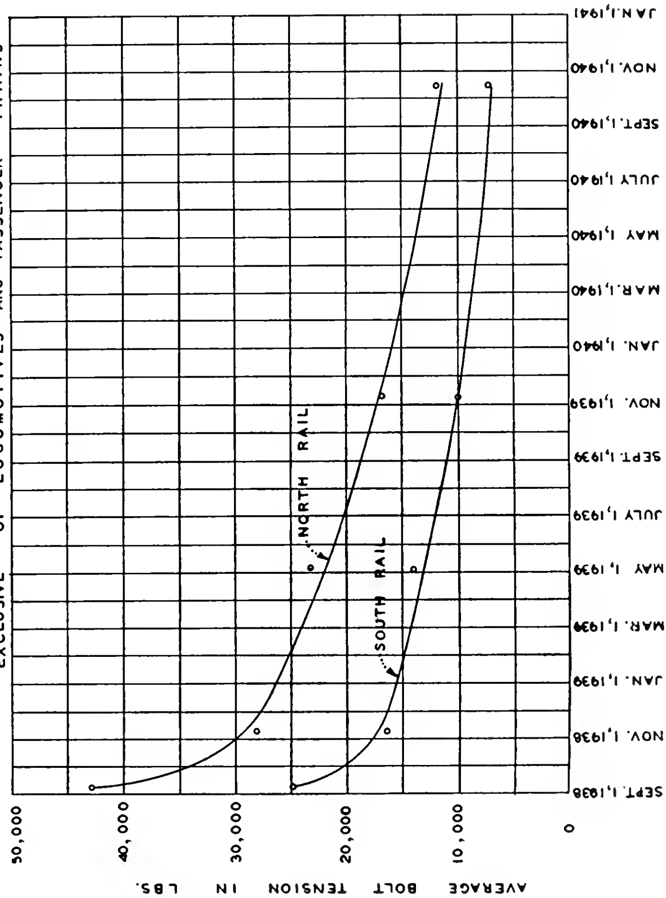


FIG. 4

D. & R. G. W. R. R. BOLT TEST INSTALLATION

VARIATION IN BOLT TENSION

OBTAINED IN TIGHTENING BOLTS

IN CONNECTION WITH RAIL LAYING

131# RAIL 4 HOLE JOINTS $1\frac{1}{8}$" DIA. BOLTS

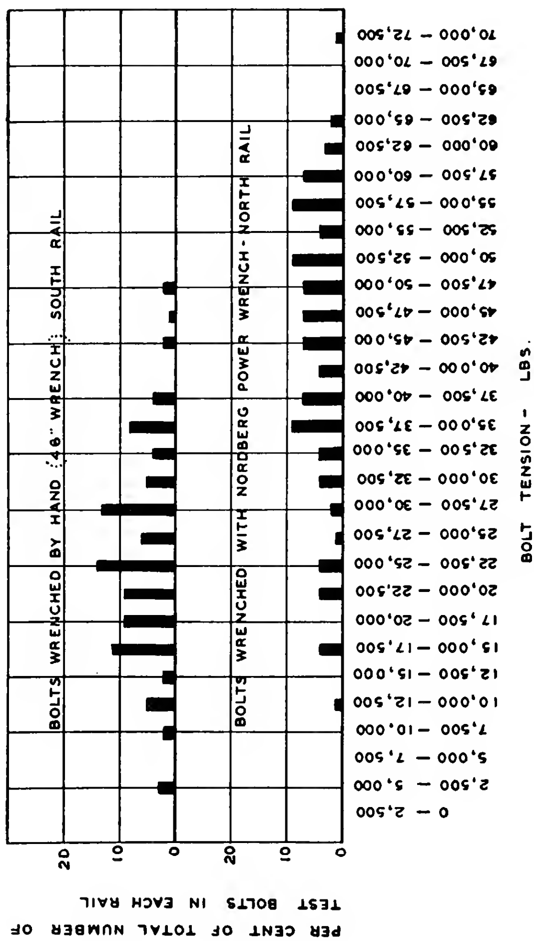


Table 5

BOLT TENSION - D. & R.G.W. TEST

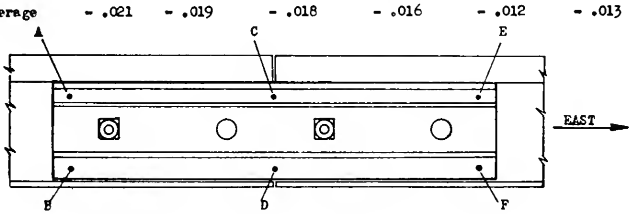
(Values given are averages per joint per bolt in lbs.)

NORTH RAIL						SOUTH RAIL					
	Date of Measurement						Date of Measurement				
Joint No.	9/7/38	11/9/38	5/3/39	11/9/39	10/10/40	Joint No.	9/7/38	11/9/38	5/3/39	11/9/39	10/10/40
			TANGENT						TANGENT		
1	43,080	34,270	30,230	25,940	18,560	26	32,610	24,270	15,710	11,660	6,660
2	42,360	31,420	25,230	21,180	15,710	27	34,270	25,940	20,940	17,140	13,330
3	-	-	-	-	-	28	38,790	34,030	30,940	25,230	19,520
4	47,600	34,750	35,220	27,850	19,280	29	34,750	22,370	23,800	16,900	9,280
5	41,170	25,230	23,800	13,570	6,190	30	28,560	19,520	19,750	11,660	7,620
6	32,130	24,990	24,990	20,940	11,420	31	19,040	13,570	13,800	6,900	5,240
7	44,270	33,560	29,510	23,090	17,610	32	22,130	15,710	16,180	10,230	7,620
8	45,220	27,610	21,180	14,520	3,810	33 *	25,990	16,710	12,360	9,190	7,290
9	49,500	34,270	28,560	19,750	12,610	34	13,800	8,570	8,810	4,050	5,000
10	41,410	24,990	20,710	14,760	11,420	35 *	25,990	16,480	13,630	8,880	7,920
11	48,310	29,990	23,320	15,710	11,420	36	28,320	23,320	22,850	16,660	15,230
12	49,270	26,890	19,990	16,180	12,380	37	27,850	21,420	16,900	9,520	9,040
13	42,600	25,700	19,040	14,520	13,330	38	19,280	11,660	9,040	1,900	1,900
14	38,560	18,800	13,570	6,430	5,240	39	17,140	8,090	8,090	4,280	4,760
15	28,320	24,510	20,710	16,180	13,330	40 *	24,090	13,000	10,780	7,290	6,020
16	40,220	26,420	18,560	7,850	4,760	41	12,850	6,900	5,950	3,090	2,380
17 *	40,580	29,800	22,820	17,430	17,430	42	14,990	8,330	7,620	5,000	4,520
18	39,030	23,320	14,280	8,810	7,140	43	23,090	9,760	6,900	3,810	2,380
19	40,700	19,750	12,380	10,710	9,760	44 *	22,510	14,900	11,410	9,830	5,390
20	49,500	32,610	21,180	16,420	11,420						
			CURVE						CURVE		
21	44,980	24,750	15,230	9,040	6,190	45	20,230	9,280	5,240	5,000	4,050
22 *	41,840	28,850	20,920	18,390	13,950	46 **	22,370	12,380	9,040	8,090	3,330
23	44,980	34,750	28,080	18,800	12,610	47 *	27,580	19,340	17,120	14,580	11,090
24	48,790	28,800	26,890	20,710	14,990	48	29,510	19,520	14,520	10,470	5,470
25	44,270	28,080	26,180	19,280	14,040	49	22,850	11,190	10,230	7,620	3,810
						50	33,320	22,850	22,610	16,900	9,280
AVERAGE	42,860	28,080	22,610	16,580	11,860	AVERAGE	24,880	16,340	14,170	9,830	7,125

NOTE: * Average 3 bolts in the joint.
** Average 2 bolts in the joint.
Joint No. 3 - Bolts loosened by trackmen before readings taken.

Table 6
OUT-TO-OUT MEASUREMENTS
Change from 9/7/38 to 10/10/40
D. & R.G.W. R.R. Test Installation
Measurements in inches. Minus sign = decrease in out-to-out distance.

Joint No.	Position A	B	C	D	E	F
			North Rail			
1	- .011	.001	- .010	- .005	- .027	- .003
2	- .023	.00	- .019	- .001	- .018	- .004
3	- .023	- .006	- .016	- .008	- .022	- .013
7	- .020	.004	- .021	- .002	- .004	- .006
8	- .027	- .012	- .029	- .019	- .017	- .009
9	- .011	- .003	- .023	- .004	- .024	- .002
11	- .006	- .021	- .012	- .019	- .004	- .013
12	- .019	- .012	- .011	- .023	- .007	- .022
13	- .007	- .012	- .011	- .018	- .011	- .027
14	- .056	- .042	- .043	- .011	- .022	.006
15	- .007	- .002	- .014	- .013	- .020	- .017
16	.004	- .023	.003	- .028	- .021	- .056
17	- .009	- .009	- .011	- .010	- .022	- .005
18	- .048	-	- .029	- .035	.004	- .020
19	- .001	- .010	- .011	- .012	- .015	- .005
Average	- .018	- .011	- .017	- .014	- .015	- .013
			South Rail			
26	- .001	- .010	- .001	- .017	.005	- .009
27	- .015	- .006	- .012	- .005	- .014	- .010
29	- .003	- .007	- .008	- .010	- .011	- .015
30	- .010	- .019	- .009	- .016	- .004	- .014
32	- .007	- .008	- .011	- .012	- .009	- .012
33	.00	- .020	- .008	- .025	- .008	- .013
34	- .004	- .015	- .012	- .024	- .026	- .038
35	- .065	- .061	- .026	- .017	- .006	- .031
36	- .007	- .009	- .018	- .006	- .021	- .004
38	- .048	- .007	- .038	- .004	- .032	.006
40	- .020	- .032	- .018	- .023	- .003	- .003
41	- .039	- .053	- .020	- .029	.012	- .007
42	- .058	- .054	- .024	- .027	- .004	- .005
43	- .035	.015	- .057	- .010	- .060	- .026
44	- .004	- .003	- .009	- .021	- .002	- .021
Average	- .021	- .019	- .018	- .016	- .012	- .013



been prepared to give this information. This figure shows the percentage of the test bolts which lay within successive ranges of bolt tension. It will be noted that the bolt tension obtained varied over a very wide range with both the hand and machine-tightened bolts.

Out-to-Out Measurements of Joint Bars

On September 7, 1938, following the bolt tightening, careful measurements were made of the out-to-out distance between joint bars on both bottom and top ribs near each end of the bars and at their center. These measurements were repeated on October 10, 1940, and the individual measurements are shown in Table 6, together with the average at each joint location. A particular purpose of these measurements was to determine whether the amount of bolt tension had a major effect upon the rate of wear of the joint bars. Although the tension on the north rail was very much above the tension on the south rail throughout the test period, it will be noted that there is little change in the respective amount of out-to-out distance on each rail, indicating that the amount of joint bar wear was approximately the same regardless of the bolt tension. Also, there does not seem to have been much more wear at the center of the joints than at the ends during this traffic period. A somewhat greater amount of wear apparently occurred at the A and B positions, which would be the receiving end of the joint in the direction of fast movement down grade.

Continuation of Measurements

The test bolts were replaced with new bolts on October 11, 1940, and retightened by hand, and bolt tension measurements were taken. It is planned to continue measurements to determine the rate of loss in bolt tension and also joint bar wear. Joint gap readings were taken but they will not be shown at this time as no significant change appears to have occurred since the recording of the facts given in Table 7, page 586, Vol. 41.

Erie Railroad Test Installation

The test installation on the Erie is on the westbound track of the double-track main line at M.P. 223, near Griffith, Ind. The rail is 112-lb. section laid new on July 19, 1939, with 6-hole angle bars and one-inch heat-treated bolts. The test installation consists of 8 joints on the north rail and 10 joints on the south rail, a total of 18 joints and 105 test bolts. Triflex springs were placed on 33 of the test bolts, chrome improved Hi Power spring washers on 33, and improved Hi Power spring washers on 39.

Loss of Bolt Tension Under Traffic

Last year's report included a chart showing the range of bolt tension obtained in tightening. The bolts were left undisturbed following this tightening until December 17, 1939, approximately five months, at which time the bolt tension remaining in the bolts was measured. The individual bolt tensions measured at this time and at the original tightening on July 14, 1939, are shown in Table 7 and the average values are given for both bolt positions and joints for each type of spring washer used.

The bolts were then retightened with a Raco power wrench and the tension measured. No further tightening was done until October 15, 1940, at which time the tension remaining in the bolts was read. The individual bolt tension measurements obtained at these two times are shown in Table 8.

Out-to-Out Measurements of Joint Bars

At the time of making the bolt tension measurements, the out-to-out distance between joint bars was measured with the joint bar caliper on the center line of the joint bar near each end and at the middle. Readings could not be taken on the bottom ribs with the caliper because the joint bars were of the angle bar type and the caliper would not span the outstanding flanges.

In Table 9, the change in out-to-out measurements at each location of measurement is shown during the periods that the loss of bolt tension under traffic was measured. Comparison of the loss in bolt tension with the change in out-to-out distance affords an interesting study. In the first five months' period after the rail was laid, the change in out-to-out distance averaged about 0.02 in., being perhaps 50 percent greater at the middle of the joints than at the ends and nearly the same for the different types of springs. The bolt tension decreased considerably in this period with the Hi Power springs and decreased more at the two center bolts than at the remaining bolts. The loss in bolt tension was somewhat less, with the Triflex springs.

TABLE 7

BOLT TENSION MEASUREMENTS
Erie R.R. Test Installation

Joint No.	Original Tightening - July 19, 1939 Bolt Position 1	2	3	4	5	6	Average	Joint No.	Bolt Tension Remaining - December 17, 1939 Bolt Position 1	2	3	4	5	6	Average
						Chrome Hi-Power Spring Washers									
1-N	10,700	12,400	18,100	15,700	16,500	21,200	15,800	1-N	9,100	10,700	4,900	3,300	6,600	9,100	7,300
2-N	15,700	17,300	17,300	16,500	14,000	14,000	15,800	2-N	3,300	5,800	5,800	2,500	2,500	2,500	3,700
3-N	15,700	14,000	14,000	-	-	-	14,600	3-N	11,500	800	800	-	-	-	4,300
1-S	10,700	11,500	5,800	9,900	12,400	18,100	11,400	1-S	4,900	2,500	4,100	2,500	3,300	3,300	3,400
2-S	12,400	17,300	9,900	9,100	14,000	10,700	12,200	2-S	9,100	5,800	0	3,300	8,200	4,900	5,200
3-S	19,800	13,200	10,700	5,800	14,000	12,400	12,700	3-S	10,700	3,300	1,600	5,800	12,400	9,900	7,300
Average	14,200	14,300	12,600	10,400	14,200	15,300	13,700	Average	8,100	4,800	2,900	3,500	6,600	5,900	5,300
							Triflex Springs								
3-N	-	-	-	12,400	13,200	14,700	13,400	3-N	-	-	-	8,500	7,000	10,800	8,800
4-N	15,500	10,800	10,100	7,700	13,200	9,300	11,100	4-N	11,600	9,300	7,700	8,500	7,700	7,700	8,700
5-N	11,600	7,700	13,200	12,400	8,500	12,400	11,000	5-N	8,500	7,000	11,600	11,600	7,700	10,100	9,400
4-S	11,600	15,500	14,000	10,800	14,700	12,400	13,200	4-S	-	13,900	11,600	5,400	14,700	9,300	11,000
5-S	13,200	14,000	10,100	7,000	16,300	21,800	13,700	5-S	8,500	8,500	7,700	3,100	10,800	12,400	8,500
6-S	18,600	16,300	13,200	14,000	14,000	11,600	14,600	6-S	13,900	13,900	10,100	10,100	10,800	11,600	11,700
Average	14,100	12,900	12,100	10,700	13,300	13,700	12,800	Average	10,600	10,500	9,700	7,900	9,800	10,300	9,700
							Hi-Power Spring Washers								
6-N	13,200	14,000	9,900	5,800	7,400	14,000	10,700	6-N	9,900	9,900	8,200	3,300	2,500	7,400	6,900
7-N	13,200	12,400	8,200	7,400	13,200	10,700	10,900	7-N	10,700	4,100	4,100	2,500	7,400	8,200	6,200
8-N	11,500	14,800	6,600	4,100	4,100	12,400	8,900	8-N	8,200	9,100	800	1,600	0	4,900	4,100
7-S	15,700	10,700	5,800	12,400	14,000	16,500	12,500	7-S	4,100	7,400	2,500	5,800	7,400	14,800	7,000
8-S	15,700	9,900	9,100	10,700	8,200	13,200	11,100	8-S	15,700	6,600	4,900	4,900	3,300	9,100	7,400
9-S	12,400	11,500	13,200	9,100	22,300	16,500	14,200	9-S	8,200	7,400	4,900	4,900	14,800	11,500	8,600
10-S	9,100	16,500	12,400	-	-	-	12,700	10-S	3,300	7,400	4,900	-	-	-	5,200
Average	13,000	12,800	9,300	8,200	11,500	13,900	11,500	Average	8,600	7,400	4,300	3,800	5,900	9,300	6,600

Note: Bolt positions are numbered from east to west against the direction of traffic.

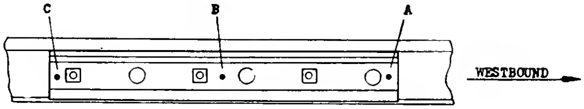
TABLE 8

BOLT TENSION MEASUREMENTS
Erie R.R. Test Installation

Joint No.	Bolt Tension Applied in Retightening - Dec. 13, 1939: Bolt Position 1	2	3	4	5	6	Average	Joint No.	Bolt Tension Remaining - October 15, 1940: Bolt Position 1	2	3	4	5	6	Average
Chrome Hi-Power Spring Washers															
1-N	14,000	15,700	16,500	11,500	12,400	18,100	14,700	1-N	15,700	9,900	4,900	3,300	6,600	12,400	8,800
2-N	14,000	14,800	19,000	9,100	12,400	12,400	13,600	2-N	9,100	8,200	9,900	5,800	7,400	5,800	7,700
3-N	20,600	6,600	14,000	-	-	-	13,700	3-N	17,300	3,300	8,200	-	-	-	9,600
1-S	23,900	28,000	19,000	21,400	17,300	31,300	23,500	1-S	4,900	19,000	3,300	9,900	9,100	20,600	11,100
2-S	22,300	19,800	15,700	18,100	22,300	21,400	19,900	2-S	15,700	13,200	7,400	7,400	14,000	14,000	11,900
3-S	25,600	15,700	16,500	18,100	23,100	18,100	19,500	3-S	22,300	11,500	9,100	5,800	19,800	12,400	13,500
Average	20,100	16,800	16,800	15,600	17,500	20,300	17,800	Average	14,200	10,800	7,100	6,400	11,400	13,000	10,500
Triflex Springs															
3-N	-	-	-	12,400	12,400	11,600	12,100	3-N	-	-	-	11,600	7,700	9,300	9,500
4-N	17,000	13,900	15,500	10,800	11,600	12,400	13,500	4-N	12,400	7,700	10,100	8,500	6,200	7,000	8,600
5-N	13,200	11,600	17,000	17,800	11,600	13,200	14,100	5-N	6,200	7,700	12,400	11,600	7,000	8,500	8,900
4-S	-	20,900	19,400	11,600	20,100	15,500	17,500	4-S	-	16,300	12,400	6,200	11,600	10,100	11,300
5-S	13,900	14,700	11,600	10,800	17,000	15,500	13,900	5-S	9,300	9,300	8,500	2,300	11,600	12,400	8,900
6-S	20,900	21,700	14,700	15,500	16,300	15,500	17,400	6-S	14,700	13,200	10,800	10,100	10,800	11,600	11,900
Average	16,200	16,600	15,600	13,200	14,800	13,900	14,900	Average	10,600	10,800	10,800	8,400	9,100	9,800	9,800
Hi-Power Spring Washers															
6-N	16,500	16,500	26,400	20,600	16,500	17,300	19,000	6-N	10,700	8,200	12,400	11,500	12,400	14,800	11,600
7-N	21,400	19,800	9,900	4,100	14,000	11,500	13,400	7-N	14,800	13,200	4,900	2,500	10,700	9,100	9,200
8-N	18,100	16,500	13,200	12,400	10,700	16,500	14,600	8-N	9,900	13,200	3,300	4,100	4,900	12,400	8,000
7-S	23,900	18,100	12,400	19,800	18,100	28,000	20,100	7-S	15,700	11,500	9,100	11,500	13,200	19,800	13,500
8-S	30,500	20,600	25,600	25,600	14,800	19,800	22,800	8-S	20,600	12,400	11,500	17,300	2,500	12,400	12,800
9-S	19,000	16,500	16,500	18,100	24,700	23,900	19,800	9-S	13,200	12,400	7,400	9,900	16,500	16,500	12,700
10-S	14,000	21,400	15,700	-	-	-	17,000	10-S	7,400	19,800	9,100	-	-	-	12,100
Average	20,500	18,500	17,100	16,800	16,500	19,500	18,200	Average	13,200	13,000	8,200	9,500	10,100	14,200	11,400

Note: Bolt positions are numbered from east to west against the direction of traffic.

TABLE 9



Change in Out-to-Out Measurement of Joint Bars
Erie R.R. Test Installation

Joint No.	July 14, 1939 to Dec. 17, 1939 Position A	B	C	Dec. 17, 1939 to Oct. 15, 1940 Position A	B	C
			Chrome Hi-Power Spring Washers			
1-N	- .012	- .007	- .021	- .010	- .017	- .006
2-N	- .015	- .019	- .017	- .008	- .025	- .008
3-N	- .017	- .012	- .030	- .007	- .027	- .000
1-S	- .029	- .043	- .007	- .004	- .006	- .014
2-S	- .017	- .030	- .015	- .007	- .014	- .009
3-S	- .020	- .033	- .014	- .004	- .012	- .002
Average	- .018	- .024	- .017	- .007	- .017	- .006
			Triflex Springs			
3-N	- .017	- .012	- .030	- .007	- .027	- .000
4-N	- .013	- .033	- .022	- .009	- .016	- .008
5-N	- .015	- .025	- .010	- .011	- .010	- .007
4-S	- .018	- .026	- .020	- .007	- .016	- .014
5-S	- .022	- .031	- .015	- .006	- .013	- .003
6-S	- .016	- .020	- .019	- .010	- .010	- .006
Average	- .017	- .024	- .019	- .008	- .015	- .006
			Hi-Power Springs			
6-N	- .015	- .034	- .019	- .010	- .016	- .009
7-N	- .026	- .016	- .019	- .001	- .023	- .003
8-N	- .022	- .034	- .023	- .010	- .019	- .005
7-S	- .026	- .032	- .014	- .000	- .011	- .011
8-S	- .021	- .027	- .019	- .000	- .010	- .010
9-S	- .025	- .016	- .019	- .001	- .017	- .003
10-S	- .013	- .026	- .005	- .003	- .007	- .016
Average	- .021	- .026	- .017	- .004	- .016	- .008

Note: Measurements shown represent decrease in out-to-out distance of joint bars.

In the ten months' period following retightening of the bolts, the loss in bolt tension was about the same as in the preceding test period of only five months. In this period, the change in out-to-out distance averaged about 0.01 in. and was about twice as great at the two center bolts as at the remaining bolts. Again, there was little difference in out-to-out change with the different types of springs. Also, in this latter period there was not so marked a difference in the loss of bolt tension with the various types of springs. The Hi Power springs had a higher initial tension than the Triflex and also had a higher tension at the close of the test period. The performance of the Triflex was somewhat better in maintaining more uniform tension at individual bolts.

Continuation of Measurements

The bolts were retightened on October 15, 1940, and the measurements will be continued. It is also planned to make some laboratory tests on the overall reactance properties of the various types of springs to include the reactance effects of the bolt. With this information it will be possible to determine to what extent inward movement of the joint bars as a result of fishing surface wear, explains the measured loss in bolt tension under traffic.

Pennsylvania Railroad

This test installation on the Pennsylvania Railroad is located on Track 1 of the three-track main line near Birmingham, Pa. This track carries the major portion of the eastbound passenger and freight traffic and the traffic density is quite high, from 50,000,000 to 70,000,000 gross tons per year. The rail is 152-lb. Pennsylvania section, with 6-hole toeless controlled bearing joint bars, 1⅛-in. bolts, and spring washers. The bolts were especially selected for the test to insure that the nut could be freely turned by hand over the entire threaded portion of the bolt. The rail was laid new in the early part of August, 1939.

Uniformity of Bolt Tension Obtained in Tightening

Last year's report included a chart (Vol. 41, page 589) showing the range in bolt tension obtained in tightening the bolts with a Raco power wrench. On June 21, 1940, the bolts were loosened and retightened with a Raco power wrench with the improved type "kick-off". Of the 103 test bolts, 24 were tightened by hand because of lack of clearance for the machine chuck with the special type of joint tie plate used. In Fig. 5, the range of bolt tension obtained in tightening these bolts with the power wrench is shown. The bolts tightened by hand are, of course, not included. It will be noted from

FIG. 5

PENNSYLVANIA R. R. BOLT TEST INSTALLATION
VARIATION IN BOLT TENSION
OBTAINED IN TIGHTENING WITH IMPROVED
RACO POWER WRENCH ON JUNE 21, 1940
152# RAIL — 6 HOLE TOELESS JT. BARS — 1⅛" H. T. BOLTS.
WITH SPRING WASHERS

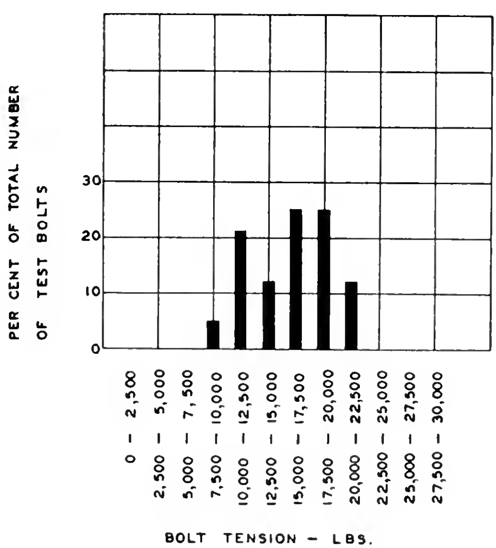
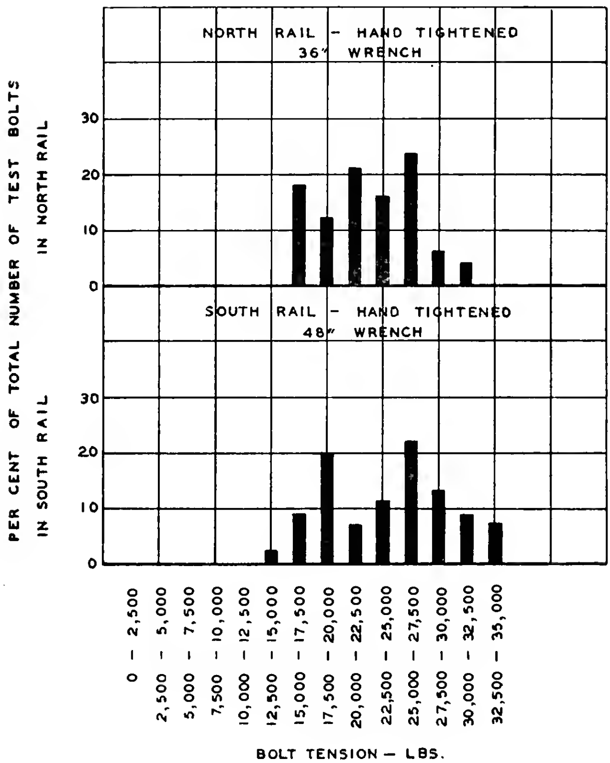


FIG. 6

PENNSYLVANIA R. R. BOLT TEST INSTALLATION
VARIATION IN BOLT TENSION
OBTAINED IN TIGHTENING WITH HAND WRENCHES
ON NOV. 14, 1940
152# RAIL ~ 6 HOLE TOELESS JOINT BARS ~ 1⅛" H.T. BOLTS
WITH SPRING WASHERS



comparison with the chart in last year's report that an improvement has been affected in uniformity. However, there is still a wide range in the applied tension, even with the free turning nuts. Tests conducted with this machine by the Pennsylvania Railroad in the laboratory at Altoona indicated that the torque delivered by this machine, and also with a Nordberg power wrench, at the time of kick-off was much more uniform than the range of bolt tension obtained in these tests. It seems therefore that the variation in thread friction during tightening, even with free turning nuts, is sufficient to produce considerable variation in the bolt tension obtained.

On November 14, 1940, these test bolts were retightened with hand wrenches. One track man tightened the bolts on the north rail with a 36-in. wrench, and another man tightened the bolts in the south rail with a 48-in. wrench. The men were instructed to tighten these bolts just as they would do in regular maintenance work. The range in

Table 10
BOLT TENSION MEASUREMENTS
P. R.R. Test Installation

Joint No.	Date of Measurement - 6/21/40 Bolt Position 1	2	3	4	5	6	Average	Joint No.	Date of Measurement - 11/14/40 Bolt Position 1	2	3	4	5	6	Average
1	16,500	27,500	19,800	29,700	18,700	20,900	22,200	1	15,400	15,400	8,800	17,600	11,000	12,100	13,400
2	15,400	14,300	20,900	19,800	19,800	18,700	18,200	2	9,900	8,800	5,500	7,700	11,000	6,600	8,200
3	18,700	25,300	15,400	25,300	17,600	16,500	19,800	3	12,100	15,400	3,300	7,700	6,600	5,500	8,400
4	15,400	15,400	25,300	15,400	13,200	22,000	17,800	4	9,900	3,300	4,400	4,400	1,100	11,000	5,700
5	19,800	25,300	12,100	22,000	9,900	18,700	18,000	5	6,600	14,300	0	8,800	4,400	11,000	7,500
6	34,100	11,000	-	14,300	20,900	16,500	19,400	6	18,700	5,500	-	2,200	9,900	4,400	8,100
7	15,400	13,200	20,900	23,100	19,800	11,000	17,300	7	8,800	6,600	8,800	12,100	4,400	1,100	7,000
8	12,100	15,400	34,100	17,600	12,100	14,300	17,600	8	5,500	3,300	16,500	16,500	2,200	8,800	8,800
9	12,100	15,400	12,100	25,300	17,600	16,500	16,500	9	1,000	9,900	0	11,000	8,800	4,400	5,900
10	25,300	24,200	23,100	12,100	28,600	13,200	21,100	10	13,200	14,300	9,900	1,100	19,800	5,500	10,600
11	15,400	12,100	20,900	20,900	22,000	23,100	19,000	11	7,700	3,300	7,700	9,900	8,800	12,100	8,200
12	24,200	12,100	22,000	-	18,700	12,100	17,800	12	7,700	0	8,800	-	12,100	9,900	7,700
13	20,900	19,800	17,600	17,600	17,600	15,400	18,100	13	14,300	12,100	5,500	8,800	13,200	5,500	9,900
14	22,000	12,100	23,100	9,900	25,300	12,100	17,400	14	11,000	7,700	11,000	2,200	17,600	5,500	9,100
15	13,200	34,100	16,500	25,300	18,700	12,100	20,000	15	12,100	25,300	7,700	12,100	13,200	4,400	12,500
16	15,400	9,900	20,900	16,500	16,500	13,200	15,400	16	14,300	9,900	3,300	7,700	14,300	9,900	9,900
17	13,200	-	27,500	25,300	24,200	12,100	20,500	17	4,400	-	17,600	14,300	17,600	11,000	13,000
Average	18,200	17,900	20,800	20,000	18,900	15,800	18,600	Average	10,200	9,700	7,400	9,000	10,300	7,600	9,000

Note: Bolt position numbers are from west to east in the direction of traffic.

bolt tension obtained is shown in Fig. 6. The amount of variation was somewhat greater than was obtained with the power wrench (Fig. 5), but not markedly so. The average bolt tension obtained was approximately ⅓ greater with the hand tightening. The average bolt tension obtained on the south rail using the 48-in. wrench was 12 percent greater than on the north rail using the 36-in. wrench. The 48-in. wrench should have afforded 33 percent more torque, but it was observed that the track man did not grasp the wrench at its end and thus did not fully avail himself of the increased length.

Loss of Bolt Tension Under Traffic

In the presentation of the test results, measurements of individual bolts have not been given generally because of the space required. However, for this test installation the number of bolts used permits showing the individual measurements. In Table 10, the bolt tension applied June 21, 1940, is shown, and also the tension remaining on November 14, 1940. During this service period of approximately five months the average bolt tension decreased from 18,600 lb. to 9,000 lb. The table shows the bolt tension loss at the different bolt positions.

Bolt Position	*Average Tension Loss Lb.*
1	8,000
2	8,200
3	13,400
4	11,000
5	8,600
6	8,200

In this test, the bolt tension loss was approximately 50 percent greater at the two center bolt positions than at the remaining bolt positions.

In comparing this test with the other test installations, the large amount of traffic carried during the test period should be kept in mind.

Continuation of Test

The bolts were retightened on November 14, 1940, and the applied bolt tension measured. Measurements were also made of the out-to-out distance between joint bars so that information would be available on the rate of joint bar wear in the future.

Report on Assignment 10

Lubrication of Rail on Curves

Collaborating with Committee 16—Economics of Railway Location and Operation

F. S. Hales (chairman, subcommittee), L. L. Adams, W. H. Bettis, L. H. Bond, A. F. Huber, F. J. Jerome, E. E. Martin, K. R. McLennan, S. H. Poore, C. R. Strattman, M. J. T. Zeeman.

The two preceding reports on this subject are in the Proceedings noted below:

Vol. 39, pages 419 to 421—

This report listed four methods of lubrication and a method of determining the economy of rail lubricators was described.

Vol. 40, pages 575 to 581—

This second report presented information concerning the cost of mechanical lubricators installed in track, together with information on the effective distance over which the lubricant is carried on various curves.

Charts were presented showing the rate of wear on rail for various degrees of curves before and after installation of lubricators.

Information was furnished on the savings effected on one railroad due to increased rail life as a result of mechanical lubricators on locomotives applying lubricant direct to the rail.

Two methods of determining the economy of lubricators were shown.

A report by Committee 16 of a test on the Denver & Salt Lake Railway in 1939, (see Vol. 41, pages 151 to 154) shows the operating advantage of rail lubrication.

Since the two preceding reports, the committee has obtained some information on the saving in engine tire wear and the following is reported as of value in determining additional savings due to lubrication.

These samples are all on the same railroad but on different divisions:

		Division	
	A	*B*	*C*
Total mileage	83.05	145.50	254.4
Total curve mileage oiled	14.12	44.91	97.47
Total central angle oiled	2793°	7801°	16471°
Number of oilers	13	41	67
Number of Tires changed per year			
Before oiling	124	288	252
After oiling	109	28	48
Difference	15	260	204

		Division	
	A	*B*	*C*
Annual saving on engine tires	$ 450	$7,800	$6,120
Annual cost of lubrication	1,820	5,720	9,400
Annual saving per lubricator	34.50	190	91.50

In the case of Division B, the lubricators are justified on the saving in tire changes alone and in each case the savings listed above are in addition to the savings due to increased life of rail.

One railroad also reports as follows:

Our best illustration of the use of rail and flange lubricators is on one of our mountain divisions a distance of 82 miles, of which about 48½ percent is curve track, many of the curves running over 10 deg. There are 38 lubricator installations on this line, which averages 2.15 miles of track per lubricator. The installation cost about $375 each, installed. The annual cost for the complete lubrication, including grease, maintenance, cleaning and repairing, as well as handling and filling the lubricators, interest and depreciation, amounts to approximately $5,363. The estimated saving on the installation is $8,000 in rail and other track hardware renewals and $2,900 in engine tire expense, or a net annual saving of approximately $5,500.

In the territories where these lubricators are used the life of front tires before the lubricators were applied was 2½ months for freight engines and 2 months for passenger engines. Since application of the lubricators the life of front tires has been increased to 4½ months for freight engines and 3½ months for passenger engines.

The information shown indicates considerable saving in tire wear and is of value in determining the additional savings.

The committee has made considerable effort to determine ratios between degree of curve, central angle, increased life of rail, etc., but information from various sources shows that each location is a separate problem and such ratios are indeterminable.

This report together with others which have been made furnishes all the information necessary to determine the economy of lubricators and, while additional information would be helpful, it is felt that the conclusions presented in the committee's second report are thoroughly established.

These conclusions are as follows:

The life of rail on curves can be extended by lubrication of the rail.

Lubrication of rail on curves can be accomplished by the following methods (in order of preference).

(a) Mechanical lubricators installed in track
(b) Mechanical flange lubricators on locomotives
(c) Mechanical lubricators on locomotives applying lubricant direct to rail
(d) Manual lubrication of rail.

In addition to increasing the life of rail on curves, lubrication accomplishes the following:

(a) Decreased cost of engine tires
(b) Longer service life of ties because of decreased gaging
(c) Decreased train resistance permitting either increased tonnage, better time or less coal consumption.

The economic justification for lubrication depends upon the estimated annual saving resulting, as compared with the total estimated annual cost of lubrication.

The kind of lubricant most satisfactory in mechanical track lubricators is a grease or oil of heavy consistency.

Your committee recommends that these conclusions be adopted and published in the Manual.

Report on Assignment 11

Prevention of Damage Due to Brine Drippings on Tracks and Structures

Collaborating with Mechanical Division

G. M. Magee (chairman, subcommittee), W. G. Arn*, C. W. Baldridge, H. R. Clarke, F. W. Hillman, C. T. Jackson, J. de N. Macomb, K. R. McLennan, W. A. Murray, G. L. Sitton, C. R. Strattman, J. G. Wishart.

At the last meeting of the Joint Committee, representing the Engineering Division (AREA) and the Mechanical Division, held in the early part of 1940; it was decided that two additional series of tests should be conducted. In one series, refrigerator cars

* Mr. Arn is chairman of the Joint Committee on Prevention of Damage Due to Brine Drippings, composed of representatives of the Engineering and Mechanical divisions.

in regular service runs were to be iced and treated with salt containing inhibitor. The brine drippings from these cars were to be collected at intervals and analyzed to determine whether the sodium-dichromate dissolved at substantially the same rate as salt and offered protection throughout the test run. The other series of tests were to be track tests in which two rails in track would be sprayed daily, one rail with brine containing inhibitor, and the other with brine only. The following report is an account of two tests made on the Atchison, Topeka & Santa Fe Railway to determine the concentration of sodium-dichromate in the brine drippings from refrigerator cars.

Tests were made as follows:

1. To determine whether adding the inhibitor to the salt had any effect on the temperature of the brine.
2. To collect brine drippings at intervals from an empty car iced and salted with salt containing inhibitor and left standing at the icing dock.
3. To collect samples of brine drippings at intervals in a regular service run from a refrigerator car iced and salted with salt containing inhibitor.

Effect on the Temperature of Brine of Adding Sodium-Dichromate Inhibitor to Salt

Purpose of the Tests.—It had been assumed that due to the characteristics of sodium-dichromate and soda ash and the relatively small amount used, this inhibitor would have no effect on the refrigerating qualities of the ice and salt mixture used in refrigerator cars. It was decided to investigate this by test, before starting the refrigerator car tests.

Procedure of Test.—The test was made at the Hobart ice plant of the Santa Fe at Los Angeles on June 29, 1940. Two identical metal buckets were selected, and 24 lb. of crushed ice was placed in each bucket. In bucket No. 2, 6 lb. of salt was placed over the ice. In bucket No. 1, 6 lb. of salt containing inhibitor was placed over the ice. In each bucket the salt was mixed into the ice by stirring. The proportion of inhibitor added to the salt was the same as used in the road tests later described. (220 lb. salt—3 lb. sodium dichromate—2 lb. soda ash.) The temperature was determined by placing a thermometer in the brine mixture in each bucket.

Log of Test: June 29, 1940

1:51 p. m.: 24 lb. crushed ice (3 in. maximum size) placed in each of two buckets.

1:53 p. m.: 6 lb. salt added to bucket No. 2; 6 lb. of salt and inhibitor added to bucket No. 1.

2:25 p. m.: Bucket No. 2, salt only, 6 deg. F. Bucket No. 1, salt and inhibitor, 7 deg. F. (Taken after stirring; thermometer placed in brine).

2:37 p. m.: Bucket No. 2, salt only, 10 deg. F. Bucket No. 1, salt and inhibitor, 10 deg. F.

3:10 p. m.: Bucket No. 2, salt only, 13 deg. F. Bucket No. 1, salt and inhibitor, 13.5 deg. F.

3:40 p. m.: Bucket No. 2, salt only, 14.5 deg. F. Bucket No. 1, salt and inhibitor, 15 deg. F.

4:00 p. m.: Bucket No. 2, salt only, 17 deg. F. Bucket No. 1, salt and inhibitor, 17 deg. F.

Conclusions.—The foregoing tests show that there is very little, if any, effect on the refrigerating qualities of the salt and ice mixture due to the addition of the sodium-dichromate and soda ash inhibitor.

Test to Determine Inhibitor Concentration in Brine Dripping from a Standing Refrigerator Car

Purpose of Test.—To ice and salt one end of a bunker of a standard refrigerator car, the desired proportions of inhibitor being added to the salt before icing the car. To collect samples of the brine drippings periodically and check the inhibitor content.

Description of Test Car.—A standard refrigerator car, SFRD 4249, was used, having the following inside dimensions: Length, 33 ft. ¼ in.; width 8 ft. 2¾ in.; height, 7 ft. 3 in.; volume, 1,975 cu. ft.

Tablo #1
D.& R.G.W. R.R. Laboratory
Analysis Of A.A.R. Corrosion Tests Solutions.
Car No. S.F.R.D. 4249

Date	Time	pH	Grams per Liter of Solution		
			Salt	Soda Ash	Sodium Dichromate
6-27	10:00 AM.	7.2	2.3	Blank	Blank
	10:45 AM.	8.2	60.0	.6279	.8190
	11:00 AM.	8.4	96.0	2.5117	2.6208
	12:00 Noon	8.6	158.0	7.2561	7.3710
	2:00 PM.	8.5	224.0	4.4653	4.4772
	4:00 PM.	8.4	246.0	4.4653	4.5318
	8:00 PM.	8.4	262.0	3.6280	3.7128
6-27/28	12:00 Noon	8.4	280.0	2.7908	2.9484
6-28	4:00 AM.	8.3	280.0	2.9303	3.2214
	9:00 AM.	7.9	250.0	1.9536	2.1840
	1:45 PM.	7.4	268.0	1.2557	1.3104
	5:00 PM.	7.3	262.0	.8372	.9282
	8:00 PM.	7.7	248.0	.8372	.6565
6-28/29	12:00 Noon	7.5	250.0	.6977	.6006
6-29	4:00 AM.	7.3	234.0	.6977	.4914
	10:00 AM.	7.6	186.0	.4186	.2184
	2:00 PM.	7.6	156.0	.3489	.2184
	4:45 PM.	7.8	176.0	.4884	.1638

Procedure of Test.—The test was made at the Santa Fe Hobart ice plant at Los Angeles, beginning June 7, 1940. It was desired to have 3.2 grams of sodium dichromate per liter of salt solution with sufficient soda ash added to bring the pH value to approximately 8, which amounts of dichromate and soda ash were indicated in the laboratory tests last year as being most desirable. A saturated salt solution was prepared from regular car icing salt, and the water used in making the ice. This solution had a pH value of 8 as determined by visual color pH indicator. The desired amount of sodium-dichromate was then added to this solution and it was found that the pH value was lowered considerably. Soda ash was then added and the amount required to bring the pH value back to 8 was determined. The ratio of salt to sodium-dichromate by weight in this mixture was calculated to be 60 to 1. The ratio of salt to soda ash by weight was calculated to be 70 to 1.

The salt was then mixed with inhibitor in these proportions. The regular car icing salt used was a rock salt and came packed in 55-lb. quantities in burlap sacks. Four sacks of salt (220-lb.) were placed in a mixing box and 3 lb. 11 oz. sodium-dichromate and 3 lb. 1 oz. soda ash added and mixed. The mixture was then resacked and the mixing process continued until the required amount of salt had been prepared.

Log of Tests.—(June 27, 1940)

9:30 a. m.: Started icing car. Three 300-lb. cakes of ice were broken in large chunks and placed in one end of bunker, and 3,300 lb. of crushed ice was added to this which filled the bunker 2/3 full.

10:00 a. m.: 550 lb. of salt containing inhibitor was spread over the top of the ice and poled down.
10:45 a. m.: 1,200 lb. of crushed ice added.
10:50 a. m.: 440 lb. of salt with inhibitor added.
11:00 a. m.: Remainder of bunker filled with crushed ice, approximately 6,400 lb. total used.
11:10 a. m.: 660 lb. of salt with inhibitor added. Total salt used, 1,650 lb. Ratio salt to ice, 25.8 percent.

June 28, 1940
9:10 a. m.: Poled ice down in bunker—bunker approximately ½ full.

June 29, 1940
3:10 a. m.: Ice poled down in bunker—bunker about 1/5 full.

Results of Tests.—Table 1 shows the analysis of the brine drippings from this test. This analysis was made by the Denver & Rio Grande Western laboratory.

The desired concentration of sodium-dichromate in the brine drippings is 3.2 grams per liter. It will be noted for the first few hours after icing the car, the sodium-dichromate concentration was considerably over this figure. At the end of 24 hours the ice was about half melted, and the sodium-dichromate concentration was somewhat less than 3.2 grams per liter. From that time on the concentration of sodium-dichromate in the brine drip decreased quite rapidly. The pH value of the brine drip was reasonably close to 8 throughout the test.

Inhibitor Content in Brine Drippings on Road Test

Purpose of Tests.—To give a refrigerator car standard icing with 25 percent salt containing sodium-dichromate and soda ash inhibitor. To collect samples of brine

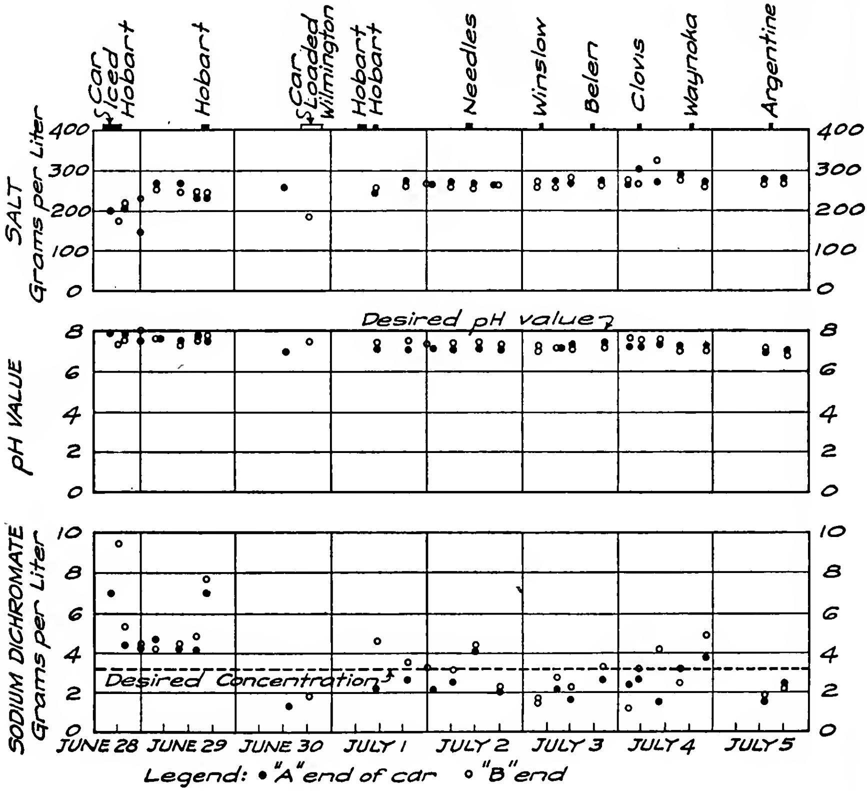
Log of Test Run - Car 5012

Location	Date	Time Icing Started	Time Icing Completed	A End Ice Added Lbs.	A End Salt & Inhibitor Added-Lbs.	B End Ice Added Lbs.	B End Salt & Inhibitor Added-Lbs.	
Hobart Ice Plant	6-28-40	2:15 PM	3:45 PM	7900	1980	1200	-	(a)
" " "	"	5:30 PM	6:22 PM			6700	1980	(a)
" " "	6-29-40	3:25 PM	3:55 PM	1300	355	1600	400	
Dock, Wilmington, Cal.	6-30-40	9:00 PM						(b)
Hobart Ice Plant	7-1-40	6:40 AM	7:00 AM	2100	523	1500	385	
" " "		10:30 AM		1500	380	350	87	(c)
Needles, Cal.	7-2-40	10:25 AM	10:55 AM	1200	330	1200	275	
Winslow, Ariz.	7-3-40	4:05 AM	4:30 AM	500	125	650	167	
Belen, N. M.		5:03 PM	5:30 PM	275	95	750	175	
Clovis, N. M.	7-4-40	4:45 AM	5:08 AM	700	175	600	150	
Argentine, Kans.	7-5-40	2:05 PM	2:16 PM	300	75	275	69	

(a) Ratio of salt to ice - 25.1 percent
(b) Car loaded with 32,530 lbs. fish livers in 40 lb. tins
(c) Car placed in train at Los Angeles at 11:30 AM.

FIG. 1

ANALYSIS OF BRINE DRIPPINGS FROM REFRIGERATOR CAR SFRD 5012



drippings during a regular road trip with car loaded, and to analyze the brine drippings for inhibitor content.

Description of Test Car.—Refrigerator car SFRD 5012 was used for this test. The capacity of this car was 92,100 lb., and the inside dimensions were length, 40 ft. 1¾ in.; width, 8 ft. 8½ in.; height, 6 ft. 1½ in.; 2,300 cu. ft.

Procedure of Test.—The car was pre-iced at the Santa Fe Railway Hobart ice plant at Los Angeles on June 28, 1940. Color checks on the brine drippings on the test of car 4249 had indicated that the pH concentration was higher than desired. Also, the salt concentration was higher than originally supposed. Consequently, the amounts of sodium-dichromate and soda ash were decreased for this test, and the following proportions were used in the mixture: 220 lb. rock salt; 3 lb. sodium-dichromate; 2 lb. soda ash. The solution was mixed with the inhibitor and resacked in the same manner as described in the test on Car No. 4249. The log of the test is given in tabular form.

Results of Tests.—The analyses of the brine drippings from this test as determined by the D. & R. G. W. laboratory are shown graphically in Fig. 1.

It will be noted that again in this test, for a very short period after icing, the dichromate concentration runs high. Throughout the test run a considerable variation was found in the dichromate concentration, but the general average was not far below the desired concentration of 3.2 grams per liter.

The pH value was somewhat lower than the 8 desired, indicating that the proportion of soda ash should be somewhat increased over the proportion used in this test.

Further Work.—It is proposed to conduct a test similar to the above on a brine tank type refrigerator car. The series of tests on track previously mentioned is in progress. Negotiations are also being conducted with salt manufacturers to determine the most practical manner of applying the inhibitor.

The National Perishable Freight committee has made a canvas of principal lines engaged in furnishing refrigerator service for perishable traffic to determine the amount of salt used in this service. The committee advises that in the period July 1, 1939, to June 30, 1940, 37,500 tons of salt were used.

To protect this quantity of salt with inhibitor would cost approximately $85,000 per year for materials only, estimated as follows:

Sodium-dichromate (1/75 x 37,500 tons) 500 tons @ $140 =	$70,000
Soda ash (75 percent of 500 tons) 375 tons @ $40 =	15,000
Total	$85,000

Report on Assignment 12

Specifications for Laying Rails Designed to Set Up the Requirements For Good Workmanship

I. H. Schram (chairman, subcommittee), Lem Adams, A. L. Bartlett, W. H. Bettis, W. H. B. Bevan, F. J. Bishop, L. H. Bond, Armstrong Chinn, H. R. Clarke, L. W. Deslauriers, H. F. Fifield, H. H. Harman, N. M. Hench, F. W. Hillman, E. T. Howson, C. T. Jackson, F. J. Jerome, A. A. Johnson, J. H. Kelly, E. E. Martin, F. H. Masters, J. A. Reed, J. F. Shaffer, G. L. Sitton, G. M. Strachan, J. G. Wishart.

Last year your committee presented as information, a tentative draft of Specifications for Laying Rail (Proceedings for 1940, Vol. 41, pages 599 to 601, inclusive), and requested comments and criticisms thereon. These specifications with minor revisions are now submitted with the recommendation that they be adopted and published in the Manual.

SPECIFICATIONS FOR LAYING RAIL

The location shall be as designated by chief maintenance officer of the railroad.

The several classes of rail shall be laid as follows:

Class of Rail	*Standard Length Feet*	*Color or Design*	*Use*
1st quality—low carbon:	39	Uncolored	Any track—preferably tangent.
1st quality—high carbon:	39	Blue end	Any track—preferably curves.
1st quality—"A" Rails:		Yellow end	Tangent track—not to be used where inspection is difficult.
1st quality—short lengths:		Green end	Any track (see second paragraph under unloading)

Class of Rail	Standard Length Feet	Color or Design	Use
2nd quality—	39 or under	White end	Any tangent track or curves not to exceed 3 deg., preferably in tracks used largely for freight or where speed does not exceed 50 mph. Not to be used where inspection is difficult.
X Rails:	39 or under	Brown end	Freight tracks, turnout side of side tracks or where designated by chief maintenance officer.

UNLOADING

Rail shall be unloaded from the car with an approved derrick or crane and placed with the head up without dropping, with sufficient support under the base and with the brand facing toward the center of the track.

Rails shall be unloaded opposite the locations in which they are to be placed in the track, with suitable gaps being allowed for short lengths. Rails shall be so placed that the joints in each line of rail shall be not more than 30 inches from the centers of the opposite rails and preferably not more than 18 inches. Locations of joints can be best determined with a steel tape.

Proper lengths of rail for road crossings, station platforms, bridges and other special locations shall be unloaded in a safe and convenient location, where they will not constitute an obstruction.

To minimize the cutting of new full-length rails, short rails shall also be distributed in proper places to provide for proper spacing at insulated joints and for connections to switches.

No rail less than 25 feet long shall be used in main tracks with the exception that shorter rails not less than 14 feet long may be used for temporary closures and for connections within turnouts.

Joints, turnouts and fastenings shall be unloaded and distributed concurrently with the rail, except that small material shall be left in the containers until the time of laying the rail.

PREPARATION OF TRACK

Track shall be in good surface prior to the laying of new rail, and where curve realinement work will require heavy throws, such work shall be done before the new rail is laid.

No portion of the track structure, the absence of which will impair its integrity, may be removed prior to the relaying of the rail. Full flag protection or slow-order protection, as may be necessary, shall be provided in cases where rail is being laid under traffic.

LAYING

All rail ends and angle bars shall, immediately in advance of laying, be painted on the contact surfaces with a lubricant equal to black lubricating oil.

Tie plates shall have a full and uniform bearing on ties and the bearings on each tie shall be in the same plane. Adzing shall be done where necessary to fulfill these requirements. All spike holes shall be plugged with treated tie plugs after the old spikes and tie plates have been removed. Creosote oil, heated when necessary, shall be applied to the ties after adzing.

Where new rail is to be laid, the track shall be fully tie plated. Where possible, plates shall be applied after preparation of tie plate beds and before the placing of the new rail.

Where practical, rail shall be laid against the current of traffic on double-track lines and against the predominant tonnage movement on single track.

Standard expansion shims shall be placed between the ends of adjacent rails to insure the proper space allowance for expansion as indicated in the following table:

Temperature of rail, degrees F.	*160 Joints per Mile 33-Foot Rails*	*135 Joints per Mile 39-Foot Rails*
0 to 25	3/16 inch	1/4 inch
26 to 50	1/8 inch	3/16 inch
51 to 75	1/8 inch	1/8 inch
76 to 100	1/16 inch	1/16 inch
Over 100	None	None

Where metal shims are used they shall be removed to within 12 rails of the laying. Wooden or fiber shims need not be removed.

In tunnels where the temperature is above 70 degrees F., rails shall be laid close without bumping; where the temperature is below 70 degrees F., an opening of 1/16 inch shall be allowed (for 39-foot rail) for each 20 degrees F. reduction in temperature.

A rail thermometer shall be used to ascertain the temperature of the rail and in making the reading it shall be placed on the rail base on the side away from the sun.

Rails shall be placed one at a time except that in cases of busy traffic where trains cannot be diverted to other tracks, stretches of rail not over 20 in number may be bolted together at one side of the track and then lined into place, using care to maintain the expansion allowance uniformly. Rails shall be laid without bumping or striking and with the ends square.

Rails shall be laid or installed so that joints will not be placed in road crossings within the limits of switch points or guard rails, or within 6 feet of the ends of open-floor bridges. Where rails longer than standard are needed for such locations, they shall be at least 60 feet long.

Rail joints shall be applied before the track is spiked, the joint bars to be lined up with rail in vertical position and the bolts tightened by starting in the middle of the joint and working towards the ends. Spring washers or other similar approved appliances shall be used.

Spikes shall be driven vertically with the face of the shank in contact with the base of the rail, and shall be so driven that it will not be necessary to straighten them during driving. Spikes shall be so staggered that all the outside spikes shall be on the same side of the ties and all the inside spikes on the opposite side.

The full quota of rail anchors shall be applied prior to the passage of a train over the new rail.

In laying the second line of rail, gaging shall be done at least at every third tie.

When necessary to make a temporary connection for the passage of a train, the union shall be made with a rail of the section being renewed. The closure rail shall not be less than 14 feet long, and shall be connected to the new rail by a compromise joint if the rails are of different sections. The connection rail shall have a full number of bolts and spikes. At the completion of a day's work a short section of new rail not less than 18 feet long shall be used in making the closure and shall be connected to the old rail with a compromise joint.

COMPLETION OF WORK

All rail laid down on any given day shall be fully spiked and bolted at the close of the day's work. Bolt holes made in the field shall be drilled and not burned with a torch.

After rail has been laid the tops of adjacent rail ends shall be ground to a level surface.

Rail ends shall be cross slotted and beveled at mill or as soon after laying as required.

Markings indicating the classification of released rail shall be placed on it promptly, and such rail and its fixtures loaded promptly.

It is desirable that other renewals of track material shall follow rail laying as promptly as possible.

All ties on which the new rail does not have a full bearing shall be tamped and the spikes re-driven; proper slow orders shall be maintained until this is done. If weather conditions do not permit this work to be carried out, any loose ties may be temporarily shimmed.

Where necessary, bolts shall be given a second tightening. After the ballasting and resurfacing of the track have been completed the bolts shall be tested and, if required, brought to a pre-determined tension.

Report on Assignment 13

Spirals for High Speed Operation

Collaborating with Committee 16—Economics of Railway Location and Operation

C. W. Baldridge (chairman, subcommittee), A. L. Bartlett, L. H. Bond, Armstrong Chinn, H. R. Clarke, L. W. Deslauriers, H. F. Fifield, H. H. Harman, F. W. Hillman, E. T. Howson, C. T. Jackson, J. H. Kelly, K. R. McLennan, J. B. Myers, G. A. Peabody, G. L. Sitton, J. G. Wishart.

The committee recommends that the matter now in the Manual, page 5–26, beginning with the sub-heading "Staking Spirals by Offsets" and ending on page 5–27 with the line above the sub-heading "Staking Spirals by Deflections" be withdrawn from the Manual and that the following matter be adopted for inclusion in the Manual and inserted following the matter which is now on page 5–28

Staking Spirals by Offsets

Calculating the Curve

When the degree of the circular curve is known and the length of spiral has been decided upon, the angle A and the angle to each "end of chord" point are found in the same manner as for staking the spiral by deflections. The offset for each "end of chord" point then may be found by formulas (5), (6) and (7) given on page 5–25. Formula (5) will determine the length of Chord C, which is used in formulas (6) and (7).

Formula (6) will give the length of X, which is the distance to be measured along the tangent *T.S.* toward *P.I.* and formula (7) gives the lengths of offsets to be measured at right angles to the tangent at the distance X for the respective "chord and point." The points so located form the center line of the spiral.

To avoid long calculations and tedious field work, all offsets should be staked from the tangent—*T.S.* to *P.I.*

Another method for staking spirals by offsets which is particularly convenient where it is desired to locate any point in the spiral which must be accurately staked at other than the end of chord points, is as follows:

Alternate Method

The spiral may be staked by offsets, one half being offset from the tangent and the other half from the circular curve, by making the offsets vary directly as the cube of the distance from the *T.S.* for one half and from the *S.C.* for the other half.

The length of the spiral and the offset between the tangent and the circular curve are determined by the following formulas:

$$L = \frac{88}{75} ES \qquad (1)$$

$$O = \frac{L^2 D}{137{,}520} = 0.015168\ E^2\ (E + 3) \qquad (2)$$

in which

E = elevation in inches
S = speed in miles per hour
D = degree of curve
L = length of spiral in feet
O = tangent offset in feet

In these formulas the values of E and S must be in accordance with the formula in the Manual, page 5–42. The length provides for a run-off of 1¼ inch per second and the tangent offset is independent of the degree of curve, provided the relations of L, E, and S are observed.

The following table gives these offsets.

(Inches)	*Offset* (*Feet*)	*Elev.* (*Inches*)	*Offset* (*Feet*)	*Elev.* (*Inches*)	*Offset* (*Feet*)
½	0.013	2¾	0.660	5	3.034
¾	0.032	3	0.819	5¼	3.449
1	0.061	3¼	1.001	5½	3.900
1¼	0.101	3½	1.208	5¾	4.388
1½	0.154	3¾	1.440	6	4.914
1¾	0.221	4	1.699	6¼	5.481
2	0.303	4¼	1.986	6½	6.088
2¼	0.403	4½	2.304	6¾	6.738
2½	0.521	4¾	2.652	7	7.432

Intermediate points on the spiral may be set conveniently by dividing each half length into five equal chords and setting off at the chord points right-angle or normal offsets, as the case may be, equal respectively to: 0.004, 0.032, 0.108, 0.256, and 0.500 of the main offset.

Points on the spiral between the chord points may be set by using the equation of the curve:

$$y = \frac{Dx^3}{34380L} \qquad (3)$$

in which x and y are the coordinates from the *T.S.* as origin. The ordinates so determined are used as right-angle offsets for the half of the curve laid off from the tangent and as normal offsets for the half laid off from the circular curve.

The simple relations among degree of curvature, speed, elevation, length of spiral, and spiral offset set forth in equations (1) and (2) afford a ready means for selecting the spiral and adjusting the speed and elevation to the particular conditions at the site. This facility of selection exists regardless of whether the actual staking of the curve be done by deflections or by offsets.

The committee recommends that the matter as outlined for inclusion in the Manual be adopted and that the subject be discontinued.

Report of Committee 4—Rail

W. H. Penfield, *Chairman,*	C. J. Geyer	Robert Faries*, *Vice-Chairman,*
J. B. Akers	F. M. Graham	Philip Petri
J. E. Armstrong	G. W. Harris	G. A. Phillips
W. J. Backes	E. M. Hastings	B. H. Prater
W. C. Barnes	B. Herman	A. N. Reece
L. H. Bond	F. S. Hewes	J. C. Ryan
N. J. Boughton	W. H. Hillis	L. H. Scheifele
C. B. Bronson	Maro Johnson	R. T. Scholes
W. J. Burton	W. H. Kirkbride	F. S. Schwinn
H. A. Cassil	C. S. Kirkpatrick	G. R. Smiley
E. E. Chapman	B. R. Kulp	A. N. Talbot
H. R. Clarke	G. M. Magee	J. C. Wallace
E. J. Cullen	R. W. Marye	Barton Wheelwright
W. A. Duff	Ray McBrian	W. P. Wiltsee
J. M. Farrin	C. E. Morgan	R. P. Winton
P. O. Ferris	J. V. Neubert**	Louis Yager
F. W. Gardiner	E. E. Oviatt	
	J. C. Patterson	*Committee*

* Died September 8, 1940.
** Died June 4, 1940.

To the American Railway Engineering Association:

Your committee reports on the following subjects:

1. Revision of Manual.

Progress report. Revised forms for recording rail failures recommended for adoption to replace corresponding material now in Manual .... page 641

2. (a) Further research, including details of mill practice and manufacture as they affect rail quality and rail failures, giving special attention to transverse fissure failures and other defects in the head, web and base, collaborating with Rail Manufacturers' Technical Committee.

Progress report, presenting Seventh Progress Report of the Rails Investigation with résumé of accomplishments to date and outline of work for 1941 .... page 681

(b) Specifications for thermal treatment of rail, such as controlled cooled, Brunorized, etc.

Progress report. Included in above Seventh Progress Report of the Rails Investigation .... page 681

3. Compilation of statistics.

(a) All rail failures, making special study of transverse fissure failures.

Progress report, presented as information .... pages 645 and 650

(b) Compilation of statistics for determining the performance of controlled cooled and Brunorized rail in service with respect to rail failures with view toward evaluating the higher price paid for treated than for untreated rails.

Progress report, presented as information .... page 656

4. Cause and prevention of rail battering and methods of reconditioning rail ends.

Progress report, presented as information .... page 658

5. Economic value of different sizes of rail.

Progress report, presented as information .... page 659

Bulletin 423, February, 1941.

6. Continuous welding of rail, collaborating with Committee 5—Track and Special Committee on Stresses in Railroad Track.

Progress report, presented as information .... page 660

7. Service tests of various types of joint bars.

Progress report, presented as information .... page 662

8. Investigate joint bar failures and give consideration to revision of design and specifications.

Progress report, presented as information .... page 666

Supplementary monograph by W. B. Leaf, presented as information .... page 672

9. Corrugated rail, causes and remedy. Effect upon riding qualities of tracks and upon the costs of track and equipment maintenance.

No report.

The Committee on Rail,
W. H. Penfield, *Chairman.*

August F. Blaess

August F. Blaess, retired chief engineer of the Illinois Central System, died at his home in Gulfport, Miss., on February 19, 1940.

By reason of his attainments and his earnest and unselfish service in connection with the activities of Comittee 4—Rail, he enjoyed the highest personal respect and esteem of its members.

The members of the committee take this opportunity to record the loss suffered in the death of August F. Blaess.

The Committee on Rail

Robert Faries

Robert Faries, assistant chief engineer-maintenance, Pennsylvania Railroad System, died at Philadelphia on September 8, 1940.

He served for a period of eight years as a member of Committee 4—Rail, and was vice-chairman at the time of his death.

By ability and untiring effort, he achieved an outstanding position in the railway engineering field. Through his unassuming leadership and wide knowledge of the subject he greatly advanced the work of the committee. His sterling qualities as a man and kindly character endeared him to all his associates.

The members of Committee 4—Rail have suffered a great loss through the death of Robert Faries.

The Committee on Rail

John V. Neubert

John V. Neubert, chief engineer maintenance of way of the New York Central System, died at New York on June 4, 1940.

Mr. Neubert served for a period of 12 years, from 1928 until the time of his death, as a member of Committee 4—Rail, during which period he was chairman of the committee for the four years from 1936 to 1940.

By his outstanding ability, his unselfish and unstinting service, and his leadership, he markedly advanced the work of the committee. His qualities of character and personality endeared him to each member.

The members of Committee 4—Rail, unanimously record the feeling of irreparable loss occasioned by the death of John V. Neubert.

The Committee on Rail

Report on Assignment 1

Revision of Manual

C. B. Bronson (chairman, subcommittee), J. E. Armstrong, W. C. Barnes, N. J. Boughton, W. J. Burton, E. E. Chapman, W. A. Duff, J. M. Farrin, F. M. Graham, G. W. Harris, E. M. Hastings, B. Herman, Maro Johnson, B. R. Kulp, E. E. Oviatt, W. H. Penfield, A. N. Reece, L. H. Scheifele, G. R. Smiley, Barton Wheelwright, Louis Yager.

Form 402-C. Yearly Summary of Rail Failures

Your committee has found it desirable to revise Form 402–C. Yearly Summary of Rail Failures, in order to separate the compound from the transverse fissures, and to eliminate the columns showing carbon content and rail failure rate at the end of the form. These two columns are not used in the compilation of the data issued yearly. A number of corrections have also been made in the Instructions for Filling in Rail Failure Form 402–C, the principal purpose of which is to bring it up to date and in line with present practice.

The revised Form 402–C, Rev., 1941 and the instructions shown as 402–C(a), Rev., 1941, are recommended for adoption and printing in the Manual as substitutions for those shown on pages 4–47 and 4–48 in the Manual.

Form 402-E. Statement of Transverse Fissure Rail Failures

Your committee has also found it desirable to revise Form 402–E. Statement of Transverse Fissure Failures, because the reports as now sent in are so voluminous that a large amount of work is required from the railroads and the engineer of tests. The form, as revised, provides all of the essential data for tabulation of the annual reports, and eliminates the reporting by individual heat numbers which do not enter into the statistics, and are not required for this purpose. A trial has been made of the revised form herewith presented and it has proved satisfactory. Minor revisions have also been made in the Instructions for Filling in Transverse Fissure Rail Failure Form 402–E in conformity with it.

The revised Form 402–E, Rev., 1941 and the instructions, shown as 402–E(a), Rev., 1941, are recommended for adoption and printing in the Manual as substitutions for those shown on Pages 4–49 and 4–50 in the Manual.

Form 402–C (a)
Issued 1931
Revised 1935, 1941

ASSOCIATION OF AMERICAN RAILROADS
ENGINEERING DIVISION

Instructions for Filling in Rail Failure Form 402-C, Rev. 1941

1. Statistics are desired for all new rail weighing 80 lb. per yd. and over, laid in all main tracks. Continue records 10 years unless rail has been removed from main tracks where originally laid. Omit information for rollings of less than 500 tons.
2. Do not include in this report rails broken or injured by wrecks, broken wheels or similar causes, wheel burned, battered or chipped-end rails and those replaced on account of wear.
3. Fill in the information for rollings in which there were no failures as well as those in which there were failures.
4. Report all rail failures, listing separately in the proper columns under general heading "Number of Failures" those which broke in service and those removed from track as a result of the use of detector cars.
5. Express the tonnage of rails and the mile-years in whole numbers, the mileage in whole numbers and hundredths.
6. Under "Kind of Steel" indicate Open-Hearth by "OH", Intermediate Manganese by "IM" or "MM", Brunorized by "BR", Controlled Cooled by "CC", and if end hardened, add "H". For other

special steels and processes, assign suitable abbreviations and if not obvious, indicate meanings by footnotes.

7. It is important that the report indicate clearly the mill at which the rails were rolled. A list of mills which have rolled rails during recent years is given here together with the corresponding designations which should be entered under "Mill."

Name of Company	*Name of Mill*	*Location*	*Designation*
Algoma Steel Co.	Algoma	Sault Ste. Marie, Ont., Can.	Alg.
Bethlehem Steel Co.	Lackawanna	Lackawanna, N. Y.	Lack.
Bethlehem Steel Co.	Maryland	Sparrows Point, Md.	Md.
Bethlehem Steel Co.	Steelton	Steelton, Pa.	Stltn.
Carnegie-Illinois Steel Co.	Edgar Thomson	Braddock, Pa.	Carn.
Carnegie-Illinois Steel Co.	Gary	Gary, Ind.	Gary
Colorado Fuel & Iron Co.	Minnequa	Pueblo, Colo.	Colo.
Dominion Iron & Steel Co.	Dominion	Sydney, Nova Scotia	Dom.
Inland Steel Co.	Inland	Indiana Harbor, Ind.	Inld.
Tennessee Coal, Iron & R. R. Co.	Ensley	Ensley, Ala.	Tenn.

8. In the first three columns which call for two entries for each item, enter "Mill," "Year Rolled" and "Section" on the first line (opposite "This Year") and "Kind of Steel," "Year Laid" and "Lb. per Yd." on second line (opposite "Total").
9. Include horizontal split heads (horizontal fissures) under "Other Head" failures.
10. To convert tons into track miles, the number of tons may be divided by the figures given below, which show the tons (2,240 lb.) of rail per mile of single track for different weights per yard of rail.

80 lb. RA–A	125.71 tons	112 lb. RE	176.79 tons
90 lb. RA–A	141.43 "	127 lb. NYC	200.04 "
100 lb. RA–A	157.77 "	130 lb. RE	203.65 "
100 lb. RA–B	157.93 "	131 lb. RE	205.54 "
100 lb. RE	159.50 "	136 lb. LV	214.03 "
105 lb. NYC	165.00 "	152 lb. PRR	238.23 "
110 lb. RE	172.86 "		

11. Each line for the different year's rollings should be completely filled in without the use of ditto marks.
12. Report only the failures for the year ending December 31 opposite the lines "This Year" and all failures from date laid to December 31 opposite the lines "Total."
13. In the column "Mile-Years" there should be entered opposite the line "This Year" the actual quantity in miles of rail in service for the individual year. Opposite "Total" the quantity should be the summation of the miles in service for each year from date of rolling. These amounts constitute the divisors for reducing the corresponding number of failures to a 100 mile-year basis, instead of the quantity in miles originally laid, which was used as the divisor up to the year 1922.
14. For Purposes of Reporting Service of Rails: Rail laid in any month in the year that the report is made is considered to have zero years age, hence zero mile-years of service. Rail laid in any month in the year preceding the year of the report shall be considered as having one year's service. Follow a corresponding rule for rail laid in preceding years.

For Example:

Assume 30 miles of rail rolled in calendar year 1937 of which
10 miles are laid in calendar year 1937 and
20 miles are laid in calendar year 1938.
None of this rail removed from track prior to 1940.

The reports for succeeding years would show service of these rails as follows:

Date of Report	*Year Rolled*	*Year Laid*	*Equiv. Track Mi.*	*Mi. Yrs.*	*Period*
Dec. 31, 1937	1937	1937	10	0	This Year
				0	Total to Date
Dec. 31, 1938	1937	1937	10	10	This Year
				10	Total to Date
	1937	1938	20	0	This Year
				0	Total to Date
Dec. 31, 1939	1937	1937	10	10	This Year
				20	Total to Date
	1937	1938	20	20	This Year
				20	Total to Date

15. In case of doubt as to the interpretation of Form 402–C or of any of these instructions, write to the Engineer of Tests, Rail Committee, Association of American Railroads, 59 East Van Buren Street, Chicago, Ill.

ASSOCIATION OF AMERICAN RAILROADS
ENGINEERING DIVISION

FORM 402-C
REV. 1941

RAIL FAILURES FOR YEAR ENDING DECEMBER 31, 19---- RAILROAD----------------------- SHEET NO.--- OF---

MILL AND KIND OF STEEL	YR. ROLLED AND YR. LAID	SECTION AND LB. PER YD.	TONS NEW RAIL LAID	EQUIV. TRACK MILES	MILE-YEARS	PERIOD	NUMBER OF FAILURES													
							TRAN. FISS.		COMP. FISS.		OTHER HEAD		BROKEN		WEB		BASE		TOTAL	
							SERV.	DET.	SERV.	DET.	SERV.	DET.	SERV.	DET.	SERV.	DET.	SERV.	DET.	SERV.	DET.
						THIS YR. TOTAL														
						THIS YR. TOTAL														
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						THIS YR. TOTAL														
						THIS YR. TOTAL														
						THIS YR. TOTAL														

IN FILLING OUT THIS FORM, FOLLOW INSTRUCTIONS ON FORM 402-C(a) REV. 1941.
THIS FORM WHEN FILLED OUT SHOULD BE RETURNED TO THE ASSOCIATION OF AMERICAN RAILROADS, 59 E. VAN BUREN ST., CHICAGO, ILL.

ASSOCIATION OF AMERICAN RAILROADS
ENGINEERING DIVISION

BESS - BESSEMER
OH - OPEN HEARTH
MM - MEDIUM MANGANESE
CC - CONTROLLED COOLED
BR - BRUNORIZED

STATEMENT OF TRANSVERSE FISSURE RAIL FAILURES

FORM 402-E
REV. 1941

FROM---------19------TO---------19------RAILWAY---------------------- SHEET NO.---OF---

RAIL					FAILURES	
KIND OF STEEL	LB. PER YD.	SECT-ION	MILL	YEAR ROLLED	SERVICE	DETECTED

RAIL					FAILURES	
KIND OF STEEL	LB. PER YD.	SECT-ION	MILL	YEAR ROLLED	SERVICE	DETECTED

RAIL					FAILURES	
KIND OF STEEL	LB. PER YD.	SECT-ION	MILL	YEAR ROLLED	SERVICE	DETECTED

HOW MANY MAIN TRACK MILES ARE IN THE TERRITORY IN WHICH YOU REPORT FISSURE FAILURES?
IS THIS THE SAME TERRITORY AS THAT IN WHICH YOU REPORT GENERAL RAIL FAILURES ON FORM 402-C?

REPORT TRANSVERSE FISSURE RAIL FAILURES ONLY. FOLLOW INSTRUCTIONS ON FORM 402E-(a) REV. 1941
THIS STATEMENT SHOULD BE RETURNED TO THE ASSOCIATION OF AMERICAN RAILROADS, 59 E. VAN BUREN ST., CHICAGO, ILL.

Form 402-E (a)
Issued 1931
Revised 1941

ASSOCIATION OF AMERICAN RAILROADS
ENGINEERING DIVISION

Instructions for Filling in Transverse Fissure Rail Failure

Form 402-E, Rev. 1941

1. Report is desired on all transverse fissure rail failures in rail weighing 80 lb. per yard and over, laid in all main track. Compound fissures and horizontal fissures (horizontal split-heads) are NOT to be reported.
2. The report year ends on December 31. Statement of transverse fissure rail failures will be made quarterly, listing the rails that have failed during the quarters ending March 31, June 30, September 30 and December 31.
3. Under "Rail" enter information from brand on rail except that under "Mill" the following mill designations should be used to make identification positive.

Name of Company	*Name of Mill*	*Location*	*Designation*
Algoma Steel Co.	Algoma	Sault Ste. Marie, Ont., Can.	Alg.
Bethlehem Steel Co.	Lackawanna	Lackawanna, N. Y.	Lack.
Bethlehem Steel Co.	Maryland	Sparrows Point, Md.	Md.
Bethlehem Steel Co.	Steelton	Steelton, Pa.	Stltn.
Bethlehem Steel Co.	Saucon	South Bethlehem, Pa.	Sauc.
Bethlehem Steel Co.	Cambria	Johnstown, Pa.	Camb.
Carnegie Steel Co.	Edgar Thomson	Braddock, Pa.	Carn.
Colorado Fuel & Iron Co.	Minnequa	Pueblo, Colo.	Colo.
Dominion Iron & Steel Co.	Dominion	Sydney, Nova Scotia	Dom.
Illinois Steel Co.	Gary	Gary, Ind.	Gary
Illinois Steel Co.	South Works	South Chicago, Ill.	SoWk.
Inland Steel Co.	Inland	Indiana Harbor, Ind.	Inld.
Lackawanna Iron & Steel Co.	Scranton	Scranton, Pa.	Scrn.
Tennessee Coal, Iron & R. R. Co.	Ensley	Ensley, Ala.	Tenn.
		Germany	Germ.

4. Report all transverse fissure rail failures whether detected by test cars or other testing devices or disclosed by inspection or by actual breakage in service.
5. List the total service failures, occurring in any one year of rolling of any one mill, being from rail identical in kind of steel, pounds per yard, and section, in column headed "Service". Likewise, list the total detected failures, occurring in any one year of rolling of any one mill, being from rail identical in kind of steel, pounds per yard, and section, in column headed "Detected".
6. Should any railroad furnishing this report not consent to its publication, notice to that effect should be given on sheet 1, of the form.
7. Include in this report all transverse fissure rail failures with as much of the information as may be available; not omitting to report any failures because part of the information is not available.
8. Double space all entries and make each complete without use of ditto marks.
9. Answers to questions appearing at bottom of Form 402 E need be answered on first sheet only of each quarter's report.
10. In case of doubt as to the interpretation of Form 402 E, or any of these instructions, write to the Engineer of Tests, Rail Committee, Association of American Railroads, 59 E. Van Buren St., Chicago, Ill.

Report on Assignment 3 (a)

Rail Failure Statistics

Part 1—General Rail Failures

By W. C. Barnes, *Engineer of Tests, Rail Committee*

The rail failure statistics for the year ended December 31, 1939, appearing in this report, have been compiled in accordance with the standard method of basing the failure rates on mile-years of service in track.

The reported tonnages and track miles of rollings for 1934 and succeeding years, included in these statistics, are as follows:

Year Rolled	*Tons*	*Track Miles*
1934	640,299	3,456
1935	364,103	1,998
1936	733,221	3,994
1937	821,684	4,489
1938	372,035	2,069
Total	2,931,342	16,006

This compares with totals of 2,717,949 tons, or 14,743 track miles, of rail reported last year for the 1933 to 1937 rollings.

TABLE I - AVERAGE FAILURES FOR 100 TRACK MILES - ALL MILLS
(Both service and detected failures are included)

Year Rolled	YEARS SERVICE				
	1	2	3	4	5
1908					398.1
1909				224.1	277.8
1910			124.0	152.7	198.5
1911		77.0	104.4	133.3	176.3
1912	28.9	32.1	49.3	78.9	107.1
1913	12.5	25.8	44.8	69.5	91.9
1914	8.2	19.8	32.9	50.9	74.0
1915	8.9	19.0	34.2	53.0	82.4
1916	11.8	29.2	47.7	70.6	105.4
1917	21.6	38.9	66.0	110.5	137.0
1918	8.9	27.6	54.0	92.8	125.4
1919	14.8	39.4	73.7	104.8	115.7
1920	14.2	32.4	63.1	84.5	119.6
1921	10.9	34.9	56.9	70.9	98.9
1922	15.9	34.8	55.2	80.4	110.0
1923	14.3	33.2	57.6	86.0	114.1
1924	14.0	33.4	58.3	82.0	110.7
1925	15.5	36.6	58.3	76.6	110.7
1926	17.1	41.2	64.6	102.6	131.3
1927	18.4	37.7	69.5	94.6	112.4
1928	11.0	28.0	45.8	57.4	76.4
1929	14.1	36.8	55.9	82.7	121.2
1930	7.8	12.8	22.4	37.6	69.0
1931	9.1	19.7	32.3	46.8	67.4
1932	4.5	11.8	21.2	39.6	64.1
1933	6.2	11.7	25.6	52.4	73.5
1934	4.6	13.6	19.3	25.9	35.8
1935	4.2	9.6	16.3	32.3	
1936	4.2	7.3	18.1		
1937	3.3	5.8			
1938	2.2				

Table 1 shows the average number of failures per 100 track miles of rail in service which accumulated during the one to five years' service in the rail reported from rollings of 1934 to 1937, inclusive, from all mills, together with similar rates of older rollings reproduced from previous reports. Both service and detected failures in all kinds of steel are included in this table.

The 1934 rollings, whose period of observation is now concluded, show an average rate of 35.8 failures per 100 track miles for the five year period. This rate is approximately one-half that of the 1933 rollings and is the lowest rate recorded to date.

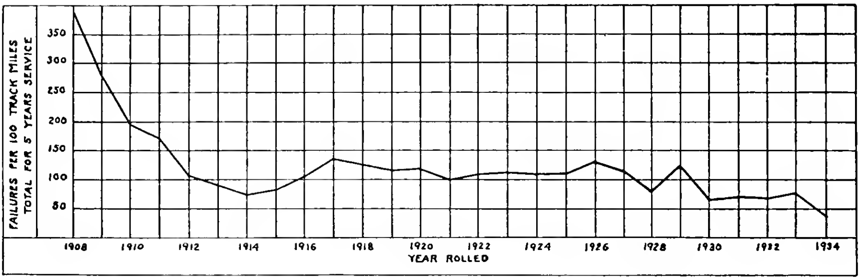

Fig. 1.—Service and Detected Rail Failures in the United States and Canada (5 Years' Service).

Figure 1 shows diagrammatically the five year average from Table 1.

Table 2 presents the accumulated failures and failure rates of rail from each of the mills for each of the rollings of 1934 to 1937, inclusive. Service plus detected failures and failure rates are shown separately.

TABLE 2.- ACCUMULATED FAILURES AND FAILURE RATES FROM DATE ROLLED TO DEC. 31, 1939, BY MILLS, COMPUTED BY MILE YEARS OF RAIL IN SERVICE. ORIGINAL TRACK MILES ARE INCLUDED FOR INFORMATION ONLY.

Year Rolled	Orig'l Trk.Mls.	SERVICE Total	SERVICE Pr.100 Trk.Mls. Pr. Yr.	SERVICE & DETECTED Total	SERVICE & DETECTED Pr.100 Trk.Mls. Pr. Yr.	Pr.100 Trk.Mls.	Orig'l Trk.Mls.	SERVICE Total	SERVICE Pr.100 Trk.Mls. Pr. Yr.	SERVICE & DETECTED Total	SERVICE & DETECTED Pr.100 Trk.Mls. Pr. Yr.	Pr.100 Trk.Mls.
	ALGOMA						DOMINION					
1934	92.25	41	8.76	56	11.96	59.60	-	-	-	-	-	-
1935	113.14	7	1.55	8	1.77		-	-	-	-	-	
1936	119.49	19	5.41	20	5.70		41.11	0	0.00	0	0.00	
1937	121.23	13	5.31	14	5.21		42.34	0	0.00	0	0.00	
1938	95.62	0	0.00	1	1.04		42.64	0	0.00	0	0.00	
	CARNEGIE						ENSLEY					
1934	539.76	154	6.59	177	7.58	37.85	593.31	122	4.22	205	7.15	35.70
1935	256.97	23	2.24	40	3.90		472.67	59	3.24	85	4.67	
1936	445.50	32	2.48	46	3.55		602.08	56	3.21	88	5.05	
1937	572.26	45	4.47	49	4.87		690.65	33	2.40	35	2.54	
1938	167.07	4	2.38	4	2.38		480.94	17	3.73	17	3.73	
	GARY						INLAND					
1934	737.67	436	12.62	508	14.71	73.50	262.22	25	2.15	31	2.64	13.25
1935	493.18	157	8.08	425	21.85		129.44	11	2.32	11	2.32	
1936	1196.49	174	5.38	387	11.96		411.74	26	2.25	33	2.85	
1937	1157.01	88	3.98	92	4.16		383.57	16	2.26	18	2.54	
1938	489.87	15	3.23	16	3.44		164.28	1	0.61	1	0.61	
	LACKAWANNA						MARYLAND					
1934	327.61	55	3.42	62	3.85	19.30	164.12	28	3.71	37	4.91	24.6
1935	106.73	16	3.77	20	4.71		18.34	0	0.00	0	0.00	
1936	193.83	19	3.35	24	4.23		37.80	0	0.00	0	0.00	
1937	312.27	9	1.50	11	1.83		106.95	2	1.19	2	1.19	
1938	134.87	0	0.00	0	0.00		87.95	2	2.27	2	2.27	
	MINNEQUE						STEELTON					
1934	361.91	27	1.73	31	1.99	10.00	376.76	17	1.13	18	1.19	5.96
1935	271.96	26	2.39	34	3.14		135.63	9	1.67	10	1.86	
1936	607.86	31	1.95	31	1.95		338.57	7	0.74	10	1.06	
1937	728.31	4	0.30	4	0.30		374.10	15	2.23	16	2.38	
1938	59.42	2	3.39	2	3.39		346.16	1	0.32	1	0.32	
	ALL MILLS (Excl. ALG. & DOM.)						ALL MILLS (Incl. ALG. & DOM.)					
1934	3363.36	864	5.66	1069	7.00	35.03	3455.61	905	5.76	1125	7.16	35.8
1935	1884.92	301	4.08	625	8.47		1998.06	308	3.94	633	8.09	32.3
1936	3833.87	345	3.24	619	5.82		3994.47	364	3.29	639	5.75	18.1
1937	4325.12	212	2.64	227	2.83		4488.69	225	2.70	241	2.89	5.8
1938	1930.56	42	2.29	43	2.34		2068.82	42	2.13	44	2.23	2.2
TOTALS	15337.83	1764		2583			16005.65	1844		2682		

Figure 2 shows diagrammatically the failure rates per 100 track miles of the 1934 and earlier rollings for five years' service, from Table 2, for combined service and detected failures.

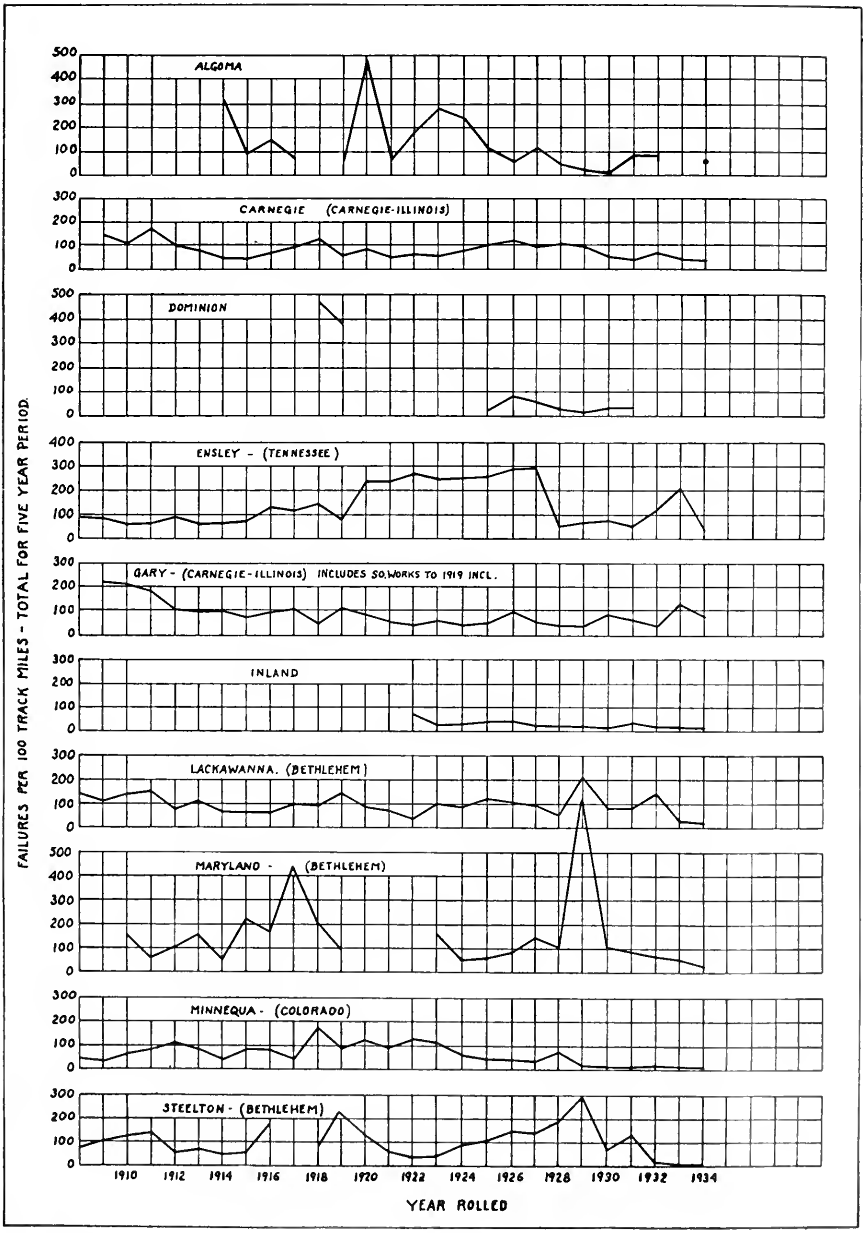

Fig. 2.—Record of Failures Per 100 Track Miles for Five Years' Service for Rollings from 1908 to 1934 (Service and Detected Failures Included).

MILL	YEAR ROLLED	FAILURES, ALL TYPES, PER 100 AVE. TRACK MILES PER YEAR: SERVICE ONLY	SERVICE AND DETECTED
CARNEGIE (CARNEGIE-ILLINOIS)	1934	6.6	7.6
	1935	2.2	3.9
	1936	2.5	3.6
	1937	4.5	4.9
	1938	2.4	2.4
ENSLEY (TENNESSEE)	1934	4.2	7.1
	1935	3.2	4.7
	1936	3.2	5.0
	1937	2.4	2.5
	1938	3.7	3.7
GARY (CARNEGIE-ILLINOIS)	1934	12.6	14.7
	1935	8.1	21.8
	1936	5.4	12.0
	1937	4.0	4.2
	1938	3.2	3.4
INLAND	1934	2.1	2.6
	1935	2.3	2.3
	1936	2.2	2.8
	1937	2.3	2.5
	1938	0.6	0.6
LACKAWANNA (BETHLEHEM)	1934	3.4	3.8
	1935	3.8	4.7
	1936	3.3	4.2
	1937	1.5	1.8
	1938	0.0	0.0
MARYLAND (BETHLEHEM)	1934	3.7	4.9
	1935	0.0	0.0
	1936	0.0	0.0
	1937	1.2	1.2
	1938	2.3	2.3
MINNEQUA (COLORADO)	1934	1.7	2.0
	1935	2.4	3.1
	1936	1.9	1.9
	1937	0.3	0.3
	1938	3.4	3.4
STEELTON (BETHLEHEM)	1934	1.1	1.2
	1935	1.7	1.9
	1936	0.7	1.1
	1937	2.2	2.4
	1938	0.3	0.3
ALL MILLS	1934	5.7	7.0
	1935	4.1	8.5
	1936	3.2	5.8
	1937	2.6	2.8
	1938	2.3	2.3

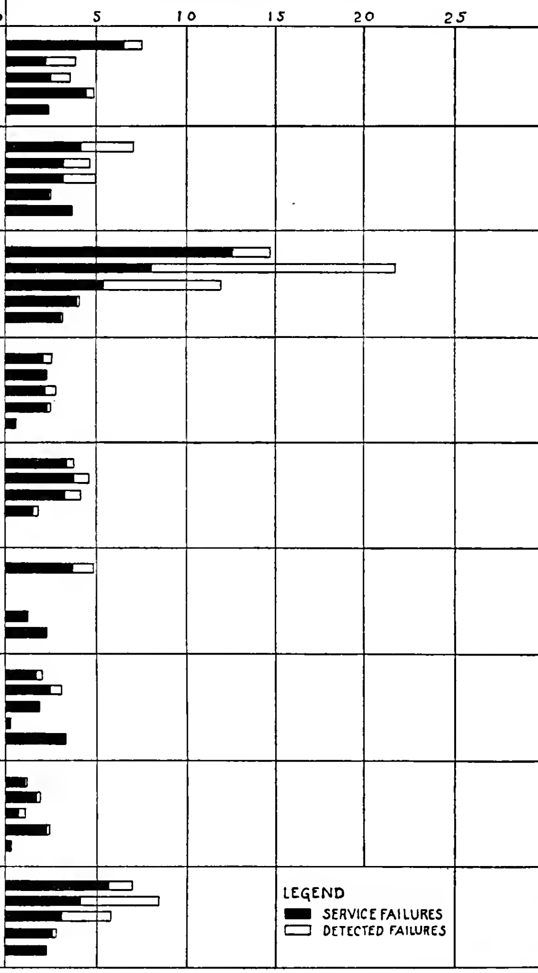

Fig. 3.—Failure Rates From Date Rolled to December 31, 1939, by Mills (Service and Detected Failure Rates Shown Separately).

Figure 3 shows diagrammatically the Table 2 failure rates per 100 track miles per year, separately for service and service plus detected failures, for each of the 1934 and subsequent rollings, by mills, unweighted for traffic.

Figure 4 shows diagrammatically the comparative performance of the various mills from data underlying Fig. 3, except that average traffic density factors have been introduced in the final computations, using the method described on pages 369–370 of Vol. 32, AREA. Proceedings for 1931. No claim is made for the entire accuracy of this

MILL	YEAR ROLLED	SERVICE ONLY	SERVICE AND DETECTED
CARNEGIE (CARNEGIE-ILLINOIS)	1934	1.7	1.9
	1935	0.5	0.8
	1936	0.6	0.9
	1937	1.2	1.3
	1938	0.5	0.5
ENSLEY (TENNESSEE)	1934	3.1	5.3
	1935	3.2	4.7
	1936	2.4	3.8
	1937	1.8	1.9
	1938	2.9	2.9
GARY (CARNEGIE-ILLINOIS)	1934	5.5	6.4
	1935	3.8	10.2
	1936	2.8	6.1
	1937	2.0	2.2
	1938	1.5	1.6
INLAND	1934	0.8	1.0
	1935	0.9	0.9
	1936	1.0	1.2
	1937	1.0	1.1
	1938	0.2	0.2
LACKAWANNA (BETHLEHEM)	1934	1.5	1.7
	1935	1.5	1.9
	1936	1.3	1.7
	1937	0.6	0.8
	1938	0.0	0.0
MARYLAND (BETHLEHEM)	1934	1.6	2.1
	1935	0.0	0.0
	1936	0.0	0.0
	1937	0.4	0.4
	1938	1.6	1.6
MINNEQUA (COLORADO)	1934	1.2	1.4
	1935	1.5	2.0
	1936	1.5	1.5
	1937	0.2	0.2
	1938	2.9	2.9
STEELTON (BETHLEHEM)	1934	0.5	0.5
	1935	0.5	0.5
	1936	0.2	0.4
	1937	0.8	0.8
	1938	0.2	0.2
ALL MILLS	1934	2.5	3.0
	1935	1.8	3.7
	1936	1.5	2.7
	1937	1.2	1.3
	1938	1.1	1.1

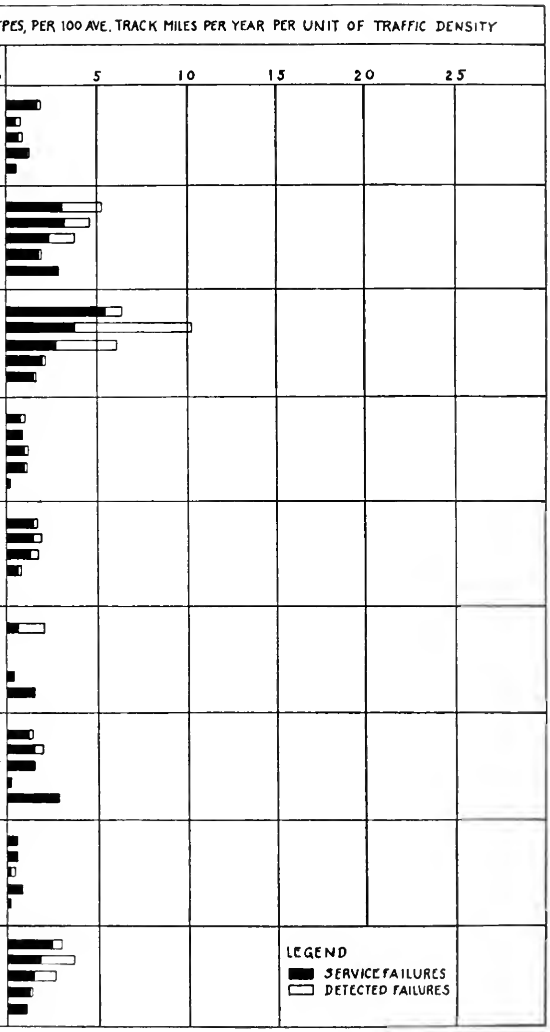

Fig. 4.—Failure Rates From Year Rolled to December 31, 1939, by Mills, Altered by Traffic Density Factors (Service and Detected Failure Rates Shown Separately).

method of rating, but it does give more consideration to the service to which the rails from the various mills are subjected than does the method of rating on which Fig. 3 is based.

Table 3 shows the average weights of rail from the various mills and from all mills which are included in these statistics.

TABLE 3

AVERAGE WEIGHTS OF RAIL COMPILED FROM TONNAGES USED IN THIS REPORT

Mill	*1934*	*1935*	*1936*	*1937*	*1938*
Algoma	105.2	106.6	105.0	105.5	101.2
Dominion			100.0	100.0	100.0
Edgar Thomson (Carn.)	129.0	128.5	125.7	127.5	126.1
Ensley (Tenn.)	106.0	106.3	107.9	108.1	107.1
Gary (Ill.)	116.1	116.2	116.8	116.1	117.5
Inland	118.3	121.0	118.5	116.5	119.3
Lackawanna (Beth.)	120.6	118.9	117.6	117.0	117.6
Maryland (Beth.)	120.1	125.7	126.7	131.0	107.6
Minnequa (Colo.)	116.7	115.8	115.6	111.5	121.6
Steelton (Beth.)	124.3	123.1	125.0	123.5	116.7
ALL MILLS	118.0	116.1	116.7	116.5	114.4

Report on Assignment 3 (a)

Rail Failure Statistics

Part 2—Transverse Fissure Failures

By W. C. BARNES, *Engineer of Tests, Rail Committee*

These statistics constitute a cumulative record of transverse fissure failures that have been reported up to and including December 31, 1939. They include all transverse fissured rails reported, whether located by actual breakage in service or detected before actual breakage by inspection or test. The totals shown, however, do not represent all such failures that have occurred for the reason that while the records of some roads have been cumulative for over 20 years, those of other roads are of more recent origin. Furthermore, a few roads do not report such failures to the Association.

Table 1 corresponds with Table 1 of the report of last year, and shows separately the number of service and detected transverse fissured rail failures which have been reported in all rollings, no matter how old, classified by roads and by years in which the failures occurred. It includes data from roads which are consistently reporting separately the service and detected failures. The total transverse fissure failures which occurred on any one road or on all roads during any given year can be obtained by adding the corresponding figures for service failures and for detected failures appearing in this table.

Table 1 differs from Table 1 of the report of last year in that the service failures which occurred prior to 1929, formerly listed under heading "Prior", have been omitted as being of little interest. Detection methods were first used to any extent in 1929. Additional explanations will be found in foot notes to the table.

The total fissure rail failures reported in 1939 compared with those in 1938 are:

	Service	*Detected*	*Total*
1939	5,765	13,823	19,588
1938	5,588	12,425	18,013
Increase in 1939	177	1,398	1,575

Table 1.—Transverse Fissure Failures By Railroad and By Year Failed—All Rollings

Roads	Service Failures												Detected Failures (a)											
	1929	1930[b]	1931	1932	1933	1934	1935	1936	1937	1938	1939	Total	1929	1930[b]	1931	1932	1933	1934	1935	1936	1937	1938	1939	Total
AT&SF	91	142	114	84	64	46	35	46	92	43	85	842					13	77	121	59	247	194	326	1,037
ACL	25	21	29	37	15	33	48	62	102	66	67	505		66			69			159	180	251	141	866
Ban & Aroos	4	7	2	1	1							15												
B & M	34	35	22	33	17	24	18	12	14	28	25	262		17		19	45	17		241	207	45	706	1,297
B & O	469	372	506	383	397	328	356	325	431	382	282	4,231	53			182	217	308	618	630	652	807	431	3,898
C P (e)	108	138	109	90	103	113	121	134	138	114	164	1,332			351	214	472	834	899	999	1,501	1,239	1,780	8,289
C of Ga	92	80	42	74	56	81	54	64	55	59	70	727		80		107	18	136	101	96	119	110	91	858
C of NJ	95	73	59	40	61	85	58	110	112	90	69	852		35	111									146
C & EI	41	18	18	28	39	23	14	18	22	23	15	259	28		59		74	43	65	29	65	77	89	529
C & O	258	181	239	330	280	316	300	227	310	187	145	2,773	22	376	667	323	978	584	1,262	1,392	891	923	786	8,204
C & NW	62	101	86	110	81	99	69	68	41	38	47	802	16	31	110	218	110	341	155	355	317	294	465	2,412
CMStP&P	11	26	45	105	125	99	71	74	53	46	45	700	43		49		156	179	247	197	357	288	285	1,801
CRI&P	123	111	116	131	139	136	97	135	121	98	74	1,281	20		18	93	13	274	62	132	344	366	336	1,658
DL&W	139	98	64	102	82	65	76	90	75	72	72	935						173	244	229	454	461	400	1,961
Erie (c)	235	156	175	181	179	187	171	167	229	123	133	1,936	27	7	4		75		165		166	264	350	1,058
GN	175	189	141	126	128	143	179	246	276	215	246	2,064		25			6	144	114	88	69	92	142	680
IC	597	439	310	281	245	275	364	467	540	515	520	4,553	25	126	204	217	273	108	284	314	447	557	596	3,151
IHB							3	2	6			11										2		2
L&HR	8	3	11	3	4	2		1	5	6	8	51												
L&NE			6	3	2	7			6	1	5	30						16			24			40
L V	60	39	22	17	34	30	31	22	28	52	41	376			78			140		140			218	576
L&N	456	285	268	220	182	215	181	253	229	178	178	2,645	101	165			358	19	341	488	577	530	408	2,987
MKT	30	31	32	30	17	20	33	39	30	35	80	377	10	12	29	76	31	98	74	77	167	169	61	804
M&O	18	26	32	42	24	25	28	45	76	55	83	454	4					1						5
NC&StL	34	22	50	42	58	20	19	50	36	19	30	380		2				40	45	17	42	70	42	258
NYC (Sys)	444	340	306	299	306	272	318	381	361	389	433	3,849	27	107	83	182	253	114	191	322	322	428	562	2,591
NYNH&H	51	40	25	24	40	59	34	37	48	39	31	428	17	67	159	106	101	100	82	60	101	92	110	995
NYO & W	63	60	48	54	67	34	34	21	37	55	33	506			1	4								5
N&W	25	43	41	29	50	33	23	38	36	22	21	361		20		5		74			84	45	44	272
N P	160	131	171	160	126	169	168	171	259	213	185	1,913	48				81	19	324	173	292	246	310	1,493
P RR (e)	584	717	426	345	345	430	414	544	672	513	443	5,433		260	576	403	851	440	1,073	690	757	857	921	6,828
P M (e)	3	7	8	10	5	7	7	7	8	4	2	68	12	18	41	23	71	39	57	58	137	34	27	517
Reading	53	57	100	111	111	160	166	162	186	164	191	1,461												
RF&P	1		1	3	5	4	4	2	4	3	2	29	3				36		67	44	53	52	61	316
Rutland	2	3	1		1		1	1	1	1	2	13				7			3					10
S P (Pac Lines)	500	458	331	322	269	208	200	324	481	394	590	4,077		131	251	142	374	580	455	767	629	637	477	4,443
Sou Rys (d)	205	201	183	160	187	232	261	368	504	256	226	2,783										1,263	1,061	2,324
U P	438	497	495	535	517	936	1,003	1,176	1,443	923	1,033	8,996	34		137	157	321	660	1,361	1,437	1,996	2,032	2,525	10,660
Virginian	12	7	24	24	28	33	30	23	36	34	39	290												
W Md	57	255	148	94	94	62	87	116	70	133	50	1,166						106			86		72	264
All Roads	5,763	5,409	4,806	4,663	4,484	5,011	5,076	6,028	7,173	5,588	5,765	59,766	490	1,545	2,928	2,478	4,996	5,664	8,410	9,193	11,283	12,425	13,823	73,235

Notes—
(a) Detection methods were first used to any extent in 1929.
(b) 1930 Data cover 11 months only, account change in fiscal year.
(c) Data revised to agree with supplementary report from road.
(d) Data reinstated as road has resumed reporting.

Figure 1 presents graphically the fissure failures by year failed from Table 1. The solid curve shows the service failures; the broken line shows the detected failures and the dotted line shows the service-plus-detected failures. It will be noted that, despite the large number of fissured rails detected and removed from track before they could fail in service, the number of service failures in 1939 is as great as it was in 1929 when detection methods were first introduced.

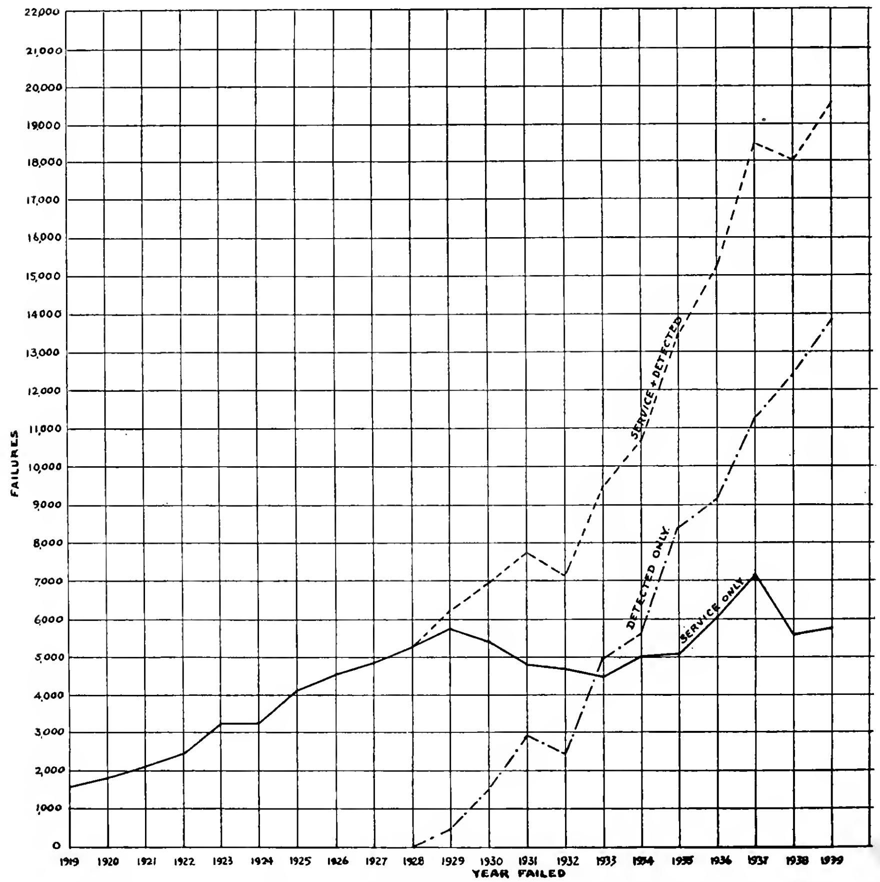

Fig. 1.—Total Fissure Failures Reported Each Year (1930 Includes 11 Months Only).

Table 2 shows all transverse fissure rail failures, including both service and detected failures, reported by all reporting roads, for the rollings of each year from 1929 to 1938 inclusive, from each mill, accumulated from the year rolled to December 31, 1939. These data are unweighted for tonnage output of mills, density of traffic or for years in service. This table is most useful in comparing the failures which were reported in the rollings of various years from any one mill.

MILL	YEAR ROLLED	FISSURE FAILURE RATES PER 100 AVE. TRACK MILES PER YEAR: SERVICE ONLY	SERVICE AND DETECTED
CARNEGIE (CARNEGIE-ILLINOIS)	1930	1.6	4.5
	1931	1.8	3.9
	1932	3.1	5.6
	1933	1.6	3.8
	1934	0.5	0.7
	1935	0.3	1.1
	1936	0.2	0.3
	1937	0.1	0.1
	1938	0.0	0.0
ENSLEY (TENNESSEE)	1930	2.6	6.7
	1931	5.3	12.1
	1932	8.8	31.6
	1933	11.6	48.8
	1934	0.7	2.5
	1935	1.5	3.8
	1936	0.0	0.0
	1937	0.0	0.0
	1938	0.0	0.0
GARY (CARNEGIE-ILLINOIS)	1930	6.1	19.5
	1931	5.1	18.9
	1932	3.0	4.2
	1933	3.2	16.2
	1934	0.3	1.5
	1935	3.0	10.6
	1936	0.9	3.7
	1937	0.3	0.5
	1938	0.0	0.0
INLAND	1930	0.8	2.5
	1931	6.1	18.2
	1932	0.5	3.2
	1933	0.7	2.6
	1934	0.1	0.3
	1935	0.0	0.0
	1936	0.0	0.0
	1937	0.0	0.0
	1938	0.0	0.0
LACKAWANNA (BETHLEHEM)	1930	0.9	2.1
	1931	2.4	4.9
	1932	0.6	2.5
	1933	0.6	0.8
	1934	0.4	0.8
	1935	1.6	2.6
	1936	0.4	1.1
	1937	0.0	0.0
	1938	0.0	0.0
MARYLAND (BETHLEHEM)	1930	18.2	69.5
	1931	12.8	55.2
	1932	0.9	56.6
	1933	0.0	2.8
	1934	0.0	1.8
	1935	0.0	0.0
	1936	0.0	0.0
	1937	0.0	0.0
	1938	0.0	0.0
MINNEQUA (COLORADO)	1930	0.2	1.0
	1931	0.9	1.8
	1932	0.1	0.6
	1933	0.0	0.0
	1934	0.1	0.2
	1935	0.4	0.6
	1936	0.1	0.2
	1937	0.0	0.0
	1938	0.0	0.0
STEELTON (BETHLEHEM)	1930	5.8	18.7
	1931	10.3	21.7
	1932	2.0	7.2
	1933	0.0	0.5
	1934	0.1	0.2
	1935	0.5	0.8
	1936	0.3	0.4
	1937	0.0	0.0
	1938	0.4	0.4
ALL MILLS	1930	4.6	10.9
	1931	6.2	14.1
	1932	3.8	9.8
	1933	2.6	10.3
	1934	0.4	1.0
	1935	1.3	3.8
	1936	0.4	1.2
	1937	0.1	0.2
	1938	0.1	0.1

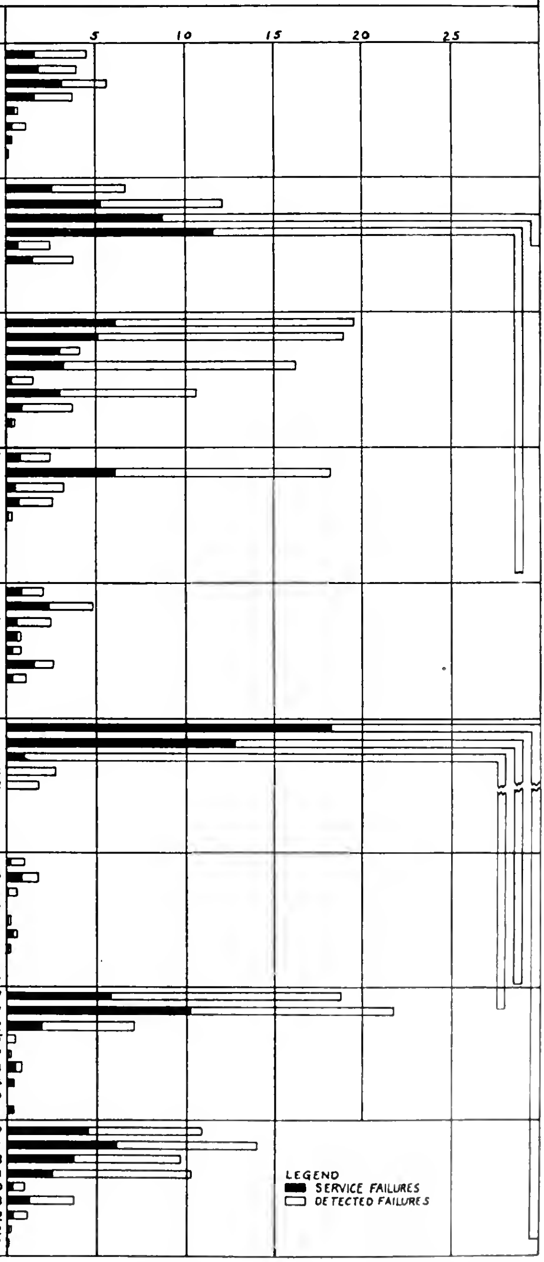

Fig. 2.—Fissure Failure Rates From Date Rolled to December 31, 1939, by Mills (Service and Detected Failures Shown Separately).

FISSURE FAILURES PER 100 AVE. TRACK MILES PER YEAR PER UNIT OF TRAFFIC DENSITY

Mill	Year Rolled	Service Only	Service and Detected
CARNEGIE (CARNEGIE-ILLINOIS)	1930	0.5	1.3
	1931	0.5	1.1
	1932	0.8	1.2
	1933	0.4	0.9
	1934	0.1	0.2
	1935	0.1	0.2
	1936	0.0	0.1
	1937	0.0	0.0
	1938	0.0	0.0
ENSLEY (TENNESSEE)	1930	1.7	4.5
	1931	5.3	12.1
	1932	5.6	20.0
	1933	8.0	33.9
	1934	0.5	1.8
	1935	1.2	2.9
	1936	0.0	0.0
	1937	0.0	0.0
	1938	0.0	0.0
GARY (CARNEGIE-ILLINOIS)	1930	2.7	8.5
	1931	2.1	7.7
	1932	1.5	2.1
	1933	0.9	3.9
	1934	0.1	0.6
	1935	1.2	4.3
	1936	0.5	1.8
	1937	0.1	0.3
	1938	0.0	0.0
INLAND	1930	0.3	1.0
	1931	1.8	5.2
	1932	0.2	1.5
	1933	0.2	0.6
	1934	0.0	0.1
	1935	0.0	0.0
	1936	0.0	0.0
	1937	0.0	0.0
	1938	0.0	0.0
LACKAWANNA (BETHLEHEM)	1930	0.3	0.8
	1931	0.8	1.6
	1932	0.2	0.9
	1933	0.2	0.3
	1934	0.2	0.3
	1935	0.6	1.0
	1936	0.2	0.5
	1937	0.0	0.0
	1938	0.0	0.0
MARYLAND (BETHLEHEM)	1930	5.3	22.2
	1931	4.4	18.8
	1932	0.4	25.4
	1933	0.0	0.6
	1934	0.0	0.7
	1935	0.0	0.0
	1936	0.0	0.0
	1937	0.0	0.0
	1938	0.0	0.0
MINNEQUA (COLORADO)	1930	0.1	0.8
	1931	0.6	1.2
	1932	0.1	0.5
	1933	0.0	0.0
	1934	0.1	0.2
	1935	0.3	0.4
	1936	0.1	0.1
	1937	0.0	0.0
	1938	0.0	0.0
STEELTON (BETHLEHEM)	1930	1.8	5.8
	1931	3.4	7.1
	1932	0.6	2.2
	1933	0.0	0.1
	1934	0.1	0.1
	1935	0.1	0.2
	1936	0.1	0.1
	1937	0.0	0.0
	1938	0.2	0.2
ALL MILLS	1930	1.9	4.6
	1931	2.7	6.1
	1932	1.7	4.5
	1933	0.8	3.1
	1934	0.2	0.4
	1935	0.5	1.4
	1936	0.2	0.5
	1937	0.0	0.1
	1938	0.0	0.0

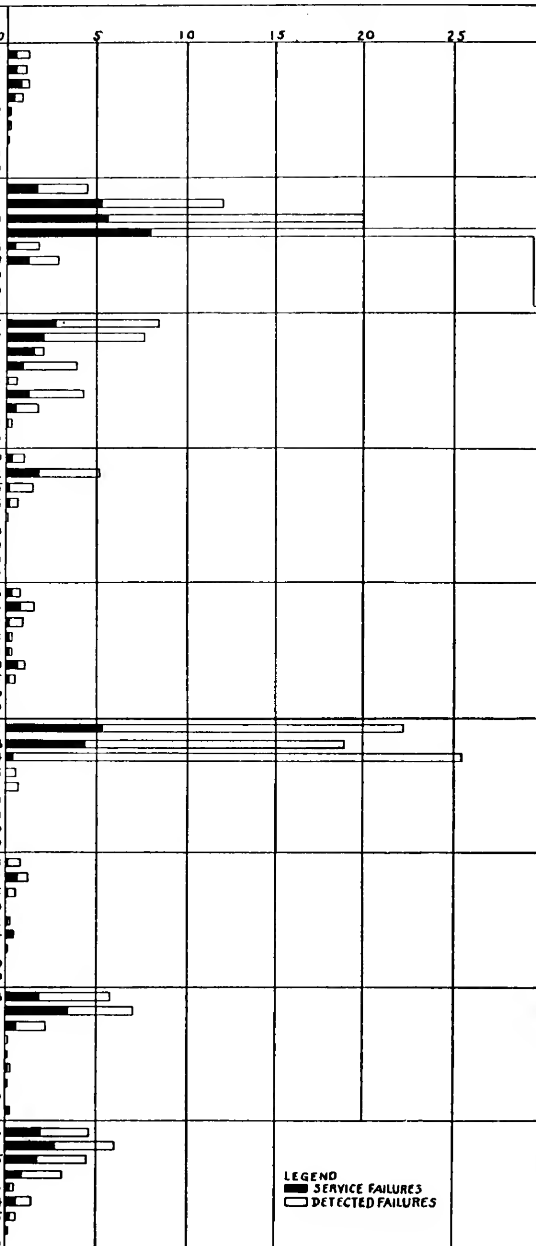

Fig. 3.—Fissure Failure Rates From Date Rolled to December 31, 1939, by Mills. Altered by Traffic Density Factors (Service and Detected Failures Shown Separately).

TABLE NO. 2. - ACCUMULATED TRANSVERSE FISSURE FAILURES REPORTED TO DEC. 31, 1939 BY YEAR ROLLED AND BY MILL
(Includes Service and Detected Failures)

Year	Algoma			Carnegie			Colorado			Dominion			Gary			Inland		
Rolled	Prior	1939	Total	Prior	1939	Total	Prior	1939	Total	Prior	1939	Total	Prior	1939	Total	Prior	1939	Total
1929	86	12	98	687	134	821	149	67	216	18	16	34	498	145	643	169	39	208
30	3	17	20	302	56	358	49	15	64	19	46	65	1906	412	2318	73	37	110
31	21	18	39	147	61	208	19	24	43	0	1	1	920	370	1290	222	88	310
32	39	17	56	75	29	104	9	2	11	0	0	0	26	42	68	6	12	18
33	0	0	0	38	12	50	0	0	0	0	0	0	174	31	205	9	2	11
34	30	19	49	13	9	22	1	2	3	0	0	0	24	46	70	2	4	6
35	0	0	0	6	5	11	4	5	9	0	0	0	99	178	277	1	3	4
36	0	0	0	3	1	4	1	1	2	0	0	0	16	220	236	0	1	1
37	0	0	0	1	0	1	1	0	1	0	0	0	2	8	10	0	0	0
38	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	179	83	262	1272	309	1581	233	116	349	37	63	100	3665	1452	5117	482	186	668

	Lackawanna			Maryland			Steelton			Tennessee			All Mills		
	Prior	1939	Total	Prior	1939	Total	Prior	1939	Total	Prior	1939	Total	Prior	1939	Total
1929	1128	308	1436	6235	471	6706	1501	724	2225	1010	230	1240	11481	2146	13627
30	56	29	85	957	217	1174	773	104	877	383	112	495	4521	1045	5566
31	93	44	137	483	123	606	614	97	711	662	290	952	3181	1116	4297
32	10	8	18	124	19	143	15	4	19	351	117	468	655	250	905
33	3	0	3	28	4	32	0	1	1	214	60	274	466	110	576
34	6	5	11	0	12	12	1	2	3	25	30	55	102	129	231
35	5	5	10	1	0	1	0	2	2	27	25	52	143	223	366
36	4	2	6	1	2	3	1	2	3	3	0	3	29	229	258
37	0	0	0	0	0	0	0	0	0	0	0	0	4	8	12
38	0	0	0	0	0	0	0	1	1	0	1	1	0	4	4
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	1305	401	1706	7829	848	8677	2905	937	3842	2675	865	3540	20582	5260	25842

Fissure rail failures reported since 1924, as occurring in the first year of service, are as follows:

29	Failures	in	1925	from	1925	Rollings,	All	Mills
50	"	"	1926	"	1926	"	"	"
114	"	"	1927	"	1927	"	"	"
58	"	"	1928	"	1928	"	"	"
106	"	"	1929	"	1929	"	"	"
33	"	"	1930	"	1930	"	"	"
32	"	"	1931	"	1931	"	"	"
3	"	"	1932	"	1932	"	"	"
0	"	"	1933	"	1933	"	"	"
0	"	"	1934	"	1934	"	"	"
3	"	"	1935	"	1935	"	"	"
3	"	"	1936	"	1936	"	"	"
1	"	"	1937	"	1937	"	"	"
0	"	"	1938	"	1938	"	"	"
0	"	"	1939	"	1939	"	"	"

Figure 2 is a mill rating chart which shows separately, for each mill, the service and detected transverse fissure rail failure rates per 100 average track miles per year, from date of rolling to December 31, 1939, unweighted for traffic, for each of the rollings of 1930 to 1938, inclusive.

Figure 3 shows graphically the average rates of failure, by mills, from Fig. 2, modified by the application of average traffic density factors, the derivation of which is explained on pages 369–70 of Vol. 32 of the AREA Proceedings for 1931. Owing to the necessity of using factors obtained from average traffic per mile of road, instead of actual traffic over the particular rails in question, this chart can be considered only as an approximation.

Report on Assignment 3 (b)

Controlled-Cooled and Brunorized Rail

Compilation of Statistics for Determining the Performance of Controlled Cooled and Brunorized Rail in Service With Respect to Rail Failures, with the View Toward Evaluating the Higher Price Paid for Treated Than for Untreated Rails

By W. C. Barnes, *Engineer of Tests, Rail Committee*

Data are being accumulated to assist in determining the performance in service of controlled-cooled and Brunorized rail rolled under contract.

Controlled-cooled rail was first rolled under contract by the various mills as follows: Dominion—January, 1931; Algoma—December, 1933; Steelton—March, 1935; Inland—April, 1935; Lackawanna—May, 1935; Carnegie—October, 1935; Colorado—January, 1936; Ensley—February, 1936; Gary—April, 1936.

Brunorized rail was first rolled under contract at Gary by the old process in October, 1936. This process was revised on April 27, 1938, to provide for holding the rails at a temperature of 800–1,000 deg. F. for 2½ hours before charging them into the Brunorizing furnace.

Table 1 lists the tonnages of all such contract rail, from all mills, purchased by roads represented on the Rail committee as reported to June 30, 1940. It includes a total of 3,022,206 tons of controlled-cooled rail and 123,873 tons of Brunorized rail, making a total of 3,146,079 tons. This represents an increase of 916,160 tons of controlled-cooled rail and 30,244 tons of Brunorized rail over the tonnages reported purchased to June 30, 1939.

Table 2 lists failures that have been reported to October 21, 1940, in the rail listed in Table 1. These failures are classified in accordance with AREA standards. The few transverse and compound fissure failures in controlled-cooled rails which are listed have been verified, but in all cases investigation has shown that they developed from inclusions and not from the shatter cracks which the controlled-cooling process is supposed to prevent. It will be noted that a number of fissures have developed in Brunorized rails which were rolled prior to the change made in that process in October, 1936. No fissures have been reported in any Brunorized rail made under the revised process.

Table 1

Tonnage of Controlled-Cooled and Brunorized Contract Rail Purchased to June 30, 1940

Road	*Controlled Cooled*	*Brunorized*	*Total*
AT&SF	295,119	3,571	298,690
ACL	3,039	0	3,039
B&O	31,043	0	31,043
B&M	15,514	0	15,514
CPR	178,028	0	178,028
CNR	188,978	0	188,978
C&NW	68,972	19,572	88,544
C&O	176,558	0	176,558
CB&Q	96,556	18,823	115,379
CMStP&P	62,449	36,413	98,862
CRI&P	109,387	0	109,387

Road	*Controlled Cooled*	*Brunorized*	*Total*
D&H	28,974	0	28,974
D&RGW	42,037	0	42,037
DL&W	38,332	0	38,332
ERIE	95,731	0	95,731
GN	54,764	15,934	70,698
IC	53,358	5,555	58,913
IRT Co.	12,932	0	12,932
KCS	12,956	6,186	19,142
LV	6,835	0	6,835
L&N	93,682	0	93,682
MKT	0	204	204
MP	108,489	0	108,489
MeCent.	6,297	0	6,297
NY Sys	196,043	13,117	209,160
NYC&StL	44,440	0	44,440
NYNH&H	46,037	0	46,037
N&W	66,360	0	66,360
NP	112,223	0	112,223
PM	27,520	0	27,520
PRR	225,238	0	225,238
READING	4,837	0	4,837
RF&P	8,925	0	8,925
SP	235,365	0	235,365
Sou Sys	96,786	0	96,786
UP	178,402	4,498	182,900
TOTAL TONS	3,022,206	123,873	3,146,079

TABLE 2

FAILURE DATA OF CONTROLLED-COOLED AND BRUNORIZED RAIL—SUMMARY BY MILLS—ALL ROLLINGS

Accumulated Failures to October 21, 1940

Controlled Cooled Rail

Mill	*Trans. Fiss.*	*Comp'd Fiss.*	*Other Head*	*Broken*	*Web*	*Base*	*Total*
Algoma	0	0	43	11	8	55	117
Carnegie	1*	0	4	6	8	3	22
Colorado	0	0	6	1	2	2	11
Dominion	0	0	42	4	17	10	73
Gary	0	0	13	14	7	16	50
Inland	0	0	13	39	5	13	70
Lackawanna	0	0	5	2	2	1	10
Steelton	2*	1*	8	5	3	1	20
Tennessee	0	0	33	18	57	6	114
All Rollings, All Mills	3	1	167	100	109	107	487
Brunorized Rail							
Gary (Old Process)	35	4	5	5	1	4	54
Gary (Revised Process)	0	0	0	0	0	0	0

* Developed from inclusions.

Report on Assignment 4

Cause and Prevention of Rail Battering and Methods of Reconditioning Rail Ends

F. M. Graham (chairman, subcommittee), W. C. Barnes, L. H. Bond, N. J. Boughton, C. B. Bronson, H. A. Cassil, E. E. Chapman, H. R. Clarke, E. J. Cullen, F. W. Gardiner, C. J. Geyer, B. Herman, F. S. Hewes, W. H. Hillis, W. H. Kirkbride, B. R. Kulp, G. M. Magee, R. W. Marye, Ray McBrian, C. E. Morgan, E. E. Oviatt, J. C. Patterson, Philip Petri, J. C. Ryan, L. H. Schiefele, R. T. Scholes, F. S. Schwinn, G. R. Smiley, A. N. Talbot, J. C. Wallace, Barton Wheelwright, R. P. Winton.

Subcommittee 6 is continuing to cooperate with the Rails Investigation at the University of Illinois in studying the prevention of end batter of rails by suitable heat treatment. The investigation is being continued to observe the field test of heat-treated rail ends on the Chesapeake & Ohio Railway, north of Carey, Ohio, in the manner outlined in Appendix F of the 1940 Report of Committee 4—Rail.

The heat-treated rail ends show generally less batter than the comparative untreated rail ends. The gross tonnage moving over the test territory since the test was started and up to October, 1940, is about 60,000,000 tons.

Some of the heat-treated rail ends are showing slight evidence of cracks in a generally horizontal plane at the ends of the rails. These cracks are about 1/16 to ⅛ in. below the top of the rail. None of them has broken out. The cause of these cracks is unknown at present, but is being studied by the Rails Investigation. It is possible that these cracks may in some manner be related to the cross grinding of these joints.

The subcommittee has initiated a study of the art of building up rail ends by various methods of welding. A questionnaire on this subject has been submitted to members of the Rail committee. The replies received have been summarized and tabulated and indicate a very great diversity in methods employed, costs, etc. Various weights of rail were involved, the annual gross tonnage over welded rail was not generally known, and the costs were apparently not stated on the same basis. For this reason it seems desirable to make a comparative field test, where methods as employed by various railroads can be carefully observed, the actual costs of material and labor recorded, the lengths and depths of added material measured, and the kinds of welding rods and other data recorded as found necessary to compare the relative merits of the methods employed.

Annual gross tonnage records will be kept, and it is believed that periodical inspections will disclose valuable information.

Several railroads have offered to participate in this test by welding up joints in the test track, using methods which have been found to be satisfactory in their own experience. However, some difficulty has been experienced in finding a suitable test site but such a site now seems available, and it is expected to install the test about May 1, 1941.

It is hoped to accumulate information with respect to reconditioning rail ends by cropping and grinding.

This is submitted as a progress report, and it is recommended that the subject be continued.

Report on Assignment 5

Economic Value of Different Sizes of Rail

J. M. Farrin (chairman, sub-committee), J. E. Armstrong, W. J. Backes, W. C. Barnes, C. B. Bronson, W. J. Burton, H. R. Clarke, W. A. Duff, P. O. Ferris, C. J. Geyer, G. W. Harris, E. M. Hastings, B. Herman, W. H. Hillis, Maro Johnson, C. S. Kirkpatrick, G. M. Magee, R. W. Marye, C. E. Morgan, W. H. Penfield, Philip Petri, B. H. Prater, A. N. Reece, G. R. Smiley, A. N. Talbot, Barton Wheelwright, W. P. Wiltsee, Louis Yager.

Ratios have been tentatively established, using both physical and mathematical rail properties, to show how the different weights of rail compare when laid in the same location under identical roadbed conditions, traffic density and maintenance standards for the following items which make up the annual cost of owning and maintaining the various rail sections:

1. Interest on investment
2. Depreciation in first location
3. Track laying and surfacing
4. Effect on life of ties
5. Effect on coal consumption

The ratios have been expressed in terms of the 152-lb. Pennsylvania Railroad section (which is taken as unity because it is the heaviest rail in use) and plotted in graph form. By means of this graph, if costs are known for the above items for any size of rail, the approximate cost for any other size of rail desired can be determined by proportion.

During the past year efforts have been directed toward checking the accuracy of these ratios by comparison with actual performance, as is illustrated in the tabulation of data for the Kansas City Southern.

Test Sections on the Kansas City Southern Railway for Item No. 3—Track Laying and Surfacing

				Labor Cost per Mile			
				1938		1939	
Size of Rail lb. per yd.	*Age Years*	*Track Miles*	*Traffic Million tons per year*	*Kansas City Southern Report*	*Farrin Ratio*	*Kansas City Southern Report*	*Farrin Ratio*
85	16½	39.88	4.750	$65	$65	$56	$56
100	9½	27.52	4.306	44	50	40	43
127	7¾	38.21	4.750	34	37	42	32

In addition, a questionnaire was sent to all members of the committee requesting information as to their experience in tonnage life in the first location of the various sizes of rail, together with man-hours of section labor expended in track laying and surfacing. Eighteen replies were received, and the information thus obtained was plotted and found to produce curves approximately parallel with those shown in the proposed plan, thus indicating that ratios plotted in the proposed plan are approximately in agreement.

The ratios were also compared with the annual costs of 100-lb. versus 131-lb. rail presented by the late Robert Faries, assistant chief engineer-maintenance, Pennsylvania

Railroad, in his testimony before Congressional committee studying maintenance of way labor under the Fair Labor Standards' Act of 1938, the comparison being as follows for track carrying 16,500,000 tons of traffic per year:

	Faries		*Farrin Plan*	
Item	*100-lb.*	*131-lb.*	*100-lb.*	*131-lb.*
Interest 5%	$514	$717	$514	$652
Depreciation	561	427	561	438
Track laying and surfacing	750	601	750	548
Ties	382	325	382	325

This report is presented as information with the recommendation that the subject be continued.

Report on Assignment 6

Continuous Welding of Rail

Collaborating with Committee 5—Track and Special Committee on Stresses in Railroad Track

J. C. Patterson (chairman, subcommittee), J. B. Akers, W. C. Barnes, W. J. Burton, E. J. Cullen, J. M. Farrin, P. O. Ferris, C. J. Geyer, G. W. Harris, E. M. Hastings, G. M. Magee, C. E. Morgan, E. E. Oviatt, G. A. Phillips, W. H. Penfield, B. H. Prater, A. N. Reece, R. T. Scholes, G. R. Smiley, J. C. Wallace, R. W. Marye, W. P. Wiltsee, Louis Yager.

The laboratory investigation of the continuous welding of rail is covered by the first and second progress reports on this assignment, published in the AREA Proceedings, Vol. 40, pages 687–713, and Vol. 41, pages 737–755, respectively. The activities of the committee at present are devoted to the development of service records to supplement the findings of the laboratory tests.

In collaboration with Professor H. F. Moore and the Track committee, a questionnaire was developed to secure service records. The answers to this questionnaire have been summarized as shown on the folded inserts, which cover the data on the original installations, a detail of the failures and a summary, the information being classified according to the various processes of welding, the process designation being the same as specified in the first and second progress reports.

As will be observed, a considerable number of installations of welded rail have had little service life to date, which fact precludes the formulation of conclusions at this period of the service investigation.

Mr. G. R. Smiley, chief engineer, Louisville & Nashville, makes the following comment on Process "B":

> Since our first attempt in welding through Vasper tunnel we have changed the process of welding and, as you will note, our experience to date, particularly on the Hayden and Parkwood tunnel jobs, has been very satisfactory. I think the manner in which the welders are proceeding with their work is a considerable improvement over our first experience on the Vasper Tunnel job.

Mr. P. O. Ferris, chief engineer, Delaware & Hudson, states:

> In submitting these statements on the failures which we have experienced, I should like to bring out several points in connection with these failures which

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INSTALLATIONS OF CONTINUOUS WELDED RAIL

Item	Missouri Pacific RR [illegible]	Missouri Pacific RR [illegible], Ark.	Missouri Pacific RR [illegible], Ark.	Missouri Pacific RR [illegible], Ark.	Missouri Pacific RR Colter, Ark.	Great Northern RR 2 Mi. east of Walker, Wash.	Central of Georgia Railroad 24 Mi. east of Birmingham, Ala.	Central of Georgia Railroad 24 Mi. east of Birmingham, Ala.	Central of Georgia Railroad 41 Mi. east of Birmingham, Ala.	Central of Georgia Railroad 41 Mi. east of Birmingham, Ala.	Central of Georgia Railroad Lovejoy, Ga.
[illegible]	[illegible] ft.	3[illegible] ft.	[illegible] ft.	[illegible] ft.	105[illegible] ft.	1122 ft.	2457 ft.	2562 ft.	1283 ft.	1389 ft.	2184 ft.
[illegible]	[illegible]	[illegible]	[illegible]	None 1938	None 19[illegible]9	None Dec. 1, 1939	None Sept. 1930	None April 1937	None Aug. 1930	None April 1937	None Oct. 1937
[illegible]	[illegible] Straight	[illegible]	[illegible] Straight	Two-way Straight -	Two-way Straight -	Two-way Both 7°20'	Two-way Both-4% curved 6°	Two-way Both-4% curved 6°	Two-way Straight -	Two-way Straight -	Two-way Both-35% curved 2°
[illegible]	[illegible] North	[illegible]	[illegible] North	Level	+ 1.[illegible] North	Level	Up-westbound	Up-westbound	Up-down both ways	Up-down both ways	Up-westbound
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 90#	[illegible] 90#	66' 121[illegible]	39' 90# RA	39' 112# RE	39' 90# RA	39' 112# RE	39' [illegible] RE
12 Total joints welded [illegible] 13 Type of weld	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] Oxweld	32 Oxweld NW Rod. Entire weld normalized by controlled cooling after completion of weld.	126 Oxy-acetylene	171 Oxy-acetylene	66 Oxy-acetylene	71 Oxy-acetylene	110 Oxy-acetylene
14 Type of track	[illegible]	[illegible]	[illegible] rock ballast [illegible]	[illegible] 8" rock ballast [illegible]	[illegible] ties to [illegible] rail, 8" rock ballast.	[illegible] tie plates-wedge tie creosoted, no ballast. [illegible] double shoulder.	90#-100% S.H. angle bars, 7½"x 1[illegible]" sgl. shld. tie plates, rail double-spiked, 7"x9"x8' creosoted pine ties, 1[illegible]" slag ballast.	90#-100% S.H. angle bars with base sheared off, applied as straps, 7½"x11" sgl.shldr. tie plates, rail double-spiked, 7"x9"x8' creosoted ties, 1[illegible]" slag ballast.	90#-100% S. H. angle bars, 7½"x 10" sgl.shldr. tie plates, rail double-spiked, 7"x9"x8' creosoted pine ties, 16" slag ballast.	90#-100% S. H. angle bars with base sheared off, applied as straps, 7½"x11" sgl.shldr. tie plates, rail double-spiked. 7"x9"x8' creosoted ties, 16" slag ballast.	90#-100% S.H. angle bars with base sheared off, applied as straps, 8"x11½" 6-hole double-shldr. tie plates, rail double-spiked and tie plate spiked to ties, 7"x9"x8' creosoted ties, 12" slag ballast.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible].29	[illegible].29	$9.14	$9.00	$6.78	$8.99	$7.12	$8.99
[illegible]	[illegible]	[illegible]	Railroad	Railroad	Railroad	Railroad under Oxweld supervision	Railroad	Railroad	Railroad	Railroad	Railroad
[illegible]	Yes	[illegible]	[illegible]	Yes	Yes	No	Yes, 90# S. H. angle bars.	Straps applied	90# S. H. angle bars.	Straps applied	Straps applied
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] M.P.H.	30 M.P.H.	30 M.P.H.	30 M.P.H.	30 M.P.H.	60 M.P.H.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible],700,000	12,200,000	4,500,000	4,500,000	4,500,000	4,500,000	10,740,000
[illegible]	Both	[illegible]	[illegible]	Both	Both	Both	Both	Both	Both	Both	Both
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Max.avg.16°-107°.	5°-75°	5°-75°	5°-75°	5°-75°	22°-116°
[illegible]	[illegible] - 12	[illegible] - 12	[illegible] - 12	[illegible] - 12	[illegible] - 1[illegible]	None	Fair - 8	Fair - 8	Fair - 6	Fair-8	Fair - 12 #
[illegible]	[illegible]	[illegible]	[illegible]		No	No	No	No	No	No	No
[illegible]	None	None	None	None	None	None	None	None	None	None	Max.E.End 2.1" W.end 2.35"
[illegible]	None 32,1[illegible] lbs.	None 32,1[illegible] lbs.	None [illegible] lbs.	None 32,1[illegible] lbs.	None 32,1[illegible] lbs.	None 36,000 lbs.	None 32,500 lbs.	None 32,500 lbs.	None 32,500 lbs.	None 32,500 lbs.	None 32,500 lbs.
[illegible]	[illegible]	[illegible] weather	[illegible]	80°	80°	36°	50°	40°	50°	40°	N.Rail 78° S.Rail 8[illegible]°
[illegible]	80° Tunnel	70° to 80° Tunnel	[illegible] Tunnel	80° Tunnel	80° Tunnel	Not Known Open	45° Tunnel	40° Tunnel	45° Tunnel	40° Tunnel	N.Rail 78° S.Rail 80° Open
							Note: Welded by single welders and not normalized or slow cooled.		Note: Welded by single welders and not normalized or slow cooled.		Note: (#) - Fair anchors; 12 per panel for 270 ft. at each end. (Fair anchors, 12 per panel, have been applied throughout the entire length of welded rail.

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INSTALLATIONS OF CONTINUOUS WELDED RAIL

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1 Location 2 Location of welded section	Southern Railway Alexandria, Va. M.P. 9.4 to 10.4	Louisville & Nashville R.R. Wagner, Tenn.	Louisville & Nashville R.R. Kufa Tunnel	Louisville & Nashville R.R. Hayden Tunnel	Louisville & Nashville R.R. Parkwood Tunnel	Louisville& Nashville R.R. Boonsboro Tunnel
3 Maximum length of rail welded without intervening joints	4125 ft.	1628 ft.	1014 ft.	2324 ft.	1092 ft.	747 ft.
4 Total length of such joints or welded section	[illegible] ft.	-	-	-	-	-
5 Date installed	Sept. 1938	May 2[illegible], 1936	May [illegible], 1938	February 1939	February 1939	April 1[illegible], 1939
6 Is traffic one-way or two-way over welded rail	One-way	Two-way	One-way	One-way	One-way	One-way
7 Straight, curve or both	Straight	1044' on 6° curve	Curve	Both	Straight	Curve
8 Maximum degree of curvature	None	6°	8° 2'	4°	-	5°
9 Grade up or down with reference to direction of traffic	0.15% up	-	Up	- 0.4	+ 0.62%	Down
10 Length of rail before welding	33'	39'	39'	39'	39'	39'
11 Weight of rail	130#	100# RE	100# RE	101.49#	101.49#	100# RE
12 Total joints welded both sides of track segregated by type of weld	162	82	52	117	54	39
13 Type of weld	Oxy-acetylene	Oxy-acetylene	Oxy-acetylene	Oxy-acetylene - Butt weld	Oxy-acetylene - Butt weld	Oxy-acetylene
14 Type of track	Full tie plated. 12" stone ballast. Tie plates are double shoulder.	Second and toeless bars, 24" long; full tie plated; copper slag ballast 12" deep; 7"x9"x8'6" creosoted ties.	Toeless bars; 7"x9"x8'6" hardwood ties; Rock ballast.	7"x9"x8'6" creosoted oak ties; 12" slag ballast; Tie plated.	7"x9"x8'6" creosoted oak ties; 12" slag ballast; Tie plated.	7"x9"x8'6" creosoted ties; 12" slag ballast; Tie plated.
15 Cost of weld in place	$9.11	$9.62	$8.20	$9.50	$9.50	$8.30
16 Work done by railroad, contractor or both	Railroad	Both	Railroad	Railroad	Railroad	Railroad
17 Were bars applied after welding in addition to the welding?	Yes	Yes	Yes	Yes - S.H. 90#	Yes - S.H. 90#	Yes
18 Maximum speed allowed	20 M.P.H.	60 M.P.H.	40 M.P.H.	70 M.P.H.	60 M.P.H.	40 M.P.H.
19 Approximate annual tonnage in gross tons - pass., frt. locos. and cars	[illegible],000,000	15,000,000	8,000,000	6,721,11[illegible]	7,147,430	6,000,000
20 Carries pass. or frt. traffic or both	Freight	Both	Both	Both	Both	Both
21 Approx. annual max. & min. atmospheric temp.	0° - 92°	0° - 100°	-10° - +80°	10° - 100°	10° - 100°	-10° - +90°
22 Type of anchor, if used, and number per rail length	Fair - [illegible]	Fair - 4	Fair - 8	Woodings - 6	Stead - 6	Fair - 8
23 Is any provision made for expansion at either end of section?	No	No	No	No	No	No
24 What, if any, creepage has been observed due to traffic or temperature change since rail was laid?	None	None	None	None	None	None
25 What subsequent work has been necessary due to creepage or expansion?	None	None	None	None	None	None
26 Maximum wheel load	31,000 lbs.	Not given	26,250 lbs.	26,250 lbs.	26,250 lbs.	26,250 lbs.
27 Atmospheric temp. when rail laid & fastened	89°	60°	65°	52°	52°	40°
28 Temperature of rail when laid and fastened	100°	60°	-	-	-	40°
29 In tunnel or open	Open	Tunnel	Tunnel	Tunnel	Tunnel	Tunnel

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INSTALLATIONS OF CONTINUOUS WELDED RAIL

Process 2 - Thermit Weld (Old Type)

1 Railroad	Bessemer & Lake Erie Railroad	Erie Railroad	Northern Pacific Railway Company	Northern Pacific Railway Company	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad
2 Location of welded section	River Valley, Pa.	Otisville, N.Y.	Near Bozeman, Mont.	Near Helena, Mont.	Albany, N. Y.	Mechanicsville, N.Y.	Schenectady, N.Y.	Windsor, N.Y.	Comstock, N. Y.	Oneonta, N. Y.
3 Maximum continuous length welded without intervening joints	1280 ft.	1616 ft.	3743 ft.	4017 ft.	2994 ft. E.B. 2661 ft. W.B.	2117 ft. S.B. 2519 ft. N.B.	6,383 ft.	3389 ft. S.B.	4054 ft. S.B.	[illegible] ft. N.B.
4 Total length of adjoining welded sections	None	None	None	None	None	None	4,804 ft.	3740 ft. S.B. 2814 ft. N.B.	3966 ft. N.B.	None S.B. 1154 ft. S.B.
5 Date installed	Oct. & Nov. 1936	June 1936	July 8, 1936	Aug. 3, 1936	Aug. & Sept. 1933	May 1934	June & Sep. 1935	1935	May & June 1935	June 1935
6 Is traffic one-way or two-way over welded rail	One-way	One-way	Two-way	Two-way	One-way	One-way	One-way	Generally two-way; territory is two-track with CTC.	One-way	One-way
7 Straight-curve or both	Both-1810 ft. straight	Straight	Straight	Straight	Both	Straight	Both	Both	Straight	Straight
8 Maximum degree of curvature	6°	-	-	-	7°30'	-	4°	3°	-	-
9 Grade up or down with reference to direction of traffic	1/2 - .65% 1/2 - level	Up 0.16% Down 0.25%	1.2% or 0.8	2.[illegible]%	1.0%	0.3%	0.7%	0.3% N.B.	0.10% down N.B.	.35% N.B. up
10 Length of rail before welding	39'	66'	39'	39'	39'	39'	39'	66'	39'	39'
11 Weight of rail	131# RE	131# RE	131# RE	131# RE	130# RE	131# RE	131# RE	131# RE	131# RE	131# RE
12 Total joints welded both sides of track (segregated by type of weld)	265	168	194	206	318	254	70 Electric Flash 551 Thermit	251	408	74
13 Type of weld	Thermit Pressure	Thermit Pressure	Thermit Pressure	Thermit Pressure	Thermit Pressure	Thermit Pressure	Thermit Pressure	Thermit Pressure	Thermit Pressure	Thermit Pressure
14 Type of track	B.E. - Treated red oak ties 7"x9"x8'6", 22" centers, cinder sub-ballast, 12" cr. stone ballast; 2-3/4"x14-21/32" tie plates - 4 screw spikes per plate.	Treated oak ties 7"x9"x8'6", 20-1/2" centers; 10"-12" stone ballast; wrot iron sgl. shldr. tie plates 7½"x12½"; 3 wrot iron spikes (not re-spiked inside); 2 malleable lag screws per plate with cad. plated spring washer.	Hardwood ties, 8" ballast	Hardwood ties, 8" ballast	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties.	M&L spring clips 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties. Track covered with crushed stone pavement to level of top of rail.
15 Cost of weld in place	Not given	$11.94	$20.42	$20.42	$19.53	$19.12	$18.11	$15.91	$13.58	$13.58
16 Work done by railroad, contractor or both	Railroad, under Contractor's supervision	Railroad, under Contractor's supvn.	Railroad, under contractor's supvn.	Railroad, under Contr's. supvn.	Railroad, under Contractor's supvn.	Railroad, under Contractor's supvn.	Railroad, under Contractor's supvn.	Railroad, under Contractor's supvn.	Railroad	Railroad
17 Were bars applied after welding in addition to the welding?	No	No	No	No	No	No	No	No	No	No
18 Maximum speed allowed	Pass.55MPH-Frt35MPH	40 M.P.H.	[illegible] M.P.H.	25 M.P.H.	2[illegible] M.P.H.	35 M.P.H.	No restriction	20 MPH (acct. sub-soil)	75 M.P.H.	20 MPH (local ord.)
19 Approximate annual tonnage in gross tons-pass., frt. locos. and cars	9,000,000	16,500,000	7,000,000	7,000,000	4,150,000 N.B. 4,286,000 S.B.	3,000,000 N.B. 2,800,000 S.B.	9,000,000	10,738,654 N.B. 6,298,241 SB (2 tks)	3,706,000 N.B. 3,714,700 S.B.	3,567,000 N.B. 3,048,000 S.B.
20 Carries pass. or frt. traffic or both	Both	Freight	Both	Both	Both	Both	Freight only	Freight	Both	Both
21 Approx. annual max. & min. atmospheric temp.	-20° to +110°	Portals -8° to +98° Center 25° to 65°	+20° to 40°	+20° to 40°	Range 125°	Range 125°	Range 125°	-20° to +90°	-25° to 97°	-20° to 95°
22 Type of rail anchor, if used, and number per rail length	None	Fair-20 per 66' rail, except 1st & last 10 rails which have 33	Fair - 22	Fair - 32	M&L Spring Clips	M&L spring clips	M&L spring clips	M&L spring clips	M&L spring clips	M&L spring clips
23 Is any provision made for expansion at either end of section?	No	No	No	No	No	No	No	No	No	No
24 What, if any, creepage has been observed due to traffic or temperature change since rail was laid?	None	None	Max. movement 1-7/16"	Max. movement 1-5/16"	None	None	None	Track goes out of line in hot weather due to poor sub-soil. *	None	None
25 What maintenance work has been necessary due to creepage or expansion?	None	None	None	None	None	None	None	None	None	None
26 Maximum wheel load	37,900 lbs.	36,000 lbs.	37,000 lbs	37,000 lbs.	32,000 lbs.	34,425 lbs.	34,425 lbs.	34,425 lbs.	32,000 lbs.	34,425 lbs.
27 Atmospheric temp. when rail laid & fastened	65°	60° - 78°	40°	40°	75°	70°	78°	70° - 90°	70° - 90°	70°
28 Temperature of rail when laid and fastened	Not given	60° - 80°	50°	50°	No record	No record	No record	80° - 120°	70° - 130°	70° - 130°
29 In tunnel or open	Open	Tunnel	Tunnel	Tunnel	Open	Open	Open	Open	Open	Open

Note: (*) this condition no different than before welding rail.

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INSTALLATIONS OF CONTINUOUS WELDED RAIL

Process C^{1} - Thermit Weld (Type K)

1 Railroad	Great Northern R.R.	Denver & Salt Lake Ry.	The Baltimore & Ohio R.R.	The Baltimore & Ohio R.R.	Delaware and Hudson Railroad	Delaware and Hudson Railroad
2 Location of welded section	East of Rexford, Mont.	Moffat Tunnel	Willow Valley, Ind.	Ft. Ritner Tunnel, Tunnelton, Ind.	Schenectady, N. Y.	Mechanicsville, N. Y.
3 Maximum continuous length welded without intervening joints	5,667.8 ft.	34,056 ft.	1365 ft.	1 rail 2145 ft. 1 rail 2137 ft.	7018 ft.	2519 ft. N.B.
4 Total length of adjoining welded sections	None	None	None	None	53224 ft.	None - W.B. 2517 - S.B.
5 Date installed	1937	July 1938	July 1939	July 1939	1937	Sept. 1939 #
6 Is traffic one-way or two-way over welded rail	Two-way	Two-way	Two-way	Two-way	One-way	One-way
7 Straight-Curve or both	Both	Both - 800' 6°15' Curve	Curve	Both	Both	Straight
8 Maximum degree of curvature	3°	6°15'	3°30'	5°	3°	-
9 Grade (Up or down with reference to direction of traffic	+0.7% E.B.	0.9% descending 0.3% ascending	0.32% ascending	0.45% descending 0.4% ascending	0.88% comp. up	0.3% up W.B.
10 Length of rail before welding	39'	66'	39'	39'	39'	39'
11 Weight of rail	110# RE	112# RE	112# RE	112# RE	131# RE	131# RE
12 Total joints welded both sides of track (segregated by type of weld)	290	1 62	68	108	1559	253
13 Type of weld	Thermit Pressure Type K	Thermit Pressure Type K	Thermit Pressure Type K	Thermit Pressure Type K	Thermit Pressure Type K	Thermit Pressure Type K
14 Type of track	M&L Fastenings, Creosoted ties, 12" washed gravel ballast	8"x11" double shldr. tie plates, Creosoted red oak ties, 12" porfyry granite and volcanic cinder ballast	Double shldr. AREA tie plates with 2 hold-down spikes, two rail clips CL16; treated ties; 24" gravel ballast.	Double shldr. AREA tie plates with 2 hold-down spikes, two rail clips CL16; treated ties; 24" gravel ballast.	M&L spring clips; 13½"x8" double shldr. tie plates lagged with two screw spikes to hardwood ties; 14" of stone ballast under ties.	M&L spring clips; 13½"x8" double shldr. tie plates lagged with two screw spikes to hardwood ties; 14" of stone ballast under ties.
15 Cost of weld in place	$18.87	$15.12	Not given	Not given	$14.40	No record
16 Work done by railroad, contractor or both	Railroad and Contractor	Contractor	Railroad	Railroad	Both	Both
17 Were bars applied after welding in addition to the welding	No	No	No	No	No	No
18 Maximum speed allowed	55 M.P.H.	50 M.P.H.	45 M.P.H.	45 M.P.H.	30 MPH (due to class of engine)	65 M.P.H.
19 Approximate annual tonnage in gross tons-pass., frt., locos. and cars	6,042,000	Not given	10,000,000	10,000,000	9,172,800	3,000,000 N.B. 2,800,000 S.B.
20 Carries pass. or frt. traffic or both	Both	Both	Both	Both	Freight	Both
21 Approx. annual max. & min. atmospheric temp.	30° - 100°	-45° - +85°	30° - 80°	30° - 80°	-20° - +96°	-20° - +96°
22 Type of rail anchor, if used, and number per rail length	None	Fair - 10 per 66' rail 6 against expansion, 4 contraction.	None	None	M&L spring clips	M&L spring clips
23 Is any provision made for expansion at either end of section?	No	No	No	No	No	No
24 What, if any, creepage has been observed due to traffic or temperature change since rail was laid?	From 1/16" to 1-1/4"	None	None	None	None	None
25 What subsequent work has been necessary due to creepage or expansion?	None	None	None	None	None	None
26 Maximum wheel load	35,000 lbs.	36,500 lbs.	32,000 lbs.	32,000 lbs.	34,425 lbs.	34,425 lbs.
27 Atmospheric temp. when rail laid & fastened	85°	65°	75° - 78°	76° - 80°	70°	70° - 90°
28 Temperature of rail when laid and fastened	92°	60°	70°	70°	No record	No record
29 In tunnel or open	Open	In tunnel 32,798' In open 1,258'	In tunnel	In tunnel	Open	Open

Note: (#) - Joints installed in 1939 replaced those installed in 1934. These 1939 joints are of the Type K, which is of improved designed, believed to overcome difficulty experienced with design used in 1934.

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INSTALLATIONS OF CONTINUOUS WELDED RAIL

[illegible] D - Electric Pressure Weld

1 Railroad	Erie Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad	Delaware & Hudson Railroad
2 Location of welded section	Otisville, N. [illegible]	Schenectady, N. Y.	Schenectady, N. Y.	Fort Henry, N. Y.	Watervliet, N. [illegible]	Bainbridge, N. Y.	Harpursville, N. Y.	Plattsburgh, [illegible]
3 Maximum continuous length welded without intervening joints	5544 ft.	[illegible],983 ft. #	591[illegible] ft.	6566 ft.	4333 ft. N.B. 12289 ft. N.B. 16622 ft. S.B.	3272 ft. N.B.	7168 ft.	14[illegible] ft.
4 Total length of adjoining welded sections	None	4,[illegible]04 ft.	54289 ft.	34697 Ft.		7287 ft.	22517 ft.	9480 ft. N.B. 10681 ft. S.B.
5 Date installed	Oct. 1935	June-Sept. 1936	1937	June-July 1937	1937	1937	1937	May 1939
6 Is traffic one-way or two-way over welded rail	One-way		One-way	Two-way Single Track	One-way	One-way	Two-way Single Track	One-way
7 Straight-Curved or both	Straight	Both	Both	Both	Both	Both	Both	Both
8 Maximum degree of curvature	-	4°	3°	7°	3°	3°	4°	3°
9 Grade (up or down) with reference to direction of traffic	Up 0.28% Down 0.18%	0.7%	0.88% comp. up	0.64% up	+ 0.75% up	0.0-0.28% up 0.4% down	1.32% S.B. up	0.31% up & down
10 Length of rail before welding	39'	39'	39'	39'	39'	39'	39'	39'
11 Weight of rail	131#	131#	131#	121#	131#	131#	131#	131#
12 Total joints welded both side of track (segregated by type of weld)	262 Flashwelded 6 Thermit	70 #	874	1987 Elec.Flash Weld 98 Thermit Type K	1622 Elec.Flash Weld 53 Thermit Type K	513 Elec.Flash Weld 47 Thermit Type K	1142 Elec.Flash Weld 65 Thermit Type K	1069 Elec.Flash Weld
13 Type of weld	Electric Flash Weld & Thermit Type E weld	Electric Flash Weld	Electric Flash Weld	Closure welds are Thermit Pressure Type K	Closure welds are Thermit Pressure Type K	Closure welds are Thermit Pressure Type K	Closure joints are Thermit Pressure Type K	Electric Flash Weld
14 Type of track	7¾"x12¾" tie plates; treated ties 7"x9"x8'6"; 12" stone ballast.	M&L spring clips. 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties. 14" stone ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" iron ore stone screenings under ties.	M&L spring clips 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" stone ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" cinder ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" cinder ballast under ties.	M&L spring clips, 13½"x8" double shldr. tie plates, lagged to tie with two screw spikes; red oak treated ties, 14" iron ore stone screenings under ties.
15 Cost of weld in place	$17.40	$9.00	$13.32	Elec.Flash $12.59	$11.33	$11.32	Flash $11.32	$11.21
16 Work done by railroad, contractor or both	Both	Contractor	Railroad and Contractor	Both	Both	Both	Both	Both
17 Were bars applied after welding in addition to the welding?	No	No	No	No	No	No	No	No
18 Maximum speed allowed	40 M.P.H.	No restriction	30 M.P.H. (due to class of engine)	65 MPH So. of Fort Henry 35 MPH No. of Fort Henry	65 M.P.H.	60 M.P.H.	60 M.P.H.	65 M.P.H.
19 Approximate annual tonnage in gross tons-Pass., frt. locos. and cars	10,250,000	9,000,000	9,172,800	2,817,200 N.B. 2,536,300 S.B.	3,567,000 N.B. 3,088,000 S.B.	16,969,738	11,860,409	5,353,500
20 Carries pass. or frt. traffic or both	Freight	Freight only	Both	Both	Both	Both	Both	Both
21 Approx. annual max. & min. atmospheric temp.	18° to 60° in tunnel	Range 125°	-20° to +96°	-25° to +96°	-20° to +96°	-20° to +96°	-20° to +96°	-30° to +94°
22 Type of rail anchor, if used, and number per rail length	Fair - 16	M&L spring clip	M&L spring clip	M&L construction	M&L construction	M&L construction	M&L construction	M&L construction
23 Is any provision made for expansion at either end of section?	No	No	No	No	No	No	No	No
24 What, if any, creepage has been observed due to traffic or temperature change since rail was laid?	None	None	None	None	None	None	None	None
25 What subsequent work has been necessary due to creepage or expansion?	None	None	None	See notes #1 & #2	None	See note #1	See note #1	None
26 Maximum wheel load	35,000 lbs.	54,425 lbs.	34,425 lbs.	32,000 lbs.	32,000 lbs.	34,425 lbs.	34,425 lbs.	32,000 lbs.
27 Atmospheric temp. when rail laid & fastened	40°	78°	65° to 95°	70° to 98°	70° to 90°	60° to 95°	79° to 92°	60° to 78°
28 Temperature of rail when laid and fastened	48°	No record	63° to 115°	80° to 125°	No record	No record	No record	71° to 95°
29 In tunnel or open	Tunnel	Open	Open	Open	Open	Open	Open	Open

(#) These flash welds were made by the General Electric Co. Rails were welded in stretches of 3 rails, after which they were laid in track and joined with Thermit Weld.

Fort Henry, N. Y.:

Note #1: At locations where insulated joints exist a piece of single rail was installed when rail was laid. This rail has been changed in winter, substituting longer rail and in summer substituting shorter rail; however, now 6-hole joint bars have been installed and this changing is unnecessary.

Note #2: One stretch approximately 720' of rail laid at 57°F kicked out of line on next hot day. This rail was loosened when temp. was around 90°F and allowed to expand, then reclipped. No subsequent difficulty has been experienced. See also report to Sub-Comm. #2 "Fastenings for Continuous Welding of Rail," page 558, Vol. 40, AREA Bulletin.

Bainbridge, N. Y.:

Note #1: Closure welds done at night with temperature around 30° to 70° F. Rail kicked out at some of these locations in next hot weather spring of 1938 and required rail to be cut and shorter length inserted. No subsequent difficulty experienced. See also report of Sub-Comm. #2 on "Fastenings for Continuous Welding of Rail," page 558, Vol. 40 of AREA bulletin.

Harpursville, N. Y.:

Note #1: Closure welds done at night with temperature around 30° to 70° F. Rail kicked out at some of these locations in next hot weather spring of 1938 and required rail to be cut and shorter length inserted. No subsequent difficulty experienced. See also report of Sub-Comm. #2 on "Fastenings for Continuous Welding of Rail," page 558, Vol. 40 of AREA bulletin.

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INSTALLATIONS OF CONTINUOUS WELDED RAIL

Process B- Gas Pressure Weld

1 Railroad	Chicago Great Western Railroad	Chicago & Illinois Midland Ry. Co.
2 Location of welded section	Oneida, Iowa. MP 213. - 213.99	Havana, Illinois
3 Maximum continuous length welded without intervening joints	2540 ft.	933.5 ft.
4 Total length of adjoining welded sections	2540 ft.	Total welded 5968.7 ft.
5 Date installed	May 1939	July 1939
6 Is traffic one-way or two-way over welded rail?	Two-way	Two-way
7 Straight-curve or both	Both	Straight
8 Maximum degree of curvature	4° - 485' long	-
9 Grade (Up or down with reference to direction of traffic)	Descending - E.B.	Level
10 Length of rail before welding	39'	39'
11 Weight of rail	112# RE	112# RE
12 Total joints welded both sides of track (segregated by type of weld)	257 machine weld 8 field weld	131
13 Type of weld	Oxweld-Automatic Pressure Process	Oxweld-Automatic Pressure Process
14 Type of track	GEO fastenings, sawed prebored and dapped #5 creosote ties, 8" new washed gravel, 24" old gravel.	8"x11" double shoulder tie plates, spiked two spikes per plate, 7"x9"x8'6" treated ties, 9" gravel ballast under ties, 3" ballast over ties, upon which is placed a surfacing of 1-1/2" of limestone chats.
15 Cost of weld in place	$9.87	$11.18
16 Work done by railroad, contractor or both	Railroad	Both
17 Were bars applied after welding in addition to the welding?	No	No
18 Maximum speed allowed	60 M.P.H.	15 M.P.H. - City Ordinance
19 Approximate annual tonnage in gross tons-pass., frt. loco. and cars	8,000,000	7,000,000
20 Carries pass. or frt traffic or both	Both	Both
21 Approx. annual max. & min. atmospheric temp.	-20° to $+110^{\circ}$	-10° to $+105^{\circ}$
22 Type of rail anchor, if used, and number per rail length	None, use GEO construction	1526 Stead anchors bunched at ends of welded stretches
23 Is any provision made for expansion at either end of section?	None - Additional rail anchors were placed on rails for 5 lengths at each end of welded section.	No
24 What, if any, creepage has been observed due to traffic or temperature change since rail was laid?	None	None
25 What subsequent work has been necessary due to creepage or expansion?	None	None
26 Maximum wheel load	30,500 lbs.	32,400 lbs.
27 Atmospheric temp. when rail laid & fastened	53° - 88°	62° - 102°
28 Temperature of rail when laid and fastened	74°	No record
29 In tunnel or open	Open	Open

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CONTINUOUS WELDED RAIL

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[illegible] Road	Location	Date Installed	[illegible] Reported	[illegible] this report	Date Failure	Location of Failure	In weld or away from weld	Type of Failure	Tonnage to date of failure	Separation of rails at failure	How Repaired	Total Failures
[illegible]	[illegible]	[illegible]	[illegible]		Data not available for these failures							22
	[illegible]	[illegible] 1930	1[illegible]			"	"					10 32
[illegible]	[illegible]	[illegible]	3			"	"					
[illegible]	[illegible], Tenn	[illegible] 192[illegible]	[illegible]	2	1927	Curve	In weld	2 Vertical 1 angular	1[illegible],000,000 G.T. per year	0"	First failures repaired by removing length of rail including weld and replacing this length by welding in new piece with position weld, in track later, ends of rail containing welded metal were cut off, closures made by driving rail and splices applied and joints bonded.	37
				19	1928	"	"	9 Vertical 9 angular		0"		
				9	1928	Tangent	"	5 Vertical 4 angular		0"		
				2	1929	Curve	"	2 Vertical		0"		
				5	1929	Tangent	"	5 " All failures due to slag inclusion		0" No separation joints protected by splices.		
[illegible]	[illegible]	Apr. [illegible]		1	1[illegible]-28-3[illegible]	No data reported						
				1	2- [illegible]-40							
				1	2-27-4[illegible]							3 43
[illegible]	[illegible], [illegible]	[illegible] 1936	[illegible]	1	11- 2-[illegible]8	Tangent	In welded metal	[illegible]	37,041,663	1/16"	39' rail installed, welded rail drilled and angle bars applied.	
				1	11- [illegible]-38	"	"	"	37,081,907	1/8"		
				1	2-24-39	"	"	"	40,750,000	1/8"		
				1	[illegible]-1[illegible]-3[illegible]	"	"	"	4[illegible],000,000	3/16"		
				1	[illegible]-2[illegible]-3[illegible]	"	"	"	42,041,666	1/16"		
				1	[illegible]-22-3[illegible]	"	"	"	43,250,000	5/32"		
				1	7-28-[illegible]	"	"	"	45,750,000	3/16"		
				1	1[illegible]-1[illegible]-[illegible]9	"	"	"	50,75[illegible],000	3/32"		
				1	11-[illegible]-39	"	"	"	5[illegible],000,000	1/16"		
				1	1-1[illegible]-4[illegible]	"	"	"	53,870,000	1/16"		
				1	[illegible]-26-40	"	"	"	54,203,000	3/16"		
				1	2- [illegible]-4[illegible]	"	"	"	54,500,000	1/8"		
				1	2- 8-40	"	"	"	55,238,[illegible]	1/8"		
				1	2-20-4[illegible]	"	"	"	55,320,000	1/16"		
				1	4-1[illegible]-4[illegible]	"	"	"	5[illegible],83[illegible],000	1/8"		
				1	[illegible]-2[illegible]-4[illegible]	"	"	"	6[illegible],250,000	3/16"		16
[illegible]	[illegible], Cont.	July 19[illegible]	2	1	[illegible]-40	Tangent	In rail, near weld	Straight break	31,000,000	Fraction of 1"	Temporary by angle bars.	3
[illegible]	[illegible], [illegible]	[illegible] 1936	[illegible]	1	[illegible]- 4-[illegible]	"	"	"	18,000,000	" " 1"	Repaired by welding in short section of rail (Thermit).	
				1	4- [illegible]-40	"	"	"	24,000,000	" " 1"		2
[illegible]	[illegible] Valley, [illegible]	[illegible] 1936	[illegible]	1	8-2[illegible]-37	[illegible] Curve	In weld	Diagonal break	29,900,000	0'	Temporary 15' piece of rail cut in, with angle bars. Repaired by welding in 39' piece of rail.	2
				1	1- [illegible]-40	"	"	"	55,[illegible]00,000	[illegible]"		

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Sheet #2

[illegible]	Location	Date Installed	No. of failures previously reported	Failures this report	Date of Failure	Location of Failure	In weld or away from weld	Type of Failure	Tonnage to date of failure	Separation of rails at failure	How Repaired	Total Failures
Delaware & H[illegible] R. R.	[illegible]	[illegible] and Sept. [illegible]3		(1T)1	10-27-33	Tangent	Weld Zone	Full fracture starting from crack in head of rail.	3,[illegible]	No record	Portion of rail containing failed joint cut out and piece of rail inserted with angle bars, angle bars subsequently removed and joints welded by Thermit in track.	
				(2T)1	1[illegible]-20-33	"	In weld metal	Full fracture apparently starting from defect in Thermit base collar.	4,[illegible]	1-11/16"	"	
				(3T)1	2-[illegible]-34	Low rail	" " Zone	Straight square break in joint.	[illegible]	2-1/[illegible]"	"	
				(4T)1	2-[illegible]-34	"	" " "	" " "	[illegible],000	1-1/4"	"	
				([illegible]T)1	2-[illegible]-34	"	" " "	" " "	5,[illegible]	1-3/8"	"	
				([illegible]T)1	12-11-34	Tangent	" " "	Square break across head of rail, in joint, progressing downward through web and base at edge of Thermit collar.	6,000,000	1-1/4"	"	
				(7T)1	2-[illegible]-35	[illegible] rail	" " "	Full fracture with no apparent defect	10,000,000	1-1/8"	"	
				(16T)1	7-1-38	Tangent	" " "	Full fracture through weld, caused by poor weld.	24,[illegible]	0-1/8"	Angle bars applied to joint.	
				([illegible]T)1	1[illegible]-[illegible]-38	High rail	" " "	Full fracture through weld, starting in head of rail, cause - insufficient head weld.	30,000,000	0-3/4"	Portion of rail containing failed joint removed and piece of rail inserted with angle bars.	9
"	Mechanicville, N. Y.	May 1934	0	([illegible]T)1	10-28-36	Tangent	" " "	Full fracture starting in washed area under head above Thermit web collar.	6,[illegible]00,000	No record	"	1
"	Schenectady, N. Y.	June & Sept. 1935	0	([illegible]T)1	12-4-35	Low rail	" " "	Head weld on 35 per cent only.	4,500,000	2-3/8"	"	
				(1[illegible]T)1	11-24-3[illegible]	High rail	" " "	Vertical crack through head of rail and along edge of Thermit collar in web and base.	1[illegible],000,000	No record	"	
				(11T)1	7-29-37	Low rail	" " "	Fracture through joint in head and through the web collar in web, and base, account little or no head weld.	19,000,000	0-5/8"	"	
				(14T)1	11-11-37	High rail	" " "	Fracture through head and Thermit collar on web and base from crack in head at joint, caused by insufficient head weld.	24,[illegible]00,000	0-3/4"	Portion of rail containing failed joint removed and piece of rail inserted with angle bars. Bars subsequently removed and joints welded by Thermit in track.	
				(1[illegible]T)1	2-17-38	Low rail	" " "	"	25,[illegible]00,000	0-3/4"	"	[illegible]
				(25T)1	10-4-39	High rail	" " "	Full fracture through weld, caused by defective weld.	38,000,000	1-1/2"	Angle bars applied to joint	39
[illegible] THERMIT TYPE [illegible] Denver and Salt Lake R.R.	Moffat Tunnel	July 1938	0	1	1938	Tangent	In weld	Transverse fissure	Not reported	0"	By applying angle bars	
				1	1939	"	"	" "	"	0"	"	
				5	1940	"	"	" "	"	0"	"	7
Great Northern RR	Bexford, Mont.	1937	-	1	1-1[illegible]-40	Tangent	5" from weld	Vertical break	8,0[illegible]6,500	5/8"	Repaired by welding in 14'5" rail, oxy-acetylene butt weld method.	1

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FAILURES REPORTED

CONTINUOUS WELDED RAIL

Sheet #3

Process and Railroad	Location	Date Installed	No. of failures previously reported	Failures this report	Date of Failure	Location of Failure	In weld or away from weld	Type of Failure	Tonnage to date of failure	Separation of rails at failure	How Repaired	Total Failures
PROCESS "C" Continued Delaware and Hudson R. R.	Schenectady, N. Y.	1937	0	(13T) 1	10-26-37	Tangent	In weld zone	Full fracture through weld starting from crack in head at joint account insufficient head weld.	3,000,000	No record	Portion of rail containing failed joint removed and piece of rail inserted with angle bars. Bars subsequently removed and joints welded by Thermit in track.	
				(15T) 1	12-18-37	High rail	"	Fracture through head and Thermit collar on web and base from crack in head at joint, caused by insufficient head weld.	4,000,000	3"	"	
				(17T) 1	2-21-38	High rail	"	Full fracture through weld at joint-apparently imperfect weld in Thermit web collar.	6,000,000	1-3/4"	"	
				(19T) 1	Mar. 1938	Tangent	"	Square break 1 2" from center of weld in head of rail and separation of Thermit collar from web and base of rail. Caused by Thermit collar not fusing with rail.	8,000,000	2-3/4"	"	
				(23T) 1	3-10-38	High rail	"	Full fracture through joint starting from crack in head due to insufficient head weld.	16,000,000	1-1/4"	Portion of rail containing failed joint removed and piece of rail inserted with angle bars.	
				(24T) 1	3-18-38	Tangent	"	"	16,000,000	1-1/2"	"	6
"	Fort Henry, N. Y.	June & July 1937	0	(12T) 1	10-21-37	High rail	"	Piece broke out of head and web at joint, caused by web crack under head of rail before welding.	1,000,000	No record	Portion of rail containing failed joint removed and piece of rail inserted with angle bars. Bars subsequently removed and joints welded by Thermit in track.	
				(20T) 1	12- 1-38	Low rail	"	Full fracture through weld starting from base. This broken base was within Thermit collar and apparently existed before joint was welded.	7,000,000	2"	Portion of rail containing failed joint removed and piece of rail inserted with angle bars.	2
"	Harpursville, N. Y.	1937	0	(22T) 1	12-28-38	Low rail	"	Full fracture adjacent to weld caused by poor weld.	8,000,000	6"	"	1 17
PROCESS "D" Delaware and Hudson R. R.	Schenectady, N. Y.	June & Sept. 1935	0	(1F) 1	6- 3-37	High rail	"	Caused by presence of zinc in weld.	1,000,000	No record	Portion of rail containing failed joint removed and piece of rail inserted with angle bars. Angle bars subsequently removed and joints welded by Thermit in track.	
				(2F) 1	10- 8-37	Tangent	"	" Zinc in weld caused by use of galvanized iron shims during welding for purpose of aligning rail ends. Heat of welding caused zinc in these shims to vaporize and penetrate weld area. This cause of failure eliminated by discontinuance of use of galvanized iron shims.	4,000,000	"		2

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CONTINUOUS WELDED RAIL

FAILURES REPORTED

Process and Railroad	Location	Date Installed	No. of failures previously reported	Failures this report	Date of Failure	Location of Failure	In weld or away from weld	Type of Failure	Tonnage to date of failure	Separation of rails at failure	How Repaired	Total Failures
PROCESS "D" Continued												
Delaware and Hudson R. R.	Port Henry, N. Y.	June - July 1937	0	(3F)1	10-21-37	High rail	In rail 8" from weld at top and 9" at bottom	Straight break starting from burned spot at edge of bottom of base. During welding, arcing occurred between welding machine contact and rail base, causing a burned spot on the rail base. This cause for failure eliminated by proper welding procedure to assure no arcing.	3,000,000	13 16"	Portion of rail containing failed joint removed and piece of rail inserted with angle bars. Angle bars subsequently removed and joints welded by Thermit in track.	1
"	Harpursville, N. Y.	1937	0	(4F)1	1-19-38	Low rail	In weld	Piped rail - pipe extending into welded zone.	5,000,000	6-1/2"	Portion of rail containing failed joint removed and piece of rail inserted with angle bars.	1
												4
PROCESS "E"												
Chicago & Great Western R. R.	Oneida, Ia.	May 1939	[illegible]	1	5-[illegible]-39	Tangent	In shop weld	Transverse	21,918	3/8"	Repaired by field welds	
				1	5-11-39	"	"	"	197,260	3/8"	" "	
				1	10-2[illegible]-39	"	"	"	3,747,944	3/8"	" "	
				1	1- 5-40	"	"	"	5,435,614	3/8"		4

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Railroad	Length of Welded Rail: [illegible]	Feet	Number of Welded Joints	Weight of Rail	[illegible]plied	Maximum Wheel Load	Annual Tonnage	Traffic Pass.	Traffic Frt.	Speed M.P.H.	Date Installed	In Tunnel or Open	Failures	Remarks
"A" [illegible]	[illegible]	[illegible]	180	90#	Yes	[illegible],100 lbs.	2,7[illegible],000	Pass.	Frt.	30	1937	Tunnel	None	
	[illegible]	[illegible]	144	90#	Yes	[illegible],100 lbs.	[illegible],700,000	"	"	30	1938	"	"	
	[illegible]	[illegible]	178	90#	Yes	[illegible],100 lbs.	[illegible],700,000	"	"	30	1938	"	"	
	[illegible]	[illegible]	[illegible]	90#	Yes	[illegible],100 lbs.	[illegible],700,000	"	"	50	1938	"	"	
	[illegible]	[illegible]	[illegible]	90#	Yes	[illegible],100 lbs.	[illegible],700,000	"	"	50	1939	"	"	
	(C. of Ga.)	24[illegible]	12[illegible]	90[illegible]	Yes	[illegible] lbs.	4,500,[illegible]	"	"	30	Sept. 19[illegible]	"	22	Removed Apr. 1937
	(C. of Ga.)	1282	[illegible]	90#	Yes	[illegible],500 lbs.	4,500,[illegible]	"	"	[illegible]	Aug. 19[illegible]	"	10	" "
			739										32	
	[illegible] of Ga.	[illegible]	1[illegible]1	112# RE	Yes	[illegible],500 lbs.	4,500,[illegible]	"	"	30	Apr. 1937	"	None	
	[illegible] of Ga.	1389	71	112# RE	Yes	[illegible],500 lbs.	4,[illegible],000	"	"	30	" 1937	"	"	
			[illegible]02											
	[illegible]	1[illegible]	110	112# RE	[illegible]	[illegible] lbs.	1[illegible],740,[illegible]	"	"	60	Oct. 1937	Open	"	
	[illegible]	1122	[illegible]2	131# RE	No	36,000 lbs.	1[illegible]	"	"	60	Dec. 1939	"	"	Normalized by controlled cooling
[illegible]	[illegible]	1[illegible]	[illegible]	1[illegible]# RE	Yes	Not reported	1[illegible]	"	"	60	May 193[illegible]	Tunnel	37	
	[illegible]	1[illegible]	52	100# RE	Yes	[illegible] lbs.	[illegible]	"	"	40	July 1938	"	None	
	[illegible]	[illegible]24	117	1[illegible]	Yes	[illegible],250 lbs.	[illegible],721,110	"	"	70	Jan. 1939	"	"	
	[illegible]	[illegible]	[illegible]4	1[illegible]	Yes	[illegible],250 lbs.	7,147,4[illegible]	"	"	60	Feb. 1939	"	"	
	[illegible]	747	[illegible]	100# RE	Yes	26,250 lbs.	8,[illegible],000	"	"	40	Apr. 1939	"	3	
			[illegible]										40	
	[illegible]	41[illegible]	1[illegible]	100#	Yes	[illegible] lbs.	[illegible]		"	20	Sept. 19[illegible]	Open	3	
[illegible]	[illegible]	[illegible]	[illegible]58	1[illegible] RE	No	[illegible],000 lbs.	1[illegible],000		"	40	June 1936	Tunnel	15	
	[illegible]	[illegible]	194	1[illegible] RE	No	37,000 lbs.	7,[illegible],000	"	"	25	July 1936	"	5	
	[illegible]	4[illegible]17	[illegible]06	131 RE	No	[illegible],000 lbs.	7,[illegible],000	"	"	25	Apr. 1936	"	2	
			568										21	
	[illegible]	[illegible]	[illegible]69	131# RE	No	37,900 lbs.	9,[illegible],000	"	"	55-35	Oct. 1935	Open	[illegible]	
	[illegible]	2994	318	1[illegible]# RE	No	2[illegible] lbs.	12,104,[illegible]	"	"	20	Aug.-Sept. 1935	Open	9	
	[illegible]	[illegible]19	[illegible]4	1[illegible]# RE	No	40,[illegible] lbs.	[illegible],000,000	"	"	35	May 1934	"	1	
	[illegible]	11747	551	131# RE	No	40,000 lbs.	9,000,000		"	No Restr.	June-Aug. 1935	"	6	
	[illegible]	[illegible]089	[illegible]1	131# RE	No	35,900 lbs.	6,[illegible],241		"	[illegible]	1935	"	None	
	[illegible]	40[illegible]4	408	131# RE	No	33,65[illegible] lbs.	[illegible],714,700	"	"	75	May-June 1936	"	"	
	[illegible]	59[illegible]	74	1[illegible]# RE	No	[illegible],650 lbs.	7,567,000	"	"	20	June 1936	"	"	
			2155										18	
[illegible]	[illegible]	34[illegible]	1052	112# RE	No	[illegible],500 lbs.	Not Reported	"	"	50	July 1938	Tunnel	7	Moffat Tunnel
	[illegible]	1235	[illegible]	112# RE	No	[illegible],000 lbs.	10,000,000	"	"	45	July 1939	"	None	
	[illegible]	2145	10[illegible]	112# RE	No	32,000 lbs.	1[illegible],000,000	"	"	45	July 1939	"	"	
			12[illegible]8										7	
	[illegible]	5668	290	110# RE	No	[illegible],000 lbs.	[illegible],042,[illegible]00	"	"	55	1937	Open	1	
	[illegible]	7[illegible]	11[illegible]9	1[illegible]# RE	No	[illegible],[illegible]00 lbs.	9,172,800		"	[illegible]	1937	Open	6	
	[illegible]	[illegible]	2[illegible]	131# RE	No	[illegible],250 lbs.	[illegible],000	"	"	65	Sept 1939	"	None	
	[illegible]	6566	9[illegible]	131 RE	No	33,[illegible] lbs.	5,[illegible],500	"	"	65-35	June-July 1937	"	2	
	[illegible]	[illegible]168	65	1[illegible]# RE	No	35,900 lbs.	11,[illegible],409	"	"	60	1937	"	1	
	[illegible]	4[illegible]	53	131# RE	No	[illegible],[illegible]50 lbs.	[illegible],567,000	"	"	65	1937	"	None	
	[illegible]	[illegible]73	47	131# RE	No	35,900 lbs.	16,96[illegible],7[illegible]	"	"	60	1937	"	"	
			2078										9	
[illegible] Electric [illegible]	(Erie)	554[illegible]	282	1[illegible]# RE	No	3[illegible],000 lbs.	10,[illegible]50,000		"	40	Oct. 1939	Tunnel	None	
	(D. & [illegible])	11787	70	131# RE	No	40,000 lbs.	9,000,000		"	No Restr.	June-Sept 1935	Open	2	
	(D. & [illegible])	5953	[illegible]74	1[illegible]# RE	No	35,900 lbs.	9,172,500	"	"	[illegible]0	1937	"	None	
	(D. & [illegible])	656[illegible]	1587	131# RE	No	[illegible],650 lbs.	5,353,500	"	"	65-35	June-July 193[illegible]	"	1	
	(D. [illegible])	42[illegible]	1622	131# RE	No	33,[illegible]50 lbs.	3,567,000	"	"	65	1937	"	None	
	(D. & [illegible])	[illegible]273	513	131# RE	No	35,900 lbs.	16,969,738	"	"	60	1937	"	None	
	(D. & [illegible])	3168	1142	131# RE	No	35,900 lbs.	11,360,409	"	"	60	1937	"	1	
	(D. & [illegible])	1401	1069	131# RE	No	3[illegible],[illegible]50 lbs.	5,353,500	"	"	6[illegible]	May 1939	"	None	
			7277										4	
[illegible]	([illegible])	264[illegible]	257	112# RE	No	30,[illegible]00 lbs.	8,000,000	"	"	60	May 1939	Open	4	
	([illegible])	932	1[illegible]1	112# RE	No	32,400 lbs.	7,000,000	"	"	15	July 1939	"	None	
			388										4	

appear to us to have an important bearing on an analysis of the situation. These are as follows:

THERMIT WELD FAILURES:

The thermit welds which we have in our various installations have, during the period of years in which we have been welding, been developed from a more or less experimental type to the type known as the "K" weld, which was used in the 1937 and subsequent installations.

The failures which we have experienced fall in, roughly, four classes, namely:

1. Improper design and lack of accurate control or pre-heat temperature.

The failures which are on the reports being submitted with this letter which fall in this category are failures numbers 1T to 11T, 14T, 16T, 18T, 21T, and 25T. These failures have all been in the installations made in 1933, 1934, and 1935 and their cause has been eliminated by improvement in the design of the weld and improvement in the welding technique, principally by accurate control of the pre-heat temperature.

2. Man-failure due to improper welding technique.

Failure number 22T is of this type, the failure being due, I believe, to excessive pre-heating at the time of welding.

3. Failure due to defects in the rail prior to welding.

Failures numbers 12T and 20T are of this type, and it is to be noted on the report forms that the failure was due to a crack in the rail prior to welding in each case, this crack not being visible at the time of the welding.

4. Failures due to use of improper type of thermit.

Failures numbers 13T, 15T, 17T, 19T, 23T and 24T are of this type and were caused by the erroneous use of a type of thermit which did not develop sufficient heat to effect a full head weld on the rail. The reports on these failures are being furnished due to the fact that these joints were welded and placed in track before the discovery of this condition and the failures occurred in track.

Of the above types of failures, those occurring in the number 1 classification have been eliminated by improved design and welding technique. Those in the fourth classification are automatically eliminated, since their cause is from the erroneous shipment of the wrong type of material, which was replaced by the manufacturer.

It is to be noted, therefore, that in the last design of weld, that is the "K" type, there are only three failures, two of which are not actually weld failures but imperfections in the rail, and the remaining one, man-failure in the welding, which is a very small percentage of the total number of welds of this type which we have in track.

FLASH WELDS:

The flash weld failures fall in three groups:

1. Those caused by the presence of zinc in the weld.

These are failures 1F and 2F and resulted from the use of galvanized iron shims, used at the time of the welding for the purpose of alining the rail ends. When the presence of this zinc was discovered, the use of these galvanized iron shims was discontinued, eliminating this source of failure.

2. Failure caused by burned spot on edge of base of rail.

This burned spot resulted from arcing during the time of welding between the rail and the contact in the welding machine, and the cause of this type of failure was eliminated by the introduction of proper welding technique to eliminate the arcing.

3. Failure due to imperfection in the rail prior to welding.

Failure number 4F is of this type, and, as is noted, resulted from a pipe in the rail end which extended into the welded zone.

It is to be noted, therefore, in connection with the flash welded joint failures that all the causes of failure have been eliminated, with the exception, of course, of the last one, and the possibility of this type of failure is reduced by the introduction of careful inspection of the rail ends prior to welding and is one of the magnitude of failures in the rails themselves.

In connection with Process "E", the manufacturer comments as follows:

The four failures which occurred on the Chicago Great Western are the only ones that have ever occurred in any of the welds that we have made by this process and, as you know, we have been welding almost continuously since we started the operation in 1938.

In the making of welds by our process, particularly in our early development, we obtained a considerable sag at the outer edge of the rail base and we found in our laboratory investigation that this could be considerably reduced by reducing the upset at the weld from a ¾-in. shortening of the rail to ½-in. This worked out very nicely where the rail ends were perfectly true as milled in the laboratory; however when our laboratory assistant used the ½-in. upset on field operation on the Chicago Great Western job where the rail ends could not be finished as accurately as at the laboratory, the weld was not thoroughly made which resulted in the failures as reported by the Chicago Great Western. We, of course, immediately discontinued any attempt to make the weld with the ½-in. upset and have never experienced any further difficulty from breakage. In other words, this short upset could not be relied upon in all cases for a perfect weld but with a ¾-in. upset there can positively not be a weld failure.

This report is submitted as information with the recommendation that the subject be continued.

Report on Assignment 7

Service Tests of Various Types of Joint Bars

Ray McBrian (chairman, subcommittee), J. B. Akers, J. E. Armstrong, W. J. Backes, W. C. Barnes, L. H. Bond, N. J. Boughton, C. B. Bronson, W. J. Burton, H. A. Cassil, E. E. Chapman, H. R. Clarke, W. A. Duff, P. O. Ferris, F. W. Gardiner, F. M. Graham, F. S. Hewes, W. H. Kirkbride, C. S. Kirkpatrick, B. R. Kulp, G. M. Magee, R. W. Marye, C. E. Morgan, W. H. Penfield, J. C. Patterson, G. A. Phillips, B. H. Prater, J. C. Ryan, R. T. Scholes, F. S. Schwinn, A. N. Talbot, J. C. Wallace, Barton Wheelwright.

As previously reported, the service tests of various types of joint bars are being conducted on 9 mile stretches of 112-lb. rail in westbound track of the Illinois division of the Atchison, Topeka & Santa Fe Railway west of Streator, Ill., applied in June 1937, and on 12 half-mile stretches of 131-lb. rail in the eastbound track on the Fort Wayne division of the Pennsylvania Railroad east of Valparaiso, Ind., applied in August 1937.

During 1940 the periodic observations on these rail joints have been continued by members of the staff of the Committee on Stresses in Railroad Track. The principal observational tests of these joints, made in 1940, include (a) Rail surface profile; (b) joint camber measurements; (c) bolt tension; (d) rail gap; (e) out-to-out distance of bars.

Rail Surface Profiles

The rail surface profile measurements (profile of running surface of rail for a distance of 40 in. at the joint) give information on the changes in rail surface due to wear, flow, batter and bending. The profile measurements were made on 329 joints on the A. T. & S. F. and 360 joints on the P. R. R. Included in those profiles that were measured first in 1940 are a number of joints in each mile stretch of the 112-lb. rail with bolt tensions set at approximately 8,000 lb. instead of the usual effort of applying about 15,000 lb. for this rail. As the measurements at rail surface are taken from points on the lower flange of the rail for a reference base or bench, the changes occurring at the top of rail from time to time can be definitely determined. At points 20 in. from the rail ends the change or wear in the last two years on the 131-lb. rail has averaged about 0.010 in. At points ¼ in. from rail ends the changes in profile on the 131-lb. rail for the non-hardened ends for the same period averaged 0.017 in. at the leaving end and 0.021 in. at the receiving end; for the hardened ends the averages were 0.009 in. at the leaving end and 0.011 in. at the receiving end. Similarly on the 112-lb. rail the averages for the non-hardened ends were 0.017 in. at the leaving end and 0.019 in. at the receiving end; for the hardened ends the averages were 0.011 in. at the leaving end and 0.013 in. at the receiving end. It is seen that the change on the hardened ends is considerably less than that on the non-hardened ends. Presumably the principal part of the change at ½ in. from the rail ends was due to batter.

Joint Camber

The term joint camber measurement is used here as the middle ordinate at a point near the rail ends for a given length of longitudinal arc of the surface profile. A chord of 34½ in. was used and the ordinates were measured at ½ in. from the rail ends. If the arc of the profile is convex upward the measurement is called positive; if convex downward, it is called negative indicating droop and batter. Because of variations in the form of the bar along its length in its manufacture, the joint camber measurement may vary considerably from joint to joint and from one stretch of joints to another. It is to be expected that the joint camber measurement will change in amount as time goes on, due to wear and other causes, but the term will continue to be useful, though the point on the profile for measuring the middle ordinate in the future will have to be taken farther from the rail end. As found in 1937, 60 joints in each of the 9 stretches of 112-lb. rail, the camber measurement of two stretches on the north rail and one stretch on the south rail was negative (convex downward). In 1940, 9 stretches on the north rail (non end-hardened) and only one on the south rail indicated negative camber measurement. The data show that most of this change is due to batter.

On the 131-lb. rail the joint camber measurement in 1937 in 2 of the 12 stretches on the north rail (non end-hardened) was negative and 2 on the south rail. In 1940, the number of stretches showing negative camber measurement was 8 on the north rail and 2 on the south rail. Again, the increase in the number of stretches having negative camber measurement was due largely to batter. The average values of the camber measurement in 1937, 1938 and 1939 for the various stretches on two railroads, as plotted up, may be found in Fig. 1 and Fig. 2, AREA Proceedings, Vol. 41, pages 660 and 661. The values of the camber measurement for 1940 on the north rails (non hardened ends) have increased considerably from the 1939 measurements; those for the south rail show little change.

Bolt Tension

The purpose of measuring the bolt tension is to find what tension exists and to learn the effects of high, medium and low tension on the behavior of the various types of joints. On both railroads the bolts were tightened by hand wrenching in 1937 soon after the track was laid. A general tightening was given in February 1938 on the 112-lb. rail and again in March 1939; also a general tightening on the 131-lb. rail in May 1939 and October 1940. The re-tightening was done by hand except that of May 1939. Measurement has been made of the tension applied to the bolts of a sufficient number of joints in each test stretch to give an idea of the tension before and after the re-tightenings; perhaps the number measured ranged up to 15 percent of all the joints at general tightenings and at other times. Prior to bolt tightening a little time was spent in tightening, loosening and re-tightening the bolts in a few joints in order to acquaint the section men with the amount of steady pull necessary to produce a given bolt tension. A 24-in. wrench was used on the 112-lb. rail and a 42-in. wrench on the 131-lb. rail. The attempt has been made to obtain a general average tension to range between 12,000 and 15,000 lb. at the time of tightening, though of course values considerably higher and lower than these tensions have been found, some of them at the two extremes.

Some study has been made of the losses of bolt tension with time. Only two broken bolts have been reported. It is believed that the moderate tension used is largely responsible for the small breakage, as on the companion track opposite the test joints on one railroad the bolt tension has been kept high and many broken bolts have been replaced. The average movement measured at the joints due to contraction and expansion at temperatures of say 20 deg. and 110 deg. has ranged from 70 to 85 percent of the unrestricted movement corresponding to the change in temperature, and little or no grouping of tight or open joints has been apparent. It should be noted that these gap measurements were not made at the two extremes of temperature. There is some indication that the 36-in. bars restrict the temperature movement somewhat more than do the 24-in. bars.

Rail Gap

The measurement of rail gap (a quick measurement made at high and low temperatures) has furnished information on temperature movement at joints, which has been used as the basis for obtaining the estimate of restraint given in the preceding paragraph, and the lack of grouping of tight and open joints. On both the 112-lb. and 131-lb. rail of the test joints, the rail ends generally were found not to have been cut squarely. When two ends abut at the base at high temperatures, the gap at the top of the rail frequently was quite large, and for low temperatures extremely large top gaps would occur.

Out-to-Out Measurements

The out-to-out measurement was made between a point on a flange of the outer bar and a corresponding point on the inner bar. The measurement was taken for the upper flange and also for the lower flange at the two ends and at the mid-length of the bars. The purpose of the measurement is to learn of any changes in the position of the bar with respect to the rail as affected by wear at fishing surfaces or other changes, and also to show any change in the position of the top and bottom flanges that might affect the verticality or cocking of the bar. The variations in the dimensions of the flanges of the bar as between the design and the manufacture renders precise determination of the amount of cocking impracticable, but the value of the cocking measured for a pair of bars may be considered to be correct within 0.02 in. As the two bars may not have equal variation from verticality the magnitude for an individual bar cannot be definitely obtained from the measurements made between points on the flanges of the pair of bars. However, for most purposes an even division of the out-to-out distance in obtaining a value of the cocking or departure from verticality will result in a useful and generally fairly accurate measure of the cocking of one bar.

The change in out-to-out distance from 1937 to 1940 has been small. The movement usually takes place rather uniformly along the length from end to end, though occasionally one end differs from the other and there may be twisting in the bar. The average decrease in out-to-out distance at mid-length of bars for 180 joints in 9 stretches of the 112-lb. rail was 0.05 in. for the top flange measurement and 0.03 in. for the bottom flange measurement (averaging 0.025 and 0.015 in. pull-in for an individual bar), and for 100 joints in 5 stretches of the 131-lb. rail it was 0.04 in. for the top flange measurement and 0.02 in. for the bottom flange measurement (averaging 0.02 and 0.01 in. pull-in for an individual bar). Data for 7 stretches of 131-lb. rail contain some uncertainties and are not included here. The above figures show that for the 14 stretches the change in out-to-out distance at the top flange averaged 0.01 in. more than that at the bottom flange. It is apparent that the change in verticality of a bar (increase in cocking) has been small. The measurements indicate that moderate cocking of the bars on these stretches is not uncommon. Considering that the departure from verticality is the same in the two bars of a pair and using the averages for each stretch, the average cocking of an individual bar for the 112-lb. rail is 0.06 in. and the range is 0 to 0.12 in. Likewise for the 131-lb. rail the average is 0.04 in. and the range from 0.03 in. to 0.06 in.

Among other observations, longitudinal profiles of bar fishing surfaces (top and bottom) were made on a number of bars removed from track to determine to what extent wear had occurred. Generally so far this wear amounts to only a few thousandths of an inch and this only for short distances near the rail ends. For these bars diagrams were drawn giving information on the dimensions and location of the bearing areas observed on the top and bottom fishing surfaces.

The measurements and observations made to date throw light on the action of the joints in various ways, such as changes in the amount of cocking with time, effect of camber of bar, place of wear in modern bars, rate of wear with traffic, and effect of end hardening on batter. They give a basis for judgment when, with continued traffic, wear may begin to increase more rapidly with some types and result in marked differences in durability and effectiveness.

In round numbers the amount of gross traffic (including locomotives), as reported by the railroads, averaged 10,000,000 tons per year on the 112-lb. rail or 30,000,000 tons for the three years covered by this report, and averaged 12,000,000 tons per year on the 131-lb. rail or 36,000,000 tons for the three years of service.

On the question of comparison of types of bar it may be said that, except for one design of bar, the amount of wear and other changes in the bars installed have not yet been sufficient to determine definitely the relative values of the different types of joint bars.

The report is presented as information with the recommendation that the subject be continued.

Report on Assignment 8

Investigate Joint Bar Failures and Give Consideration to the Revision of Design and Specifications

Ray McBrian (chairman, subcommittee), J. B. Akers, J. E. Armstrong, W. J. Backes, W. C. Barnes, L. H. Bond, N. J. Boughton, C. B. Bronson, W. J. Burton, H. A. Cassil, E. E. Chapman, H. R. Clarke, W. A. Duff, P. O. Ferris, F. W. Gardiner, F. M. Graham, F. S. Hewes, W. H. Kirkbride, C. S. Kirkpatrick, B. R. Kulp, G. M. Magee, R. W. Marye, C. E. Morgan, W. H. Penfield, J. C. Patterson, G. A. Phillips, B. H. Prater, J. C. Ryan, R. T. Scholes, F. S. Schwinn, A. N. Talbot, J. C. Wallace, Barton Wheelwright.

The committee interprets the assignment to investigate joint bar failures to include the study of cracks which may or may not lead to ultimate breakage.

The previous report on this subject included information obtained by a questionnaire relative to the number of joint bar failures, theories as to cause, and suggested measures to eliminate any cracking. Also mentioned was research and experimental work being made by various roads. The committee also reported that, at present, based on data currently received, it found no necessity for changes in design or in specifications, but recommended that the subject be continued.

During the past year, through observations of tests in progress and examinations of joint bar failures, the subcommittee has obtained data bearing on some of the theories as to the causes of failure and suggested measures for relief from or the prevention of failures. This investigation embraces actual service data, full size of fatigue tests and laboratory studies.

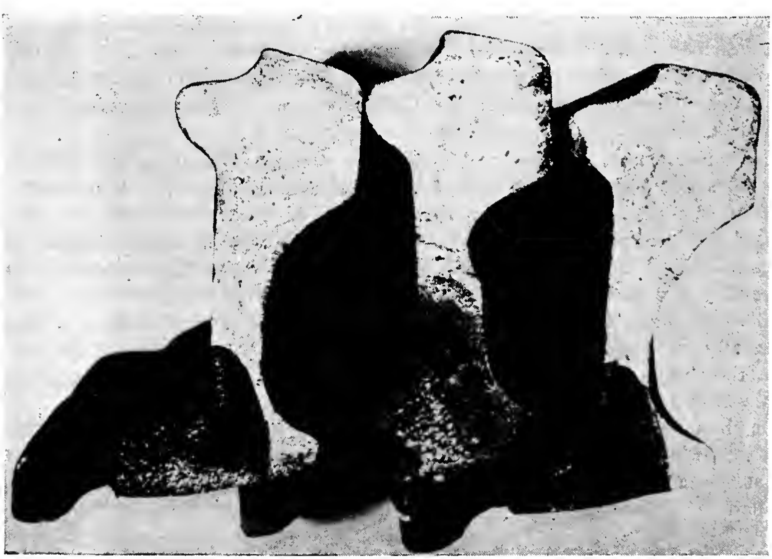


Fig. 1.—Progressive Fatigue Cracks Starting at Sharp Corner of Spike Slot.

Fig. 2.—Progressive Fatigue Cracks at Upper Contact Surface of Head-Contact Bar Originating at "A".

These types of cracking may or may not result in complete breakage of the bar in track. That breakages do occur in track is well known, and typical examples are shown in Figures 3 and 4.

The two most common types of cracking are illustrated in Figures 1 and 2, namely, (1) fatigue cracks originating in the spike slot, and (2) fatigue cracks originating at the upper contact surface of the bar.

The committee's previous report (Proceedings for 1940, Vol. 41, pages 633–637) gave in detail the results of a canvass of the railroads as to the number of failures occurring. While the seriousness of the problem may not be evident from the reported failures, the future aspects of the problem deserve consideration. Some railroads are having bars break in track; others, in their reforming operations, have found it necessary to scrap a large number of bars which, except for cracking, might otherwise have been reclaimed. The question as to whether the presence of a crack seriously reduces the stiffness of the joint is one which cannot be answered on the basis of information available at the present time.

To study possible means of eliminating the cracking of joint bars, tests in track and tests in the laboratory are being conducted along the following lines:

1. Resistance to cracking by improving the physical properties
2. Photoelastic studies as to effect of design and bolt tension
3. Fatigue tests, using full size bars of various design in assembled joints
4. Observations as to the effect of saw swelling of the rail end

1. Improving Physical Properties

Four lots of 100 pairs of bars each were installed in the track of the Chicago, Burlington & Quincy, near Ft. Morgan, Colo., MP 460 to 461.8. The four lots are all of the same rolled section, consisting of—

(a) Common chemistry, common heat treatment

(b) Common chemistry, common heat treatment plus flame hardened on top bearing surface at the center

(c) Common chemistry, water quenched and drawn

(d) Different chemistry, heat treated (yield point minimum of 85,000 lb. per sq. in. and tensile strength of 120,000 lb. per sq. in.)

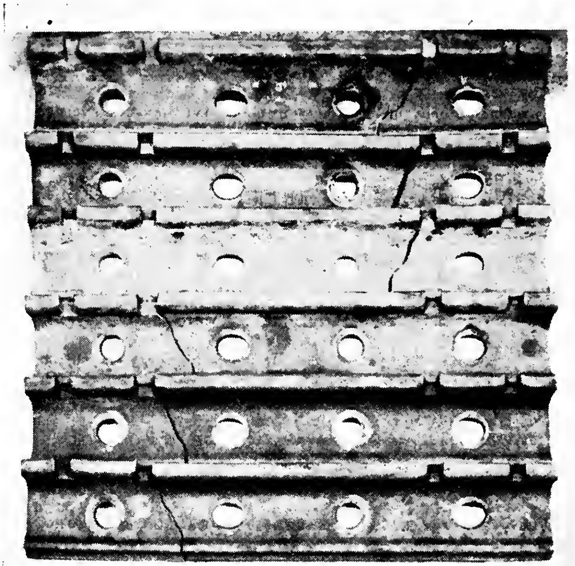


Fig. 3.—Typical Broken Bars Resulting From Fatigue Cracks in Spike Slots.

Fig. 4.—Typical Broken Bars Resulting From Progressive Fatigue Cracks Originating in Upper Contact Surface.

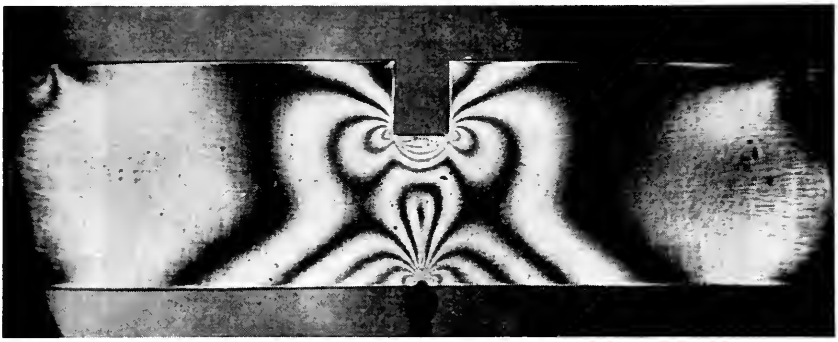


Fig. 5.—Illustration of Stress Concentration at a Square Corner.

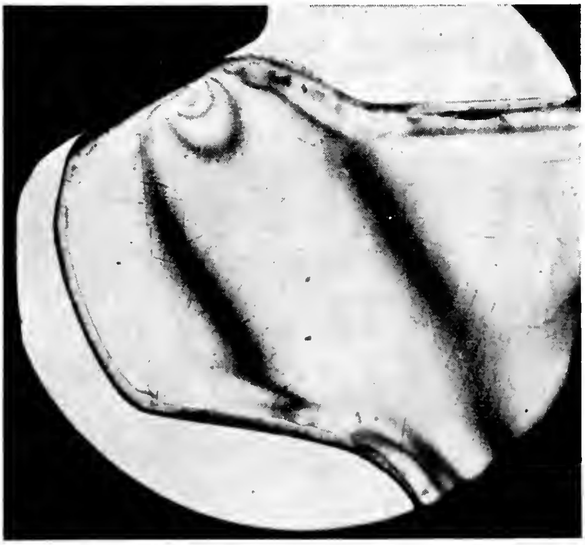


Fig. 6.—Showing Stress Concentration at Outside of Top Fishing Surface of Model of Bars Which Cracked and Broke in Service as Shown by Figures 2 and 4.

The bars were placed in track in July 1939, observational measurements being made semi-annually, but no conclusions have as yet been obtained.

2. Photoelastic Studies

Photoelastic studies, using bakelite models, to determine the effect of design and bolt tension are being made in the laboratory of the Denver & Rio Grande Western*.

* For a more complete account of these photoelastic studies, see the monograph by W. B. Leaf on page 682.

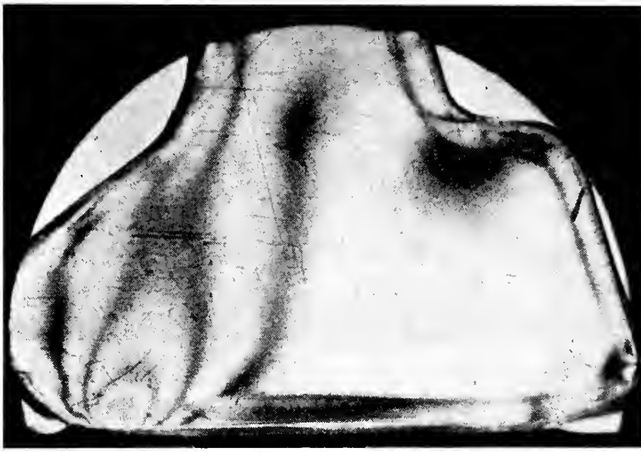


Fig. 7.—Showing Stress Concentration at Inside of Bottom Fishing Surface of a Model of Bars Which Cracked and Broke in Service as Shown by Figures 2 and 4.

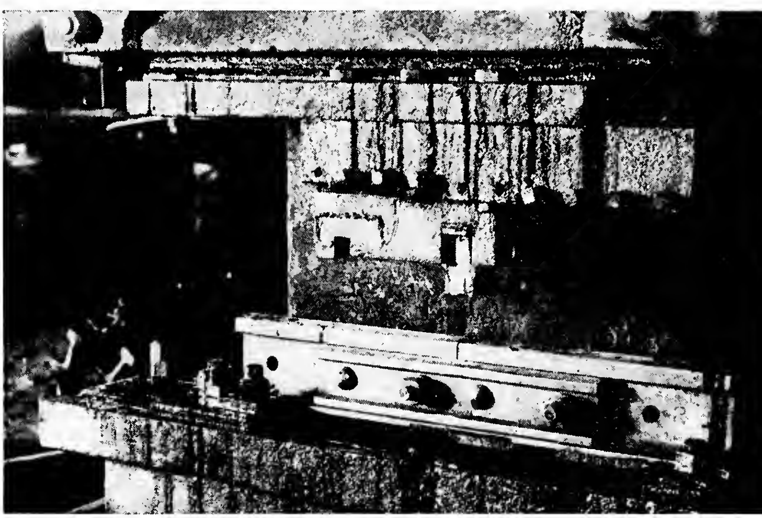


Fig. 8.—Assembled Joint in the Fatigue Testing Machine.

Examples of these studies follow:

Figure 5 illustrates by means of photoelastic study of a bakelite model, the stress concentration which occurs in the square corner of a spike slot, which may cause the progressive fatigue failures to develop as is shown in Figures 1 and 3.

Similar photoelastic studies of bakelite models of toeless bars have shown that cracking is associated with the cocking tendency of the section. As an example, Figures 6 and 7 show the stress concentration at the outside of the top fishing surface and the inside of the bottom fishing surface, respectively, of a section which is known to have given trouble in service. The stress concentrations in this case have been shown to be due to the natural cocking tendency of the section. The stress concentration is greatest at the upper fishing surface and furthermore occurs at the point where cracks in service originate. This is shown by a comparison of Figures 6 and 2.

Photoelastic studies are being made of models of the various conventional sections. No conclusions have as yet been reached.

3. Fatigue Testing

Fatigue tests of fully assembled rail joints are being conducted by the Colorado Fuel & Iron Corporation, Pueblo, Colo., in cooperation with the Denver & Rio Grande Western, by mounting the assembled joint on supports 36 in. apart and loading it at the center with a concentrated load of 65,000 lb. at a rate of 50 applications per minute. All joints were made up with 20,000 lb. bolt tension. This method of testing was found to produce cracks, identical with those encountered in service. Figure 8 shows the assembled unit ready for test.

Typical sections being tested are shown in the table (all bars rolled to standard AREA specifications unless otherwise shown).

Fatigue tests are also being conducted at the University of Illinois laboratory in the rolling-load machine in connection with the work of the Special Committee on Stresses in Railroad Track.

The tests have not been completed and no conclusions are offered.

Rail Weight Pounds	*Bar Length Inches*	*Sec. No.*	*Bar Type*	*Modifications*
110	24	T-91312	H. C. Long Toe	None
112	"	B-4	H. F.—Center overfill	"
"	"	"	"	Easement—T. C.
"	"	R E	H. C.	None
"	"	"	"	Flame Hard.—T. C.
"	"	"	"	" " & Easement—T. C.
"	"	"	"	2" Easement—T. C.—Hot Worked
"	"	"	"	I. M. Steel —As Rolled
"	"	"	"	" " " Oil Quenched
"	"	"	"	" " " " " and tempered
"	"	B-3	"	None
"	"	B-34	"	"
"	"	"	" —C. B.	"
"	"	"	H. F.	H. C. Reformed to H. F.
"	"	"	H. C.	2" Easement—T.C.
"	"	"	"	1" " "
"	"	"	"	1/8" Lower bolt holes
"	"	"	"	" " " " & Easement
"	"	"	"	Flame Hard.—T. C.
"	"	"	"	" " " & Easement
"	36	"	"	None
"	24	B-34-1	"	"
"	"	"	"	"
"	"	"	"	Flame Hard.—T. C.
"	"	"	"	Water Quench & Tempered
"	"	"	"	.70 C Oil Quench & Tempered
"	"	A-14	H. F.	None
"	"	A-59	H. C. Long toe	"
131	36	B-8	H. C.	"
"	"	R E	"	"
"	"	A-13	H. F. Long toe	"
"	"	A-39	H. C. " "	"
"	"	B-17	H. C.	"
"	"	"	" —C.B.	"
"	"	B-2	" "	"

Notes
T. C.=Top center
H. C.=Head contact
H. F.=Head free
I. M.=Intermediate Manganese

4. Effect of Saw Swelling

Observations in track and on fatigue tests are being made to determine the effect of saw swelling.

In conclusion, the results of the investigations to date indicate the possibility of changes in design and specifications, and this report is offered as information with the recommendation that the subject be continued.

Photoelastic Investigation of Design of Joint Bars

A Monograph Supplementing the Report on Assignment 7

By W. B. Leaf
Research Technician, Denver & Rio Grande Western Railroad

The photoelastic method of investigation is a means of determining the elements of design of any machine part or structure. It tells us nothing of the metallurgy or physical properties of the part under consideration. Strictly speaking, all that the photoelastic method tells us is the ratio between applied load and stress developed in the model itself. However, if the model truly represents the prototype, and the model loading represents the prototype loading; and further if the model is to full scale, the ratio between loading and developed stress at all points is the same in both model and prototype. Only one further precaution must be observed. The model must not be strained beyond the proportional limit, and it must be assumed that the prototype is similarly treated.

Description

The photoelastic method consists of observing a model made from any transparent solid or semi-solid, in plane or circularly polarized light. When the model is loaded the stress distribution is immediately seen as a series of color cycles through the model, if white light is used. Or, if monochromatic light is used, the stress pattern is seen as a succession of light and dark bands across the model.

Thus, if the model is merely a rectangular bar under a uniform bending moment along a portion of its length, as in Fig. 1, and if the load be steadily increased, cycles of color, or alternate dark and light bands, are constantly generated at the two outer edges of the bar and each one of these moves inward towards the neutral axis. The neutral axis remains uniformly dark, and as the bands move inward, they become closer spaced. It will be seen that the number of bands between the neutral axis and the outer edge is directly proportional to the applied bending moment. So the photoelastic constant of the material may be determined. This constant is the stress value per band, or cycle, directly in terms of compression or tension per square inch. Strictly speaking any one band shows the area in which the shear value is constant. However, at a free boundary of the model the stress pattern gives directly the compression or tension at that boundary. There is no evidence in the pattern as to whether the stress is compression or tension. This must be determined by a compensator or other means easily employed.

Application to Joint Bar Studies

There are a number of ramifications and refinements in the method which need not be considered here. The subject at hand is a photoelastic investigation of the various joint bar designs being studied in the test tracks on the Atchison, Topeka & Santa Fe Railway and the Pennsylvania Railroad.

In Fig. 2 the head contact bars are drawn as wedges, with lines connecting the ends of the fishing surfaces. It is seen at once that as wedges the designs leave something to be desired.

Fig. 1.—Rectangular Bar Under Uniform Bending Moment Through Center Portion.

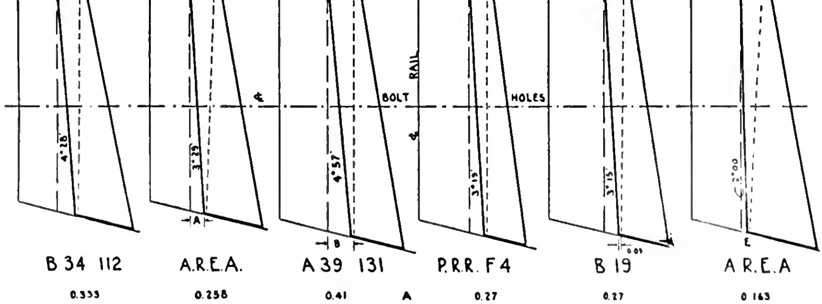


Fig. 2.—Various Head-Contact Joint Bars of Test Sections Drawn as Wedges to Show Relative Instability Against Cocking. Fishing Surfaces Shown in Theoretical Relative Positions.

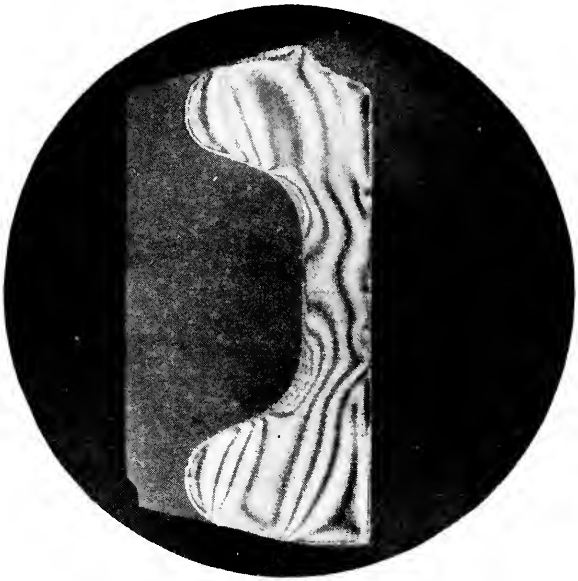


Fig. 3.—Wedge of Conventional Shape Similar to Joint Bar. Location of Fishing Surfaces Symmetrical. Fishing Surfaces of Equal Length. No Cocking and no Stress Concentration.

Fig. 4.—Wedge Similar to Fig. 3. Top Fishing Surface ½ in. in Length. Inner Contact Points Symmetrically Located. No Cocking, But Slight Stress Concentration at Top.

Consider what might happen as these various wedges are forced between the fishing surfaces of a rail or some similar shape with wide fishing surfaces. A symmetrical wedge with long surfaces, as in Fig. 3, would move straight inward as far as the distortion and elasticity of the metal would allow it to go. Distortion of the wedge would be uniform at the top and bottom if the rail were rigid. However, a wedge with very short surfaces might rotate slightly as it moves inward. This is especially true of such a wedge as the A 39 131-lb. section, or the P.R.R. F4 as shown in Fig. 5, where the top surface is somewhat to the left of the bottom one. If the wedge should rotate a small unit about a point near *E*, the amount of metal which would have to be distorted at the top is a function of the external secant of a small angle multiplied by the area of the surface. If the wedge should rotate a small unit about a point near the inside at the top of the wedge, the corresponding amount of metal to be distorted is a function of the external secant of a much larger angle multiplied by a much larger area. The various angles, their external secants and their product of multiplication by the area for a unit length of wedge are listed in the table. The angles are arrived at by this means:

With a point *E*, which is 0.05 in. inside the top or bottom contact surface as a center, a circle of suitable radius is drawn to intersect the opposite contact surface at its mid point. The angle then is that one between a tangent to the circle at its intersection with the contact surface, and the contact surface, in the plane of the diagram. The dimension 0.05 in. is used because the center of the line bearing formed with a cocked bar is at about this location.

TABLE OF PROPERTIES

Section	*Angles top and bottom*	*Ex. sec. of angles*	*Widths times es. sec.*
B 34 112	12°25′	0.024	0.012
	25°00′	0.103	0.116
AREA 112	13°30′	0.028	0.015
	24°15′	0.097	0.109
A 39 131	11°35′	0.021	0.012
	24°35′	0.100	0.100
P.R.R. F4 131	12°50′	0.026	0.011
	21°45′	0.077	0.062
B 19 131	12°50′	0.026	0.011
	22°30′	0.082	0.080
AREA 131	15°15′	0.036	0.018
	23°40′	0.092	0.128

These figures control the initial tendency of the bar to cock.

Naturally, as soon as any cocking takes place, the further movement of the bar is controlled by the new condition then in effect as to relative locations of the contact surfaces and their widths.

After the wedge cocks inward at the top, contacts are made at points slightly inside the theoretical ends of the fishing surfaces, as at *D* and *E*, or as shown in Fig. 6 for the 112-lb. B 34 bar. The closely spaced stress "loops" show a stress concentration with a tendency to form a line bearing.

The relative locations of these points for the different sections are indicated by the figures for *C–B* in Fig. 2. If *D* is directly above *E*, the shape is relatively stable in the cocked position, since the amounts of distortion at the top and bottom for additional inward movement are equal. However if *D* is relatively distant to the right of *E*, as in the AREA 131-lb. wedge, the cocked position is not the stable one, and the bar will tend

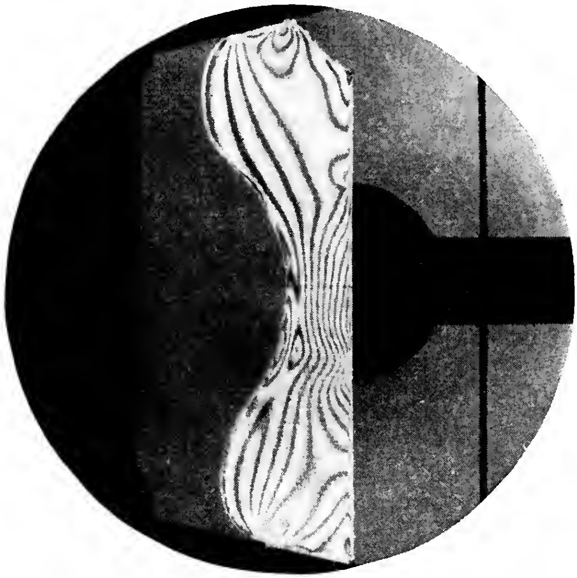


Fig. 5.—P. R. R. Section F4 131-lb. Bar. Slight Cocking Tendency and Stress Concentration.

Fig. 6.—B 34 112-lb. Bar, Showing High Compressive Stress at Outside of Top and Inside of Bottom Fishing Surfaces. Bar Cocked and Having Line Bearing.

to uncock itself. The two committee bars are the only shapes in which D is any appreciable distance to the right of E. The 131-lb. AREA bar is shown in Fig. 7.

As to 110-lb. Bars

One of the mysteries attending the cracking of 112-lb. head-contact bars was the lack of trouble in the 110-lb. bars of supposedly similar section. The reason for this lack of similar cracking in the 110-lb. bars becomes evident in the light of this analysis. The dimension A for the 110-lb. long-toe section, as used by the D.&R.G.W. is 0.35 in., which is bad, but $C–B$ is 0.18, which is favorable. In the toeless 110-lb. bar A is 0.29 in., again bad, but "C–B" is 0.20 in. Since the fishing height of 110-lb. rail is 13/32 in. lower than that of the 112-lb. rail, angles become greater for less relative lateral distances, and a small change in angle produces a relatively large change in external secant.

Wedges with controlled bearing at the top can only be less stable than the plain ones, since less than the usual amount of metal must be distorted for top inward movement, and since unit bearing pressures are higher, due to the restricted bearing area.

Other Factors Influence Wedge Action

Obviously there are a number of minor factors which influence the action of the wedges. Friction between the surfaces, gouging, location of bolt holes, rigidity of bolt head, etc., etc., are some of them. Friction becomes low over a period of time because of vibration and the longitudinal movement between bar and rail. Gouging cannot be great as there are no sharp edges on the wedges. Slight cocking is accompanied by a change in the average point of thrust by the bolt head against the bar. But the bolts are flexible, and to stabilize such a shape as A 39, the bolt hole would have to be dropped 1¾ in., as indicated by the restraining influence ratio between top and bottom. Thus the bolt has to be lowered to a point such that the products of lever arms and restraints become about equal.

It is significant that the bolts of 112 and 131-lb. sections are the same distance from the top fishing surface intersections. This is faulty design, since the 131-lb. bars then have a relatively high bolt, with increased cocking tendencies.

High Bearing Pressures

The evils of cocked bars are in that the bearing areas are restricted and unit compression is high. At the top of the bar, a wheel load imposes further compression, the total quantity being tied up in a calculation involving Poissons ratio. The amount of added compression from wheel load is a function of track stiffness, etc.

With a 20,000-lb. bolt tension, which is not unusual, the theoretical compression at the top of a 112-lb. bar with ½-in. contact at the fishing surface is 13,850 lb. per sq. in. If a line bearing is effected, with, say, ⅛-in. width, the figure becomes 55,400 lb. per sq. in. which is beyond the yield point. Obviously, if the total unit compression is beyond the yield point of the metal, plastic flow occurs during the downward movement of the joint, and during upward movement a portion of the deformed metal is then in tension. Hence a fatigue failure.

At the bottom of the bar, the positive moment tends to reduce the unit contact compression, hence the overall stress is less, and failure occurs from the top down. The progress of the crack is rapid shortly after its first appearance, but becomes less rapid as the area of high stress from contact pressures is left behind.

Negative moments are not as great as positive ones, so the bottom of the bar is not in as high overall stress as is the top. Failures from cocked 131-lb. bars are to be

Fig. 7.—AREA 131-lb. Bar, Showing Slight Cocking Tendency and Slight Concentration of Compressive Stress.

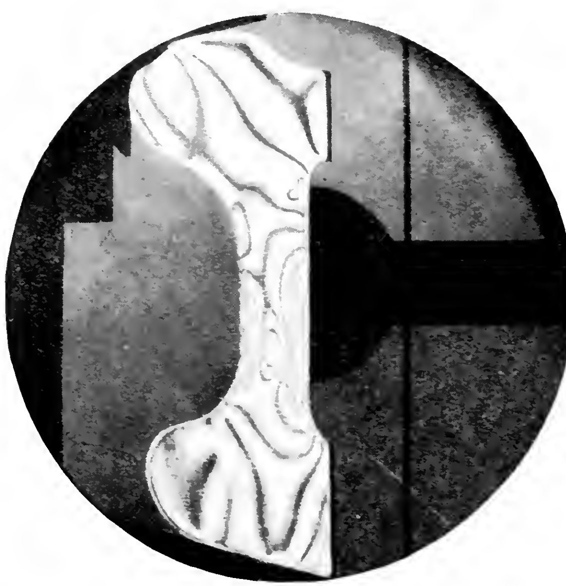


Fig. 8.—131-lb. Head-Free Bar. Note the Absence of Any Stress Concentration From Line Bearings.

expected but not in as short a time as in the 112-lb. bars since the rail and joint are much stiffer, and bending stresses are thus much reduced.

Only one head-free bar has been modeled, since this design is necessarily stable in its position. If properly rolled and applied, no line bearings will result. Fig. 8 shows a 131-lb. head-free model.

It is my contention that certain types of joint bar failures are caused by the instability of the shapes considered as wedges. A line bearing rather than a full surface contact increases contact stresses due to bolt tension and may exceed the endurance limit of the material. Failures are hastened by high bolt tension and swelled rail ends.

A remedy may be found in redesigning the bars to make a more stable wedge by lowering the bolt holes where possible and using reasonable bolt tensions.

Seventh Progress Report of the Joint Investigation of Fissures in Railroad Rails

By H. F. Moore

Research Professor of Engineering Materials, University of Illinois, in Charge of the Investigation

Summary

1. Fissures starting from the interior of the head of railroad rails first were recognized as important about 1911. Much discussion has taken place as to whether they were caused by minute flaws in rail steel (shatter cracks) or by the heavy wheel loads on rails. The development of detector cars made possible the detection of many fissures before rail fracture had occurred, but it did not touch the problem of prevention of fissures. In 1931 a joint investigation was sponsored by the manufacturers of steel rails, the Association of American Railroads and the Engineering Experiment Station of the University of Illinois. (pages 682–686)

2. A "rolling-load" testing machine was designed and built which subjected a specimen of rail to repeated cycles of wheel load and bending moment. Before testing in this machine an etch test to detect the presence of shatter cracks was made on the rail from which the specimen was cut. A long series of rolling-load tests showed the following results:

(a) In these rolling-load tests only shatter-cracked rails developed fissures, but not all shatter-cracked rails developed fissures.

(b) It is the complex stresses directly under a wheel load which cause cracks to develop into fissures. Bending moment tends to cause fissures to take a transverse direction, and accelerates their spread.

(c) No greater wheel load was required to start a fissure in a heavy rail than in a lighter rail. The minimum wheel load which started a fissure in the rolling-load tests was 40,000 lb.

(d) The wheel load necessary to start a fissure, the theoretical shearing stress in the zone where shatter cracks are located, the fatigue strength of rail steel, and the weakening effect of minute cracks (shown by fatigue tests of specimens) form a coherent picture of the mechanism of fissure formation and spread. (pages 686–691)

3. Extensive tests on four railroads where there was heavy traffic were made to get some statistical idea of the magnitude and frequency of high wheel loads under traffic. The DeForest scratch extensometer was used to measure mean strain in rail bases under passing trains. From these strains, wheel loads were computed. Records of strain under some 500,000 wheel loads were obtained, and it was found that at any location the average occurrence of wheel loads of 40,000 lb. or over was one in 1,000 wheel loads. At some locations the frequency was as much as three times this; i.e. three in 1,000. (pages 692–696)

4. A large number of hot-bed cooled test rails have been placed in various locations on the Baltimore & Ohio Railroad and on the Atchison, Topeka & Santa Fe Railway. The service record and the detector car tests made on these test rails have been carefully followed in the course of this investigation. All fissures developing in service or found by a detector car have occurred in shatter-cracked rails. (pages 696–701)

5. The solution of the problem of preventing shatter cracks in rails was attacked by making tests of specimens from rails cooled in air and also controlled cooled. Tests

were made at various steel mills using rail specimens, each specimen being cooled in an individual cooling box under carefully controlled and measured conditions. Variations in rate of cooling, temperature at placing specimens in boxes, temperature of removal from boxes and time in boxes were studied. In some tests hydrogen was introduced into one molten ingot so that rails rolled from that ingot and cooled in air would be sure to have many shatter cracks. It was found that rail specimens placed in a cooling container at temperatures not less than 700 deg. F., and which required not less than 7 hours to cool to 300 deg. F. in the cooling box developed no shatter cracks even in rail specimens from hydrogen-treated ingots. (pages 702–718)

6. The Brunorizing (normalizing) process of thermal treatment of rails was also studied, and the modified process as now practiced was found effective in preventing shatter cracks. (pages 718, 719)

7. Extensive studies of metallographic structure and of the strength and toughness of rail steel have been made. Some studies of chemical composition have been made, but the slight variation of chemical composition in the test rails furnished did not appear to be a major factor. Results of these studies are given in this report. (pages 719–743)

8. A large amount of study has been given to the problem of finding a non-destructive test which could be used to detect shatter cracks in new rails. In common with the work of previous investigators this effort has so far been unsuccessful. Shatter cracks are so minute that changes, due to these shatter cracks, in properties or structure of metal around them, are masked by other variations in the metal. (pages 743–747)

9. Experimental studies of a bend test for rails to supplement or to replace the drop test have been made. Like previous investigators the members of the test party have found the bend test distinctly superior to the drop test. (pages 747–750)

10. Unfinished work of the investigation relating to fissures includes formulation of proposed standards for control cooling of rails and for bend tests for acceptance of rails. (page 751)

11. The work of the investigation on end batter and end-hardened rails will be the subject matter of a separate report.

Foreword

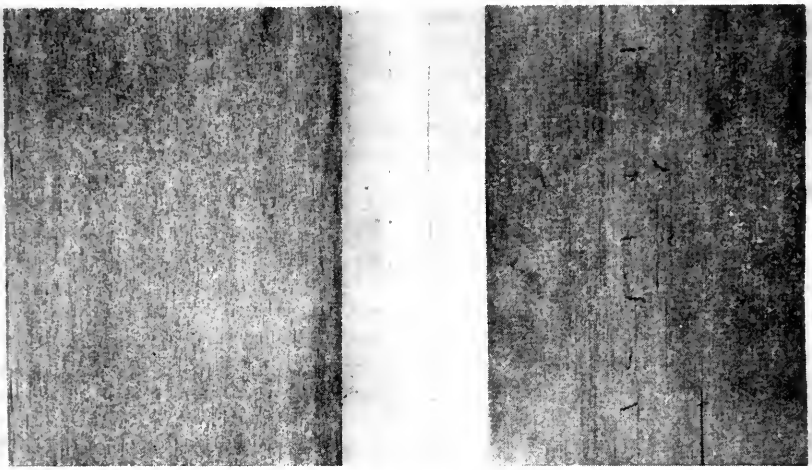
This Seventh Progress Report of the Rails Investigation is a summary of the work on the causes and prevention of fissures which has been carried on since the beginning of the investigation in 1931. A subsequent progress report will discuss the present status of the tests for batter of end-hardened rails.

In this report are given a few results of tests of specimens cut from end-hardened rails. These are included as a contribution to present-day knowledge of rail steel as a structural material.

I Introduction

1. **Historical.**—In 1911 the interest of steel manufacturers and railroads was aroused by a failure of a rail on the Lehigh Valley Railroad. An examination showed that this failure was a fracture apparently starting on the inside of the head. Other fractures of this type were reported until they became a serious problem to the railroad men and the steel rail manufacturers. A great deal of discussion arose as to whether these fissures were due to the increased wheel loads which rails had to withstand or whether they arose from defects in the steel. Etch tests by Wickhorst[1] and by Waring and Hofammann,[2] showed a large number of small cracks in specimens cut from new rails. (See Fig. 1) The question was at once raised whether these cracks were present in the original rails, or

[1] Wickhorst, M. H.—Internal Fissures in New Rails, AREA Proceedings, Vol. 16, p. 389 (1915).
[2] Waring, F. M. and Hofammann, K. E.—Deep Etching of Rails and Forgings, ASTM Proc., Vol. 19, Part II, p. 183 (1919).



(a) No Shatter Cracks (b) Shatter Cracks

Fig. 1.—Etch Tests on Specimens Cut From Two Rails.

were caused by the etching process itself. The records of the AREA showed a tendency for these "transverse fissure" failures, as they were called, to develop in rail laid in locations subjected to especially heavy traffic, and also to be more frequent in the rails rolled from certain mills than others. However rails rolled in different years by the same company also showed a wide variation in the prevalence of transverse fissure failures.

The development of the detector car about 1928 by E. A. Sperry under the sponsorship of the American Railway Association made it possible to detect the presence of many of these internal fissures before they had spread so far as to cause actual fracture of the rail. However, this did not meet the problem of the cause and prevention of such fissures; and the removal of broken rails and rails in which fissures have been detected constitutes a very considerable item of expense to the maintenance of way departments of railroads.

2. **Organization of the Investigation of Fissures in Railroad Rails.**—In 1931 there was formally started a joint investigation of the problem of internal fissures in railroad rails. The investigation was organized under the auspices of the Rail Manufacturers' Technical Committee and the American Railway Association (now the Association of American Railroads), acting through the American Railway Engineering Association. These two cooperators asked the Engineering Experiment Station of the University of Illinois to undertake the direction of the investigation.

To keep in touch with the progress of the investigation, the Technical Committee of Rail Manufacturers and the AREA Committee on Rail appointed an advisory committee and later appointed a small body from this advisory committee to serve as a contact committee. The present members of the advisory committee are:

Association of American Railroads—Rail Committee:

W. H. Penfield, Chief Engineer, Chicago, Milwaukee, St. Paul & Pacific Railroad (Chairman)

J. E. Armstrong, Chief Engineer, Canadian Pacific Railway

W. C. Barnes, Engineer of Tests, Rail Committee, AREA

C. B. Bronson, Inspecting Engineer, New York Central System

E. E. Chapman, Mechanical Assistant to Assistant to Vice-President, Atchison, Topeka & Santa Fe Railway

H. R. Clarke, Engineer Maintenance of Way, Chicago, Burlington & Quincy Railroad

G. M. Magee, Research Engineer, Engineering Division, AAR

P. Petri, Chief Engineer Maintenance, Baltimore & Ohio Railroad

Louis Yager, Assistant Chief Engineer, Northern Pacific Railway

Rail Manufacturers' Technical Committee:

L. S. Marsh, Manager, Department of Inspection and Metallurgy, Inland Steel Company (Chairman)

F. W. Bendell, Manager, Railroad Materials and Commercial Forgings Bureau, Chicago District, Carnegie–Illinois Steel Corporation

O. U. Cook, Assistant Manager, Department of Metallurgy, Inspection and Research, Tennessee Coal, Iron & Railroad Company

E. F. Kenney, Metallurgical Engineer, Bethlehem Steel Company

J. H. Reece, Chief Inspector, Colorado Fuel & Iron Company

F. A. Wickerham, Assistant to Chief Metallurgical Engineer, Carnegie–Illinois Steel Corporation

The present membership of the contact committee is as follows:

L. S. Marsh, *Chairman,*	C. B. Bronson	E. F. Kenney
W. C. Barnes	E. E. Chapman	G. M. Magee
F. W. Bendell	O. U. Cook	

During the progress of the investigation the following persons, who are no longer members, have served as members of the advisory committee.

Earl Stimson (Co-chairman for the AREA) Chief Engineer Maintenance, Baltimore and Ohio Railroad (deceased)

John V. Neubert (Co-chairman for the AREA) Chief Engineer Maintenance of Way, New York Central System (deceased)

F. W. Wood (Co-chairman for the Technical Committee of Steel Rail Manufacturers) Baltimore, Maryland (retired)

John Brunner, Manager Department of Metallurgy and Inspection, Carnegie–Illinois Steel Corporation (deceased)

A. F. Blaess, Chief Engineer, Illinois Central Railroad (deceased)

John S. Unger, Research Engineer, Carnegie Steel Company, Pittsburgh (retired)

G. J. Ray, Vice-President and General Manager, Delaware, Lackawanna & Western Railroad

W. A. Maxwell, Jr., Vice-President, Colorado Fuel & Iron Co.

T. H. Sanderson, Assistant Superintendent of Rail Mill, Carnegie–Illinois Steel Corporation, Gary Mill

Maro Johnson, Principal Assistant Engineer, Illinois Central Railroad

R. Faries, Assistant Chief Engineer—Maintenance, Pennsylvania Railroad (deceased)

C. F. W. Rys, Chief Metallurgical Engineer, Carnegie–Illinois Steel Corporation

L. H. Bond, Chief Engineer Maintenance of Way, Illinois Central Railroad

W. P. Wiltsee, Chief Engineer, Norfolk & Western Railway

The present test party, which is carrying on the work of the investigation includes the following:

H. F. Moore, Research Professor of Engineering Materials, University of Illinois, in charge of investigation

H. R. Thomas, Special Research Professor of Engineering Materials, Engineer of Tests, in charge field tests.

R. E. Cramer, Special Research Assistant Professor of Engineering Materials, metallurgical work

N. J. Alleman, Special Research Associate, rolling-load tests, bend tests of rails

J. L. Bisesi, Special Research Associate, non-destructive tests for cracks, inspection of rails in test tracks

S. W. Lyon, Special Research Assistant, physical tests of rail steel

Test Assistant: R. S. Jensen

Student Assistants (part time): E. C. Lauck, J. C. Leming, William Mareneck

Mechanicians: H. Belles, F. A. Ferris, H. H. Griesheimer, M. K. Shafer, Harley Musgrove

Assistant in Machine Shop: C. Boley

Clerk and Stenographer: Rogene Strode

The following persons have been members of the test party, but have left for other positions:

E. C. Bast, G. B. Bliss, W. D. Boone, K. Anderson, R. G. Emerson, John Haake, G. N. Krouse, J. G. Lowther, J. C. Mace, J. A. Nachowitz, R. S. Hutton, T. J. Riggs, N. H. Roy, L. G. Ramer, E. F. Ream, J. S. Shapland, J. R. Trimble, H. Wallace, C. P. Wampler, H. B. Wishart, Dave Wiegand, R. J. King, R. J. Houkal, M. W. Woodruff, J. C. Othus, A. E. Abel, Chas. Middlesworth, H. Hood, D. C. Brown, C. Beiler, P. A. Ramsdell, J. C. Leming, J. O'Neal.

3. **Previous Investigation of Fissures in Rails.**—While the problem of internal fissures in rails is of comparatively recent origin, rail breakage is a problem as old as the railroad. In the early days the list of noteworthy research workers includes Styffe in Sweden, Tetmajer in Switzerland, Wöhler in Prussia, Kirkaldy and Sandberg in England, P. H. Dudley and C. B. Dudley in the United States.

Since the 1911 rail failure on the Lehigh Valley Railroad, a large amount of study has been given to this phenomenon of internal fissures, especially to transverse fissures, and the names of Howard, C. B. Dudley, P. H. Dudley, Cushing, Wickhorst, Comstock, J. R. Freeman, Jr., Gennet, Robert Job, Quick, Rawdon, Clayton, Styri, and J. B. Young are among those who have made valuable contributions.

A cooperative investigation under the auspices of the Chicago Rapid Transit Company (the elevated railroad service) and the University of Illinois Engineering Experiment Station was in progress when the present investigation was begun, and the work of this earlier investigation was taken over by the larger investigation.

4. **Strength of Railroad Rails and Service Demands Upon Them.**—As is the case with very many problems in strength of materials, the question of failure of rails from internal fissures involves two very general questions: (1) What tensile stresses, what compressive stresses, and what shearing stresses will rails withstand without failure under service loads? and (2) What stresses in rails are set up in actual service? The first of these problems involves laboratory tests as the principal means of solution. The second must be answered by field tests with measurement of actual stresses measured under train service at a large number of typical locations where rails are subjected to heavy traffic.

5. **In What Ways Can Railroad Rail Failures Be Produced?**—Railroad rails in service are subjected to a remarkably complex system of stresses and strains. It is immediately obvious that they may fail by direct flexural action, and the classic investi-

gations of Professor A. N. Talbot and his Committee on Stresses in Railroad Track have given a very elaborate analysis for computing the flexural stresses to which rails are subjected by wheel loads. Rails sometimes fail by stresses in the web of the rail but this type of failure obviously does not originate from internal fissures in the head.

Rails may fail by a very complex system of localized stress set up directly under a wheel load. The mathematical determination of tensile, compressive and shearing stresses under a wheel resting on a rail was developed somewhat previously to this investigation independently by Professor N. M. Belajef in Leningrad, Russia, and a little later by Professor H. R. Thomas and Dr. V. A. Hoersch of the Department of Mathematics, University of Illinois.[3] These two mathematical analyses gave identical results.

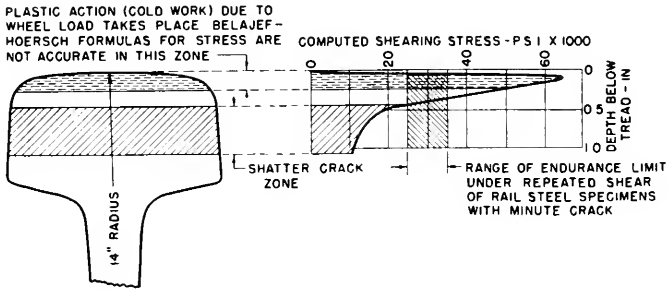


Fig. 2.—Computed Shearing Stress in Head of Rail Under a Wheel Load of 40,000 lb. on a 33-in Wheel.

An internal fissure in a rail suggests that shearing stress may be the cause, since shearing stresses tend to become a maximum below the surface of a beam. The theoretical shearing stresses below the tread of a rail under a wheel load are shown in Fig. 2. Actually these stresses are modified by the fact that near the tread of the rail there is plastic action, (cold work) so that the actual stresses are lessened near the tread of the rail. However, as was shown by Thomas and Hoersch there is evidence that at a depth of ½ in. below the tread of the rail there is fair agreement between theoretical stresses and actual stresses. Figure 2 shows the theoretical distribution of shearing stress over a vertical-longitudinal section of a rail head under a wheel load.

The complex stresses in a rail directly under a wheel are relatively high, and are confined to a small region—very small in comparison with the full section of the rail. This means that the size of rail will make little difference in its resistance to the starting of internal fissures in the head. Moreover, it is magnitude of wheel load which is significant rather than flexural stress. However, owing to the lower flexural stresses, cracks will probably spread more slowly in a heavy rail than in a light rail.

II The Development of Internal Fissures in Laboratory Tests of Rails and in Rails in Service

By H. F. Moore

6. **Test Rails.**—In carrying out the two branches of the investigation, strength of rails and service conditions which they must meet, there were supplied by five different steel mills about 5,000 tons of 130-lb. rail and 3,750 tons of 110-lb. rail to serve as test

[3] Thomas, H. R. and Hoersch, V. A.—Stresses due to the Pressure of One Elastic Solid Upon Another, Bulletin 212, Eng. Exp. Sta., University of Illinois. Mr. Belajef's work is published in Russian.

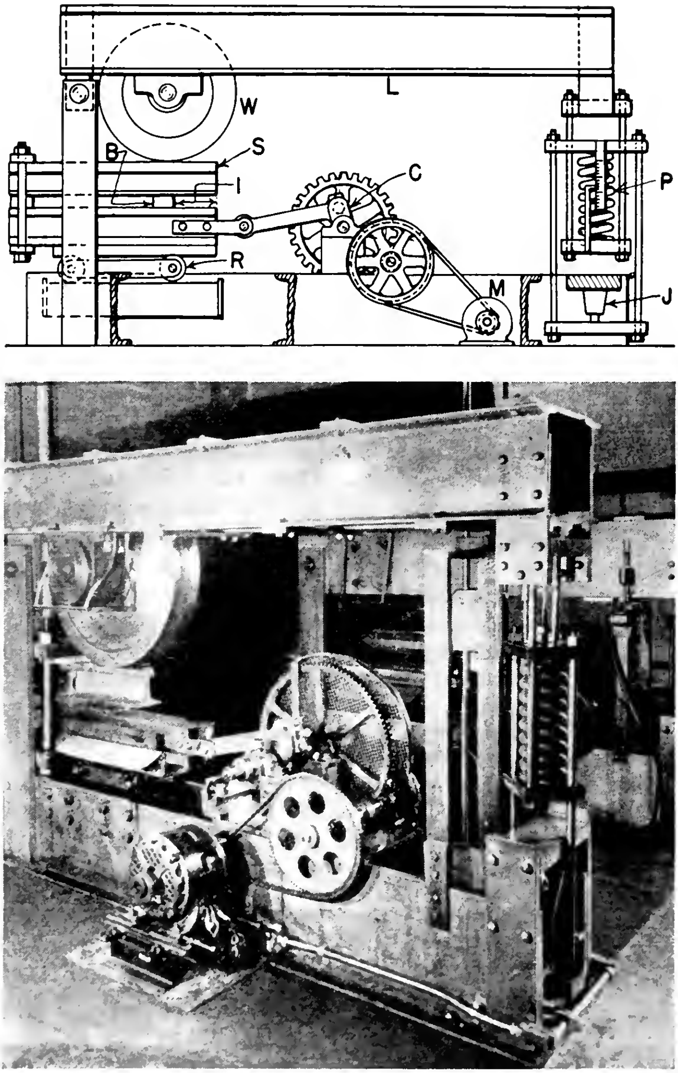


Fig. 3.—Testing Machine for Rolling-Load Tests.

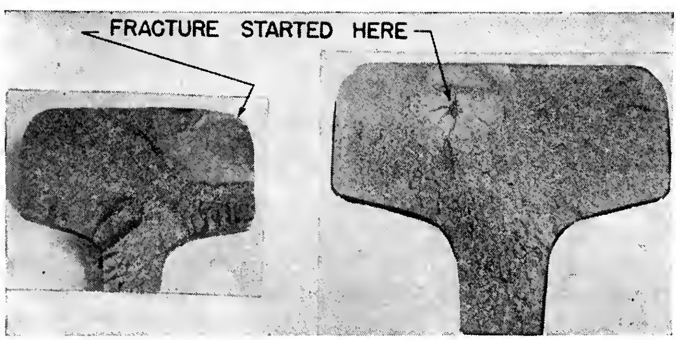
rails. These five mills are designated by the letters A, B, C, D and E. From each heat rolled three rails were sent to the University of Illinois to furnish specimens for various laboratory tests. The 130-lb. rails were put in test locations on the Baltimore & Ohio Railroad and the 110-lb. rail on test locations on the Atchison, Topeka & Santa Fe Railway.

All these rails were rolled under ordinary conditions and were cooled on hot beds. Unusually complete records were kept at all stages in their manufacture. They passed the usual routine inspection and all the test rails were from heats which were accepted.

About 289 rails were sent to the University of Illinois for test specimens and from each one of these rails one or more pieces, six inches long, were sawed off at least three feet from the end of the rail. The head of each piece was sliced horizontally and the piece then etched in a 50 percent solution of hydrochloric acid to detect shatter cracks. Eighty-two of the rails were found to contain shatter cracks. The number of shatter cracks found in an etch test varied widely. Many more longitudinal shatter cracks were found than transverse shatter cracks.

7. **Rolling-Load Testing Machine for Developing Internal Fissures in Rails.**—A special testing machine was built in which a specimen of rail could be repeatedly subjected to known wheel loads and bending moments. This machine is shown in Fig. 3. In this machine a short specimen of rail *S* is pulled backwards and forwards under a wheel load which can be varied from zero to 80,000 lb. This load is applied through the lever *L* by means of the screw jack, *J*, and is measured by the compression of the spring *P*. The bending moment can be measured as the product of the weight on the wheel times *l*, the distance of "overhang" of the specimen rail when it is in its extreme left-hand position; *l* can be varied by moving the block *B*. A revolution counter is attached to the crankshaft of the machine, and an automatic cutoff switch is operated by the drop of the lever *L* when a specimen fails. The stroke of the machine is 7 in. and its speed 60 r.p.m. Three of these machines have been built and have been used in the study of fissures in rails and later in the study of batter of rail ends.

8. **Results of Tests of Rails Under Repeated Rolling Load.**—Tests of short lengths of rails under repeated rolling load in the special testing machines designed and built for this investigation have developed failures starting as transverse fissures in a considerable number (although by no means all) of the newly-rolled test rails which, by means of etch tests, were found to contain shatter cracks. (See Fig. 1). No failures starting as transverse fissures have as yet been developed in the laboratory in newly-rolled rails which etch tests have shown to be free from shatter cracks. Such uncracked rails, when they fail under repeated rolling load, fail by fatigue cracks starting from the surface of the rail. Moreover, they require higher wheel loads to cause fracture than do shatter-cracked rails. In all, some 147 rail specimens have been tested in the special rolling-load testing machines, many of them to 1,000,000 cycles of stress, or more. Figures 4a and 4b show the two types of spreading fracture which occurred.



a

b

(a) Fatigue fracture starting at surface; this is the type of fracture in rolling-load tests of rail specimens free from shatter cracks.

(b) Internal fissure starting from nucleus in rail head; this is the type of fracture in some specimens with shatter cracks.

Fig. 4.—Two Types of Fracture in the Rolling-Load Test.

TABLE 1

INDIVIDUAL FISSURES FORMED INDEPENDENTLY OF EACH OTHER—NOT COMPOUND
Tests in Rolling-load Testing Machine

Specimen	*Flexural Stress lb. per sq. in.*	*Type of Fissure Developed*	*Maximum Shearing Stress at Point of Fracture in Rail Head lb. per sq. in.*
31–2	68,600	Trans.	36,800
473–3	47,400	Trans.	35,400
507–1	47,200	Trans.	35,400
473–1	41,900	Trans.	32,900
31–1	41,200	Trans.	25,800
610	36,500	Trans.	32,800
572–2	36,100	Trans.	38,000
451	33,500	Trans.	21,000
572–3	31,300	Trans.	37,200
701–4	26,800*	Trans.	37,600*
70–1	26,300**	Trans.	38,200
707–2	22,900	Trans.	26,000
707–1	20,600	Trans.	28,000
701–3	17,200***	Trans.	25,600
70–1	14,400**	Trans.	25,700
707–1	14,000	Horiz.	19,400
507–6	11,500	Horiz.	27,000
582	11,400	Horiz.	17,800
1005	10,900	Horiz.	19,800
1007	10,900	Horiz.	19,800
473–6	0	Horiz.	
86	0	Horiz. & †	31,900
		Vert.-Long‡	55,900
473–6	0	Horiz.	23,800
507–3	36,500	Comp'n Horiz.	30,400
	34,300	Comp'n Horiz.	23,600
43	47,000	Comp'n Diag.	27,600
	42,100	Comp'n Horiz.	19,600

* Did not rupture at theoretical critical section; fissure located by subsequent slicing and etching; depth to nucleus not precisely known.

** Did not rupture at theoretical critical section; fissure located by subsequent slicing and etching; diameter of nucleus of fissure, 0.5 in.

*** One of six transverse fissures in two inches of rail.

† Tensile stress normal to horizontal plane.

‡ Shearing stress in one direction of fracture 42,100 lb. per sq. in., and tensile stress normal to vertical-longitudinal plane (another direction of fracture) 16,900 lb. per sq. in.

In laboratory tests of rails in the rolling-load machines internal fissures have been developed under the wheel load at sections where bending moment was very small, but never, even in shatter-cracked rails, at sections of heavy bending moment outside the path of the wheel load. Hence it seems clear that the stress under the wheel load on the rail is a factor of prime importance. Table 1 shows typical results of rolling-load tests.

9. **Harmony of Test Results.**—From tests of specimens of rail steel (See Chapter VII) the endurance limit of rail steel under cycles of shearing stress varying from zero to a maximum ranges from 50,000 to 65,000 lb. per sq. in., using polished specimens. If a series of specimens is tested in which a small fatigue crack has been started the endurance limit is reduced from 40 to 50 percent. Figure 5 shows results from rolling-load tests. It will be noted that all but one of the specimens in which internal fissures were developed were subjected to theoretical shearing stresses which, if repeated, would

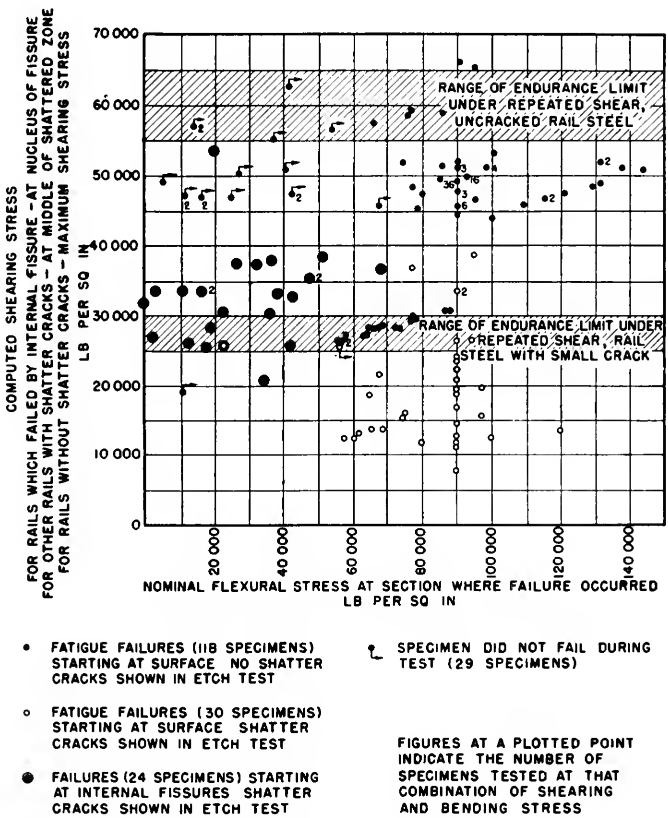


Fig. 5.—Results of Rolling-Load Tests of Rail Specimens.

cause failure in a specimen in which there was a small crack. It will be noted that about 80 percent of the specimens which had shatter cracks and which failed from cracks starting at the surface had theoretical shearing stresses below the range which might be expected to cause cracked specimens to fail.

It will be noted that specimens without shatter cracks which failed from fatigue cracks starting at the surface had computed flexural stresses above those required to develop failure in cracked fatigue specimens but, with two exceptions, within or below the range of endurance limit under repeated shear for uncracked specimens. It was impossible within the capacity of the rolling-load machines to develop fatigue failures in full-size heavy rail free from shatter cracks. In this case the section of the rail was artificially weakened in such a manner that no metal was removed from the shatter-crack zone, but the section modulus of the rail for resisting flexure was distinctly lessened. In the rolling-load tests in a shatter-cracked rail fissures have been developed by wheel loads as low as 40,000 lb. By the theory of elasticity this load would develop a shearing stress in the shatter-cracked zone of the rail head of about 25,000 lb. per sq. in. at a point ⅜ in. below the tread of the rail. This would be just about the lower limit of the range of endurance limit for cracked specimens.

In Section 16 it will be noted that wheel loads of 40,000 lb. occasionally occur under wheel loads in the test tracks studied in this investigation.

The results of the rolling-load tests give grounds for the following general conclusions:

1. Shatter cracks in the heads of rails are certainly a major and probably the major cause of fissures in the rail. Transverse fissures, vertical split heads and horizontal split heads—all have been developed under the rolling-load test.

2. During the progress of the rolling-load tests for developing fissures, the lowest wheel load which caused a shatter crack to spread into a fissure was 40,000 lb. This value has, therefore, been taken as a limiting load, below which fissures probably will not develop even though lower loads may be repeated several millions of times.

3. The minimum load which caused fissures in the rolling-load tests, the stresses set up in the rail head at the shatter-cracked zone by that load, and the results of tests of cracked fatigue specimens of rail steel form a harmonious picture of the mechanism of the development of the transverse fissure.

10. **Transverse Fissures and Shatter Cracks in Service.**—During the course of the investigation some 150 rails have been received in which transverse fissures in service have been developed. Approximately 87 percent of these when examined and etch tested were found to contain shatter cracks. Some of the others were found to contain large inclusions of oxide from which the fissure started. In some of them transverse fissures seem to start from slag streaks but in the laboratory so far no fissures have been developed from slag streaks unless etch tests showed shatter cracks around them. The service records confirm in a general way the findings of the laboratory tests that shatter cracks are the major cause of the development of fissures. However, they indicate, as might be expected, that in the unusual case of a large oxide inclusion located in the zone in which shatter cracks occur in a rail a fissure may develop if it is subjected to heavy wheel load.

11. **Effect of Flexural Stress on Growth of Fissures.**—Both the mathematical theory of stresses in rail heads and the results of rolling-load tests agree in indicating that the start of a destructive fissure is due to the direct action of the wheel load rather than to the flexural stress. The mathematical analysis of stresses due to this direct action of wheel load, which is shown to agree very well with rolling-load test results, indicates that the stresses set up are practically independent of the size of rail. Hence, it seems that the starting of fissures would not be hindered by the use of heavier rails, except insofar as they might make track conditions smoother and reduce the "dynamic augment" of wheel loads. They could not be expected to reduce the wheel loads due to flat spots on wheels. The etch tests made indicated that shatter cracks were more frequently found in heavy rails than in light rails.

However, an examination of Table 1 indicates that the relative magnitude of wheel load and of bending stress in the rail is a large factor in determining the direction of the fissure. A heavy bending stress tends to cause a fissure to spread in a transverse direction, while a heavy wheel load accompanied by light bending stress tends to cause a horizontal split head. That is, the use of a heavier rail which would diminish flexural stress might tend to reduce the number of transverse fissures as compared with horizontal fissures. Also, the rolling-load tests give some evidence that flexural stresses accelerate the spread of shatter cracks into fissures, once these fissures have been started by the action of wheel loads.

III Field Tests For Wheel Loads

By H. R. Thomas

12. **Object of Tests.**—As a result of the rolling-load tests in the laboratory it was found that the minimum wheel load which would cause a shatter crack to grow in size and become a transverse fissure was approximately 40,000 lb. This wheel load was somewhat higher than the usual locomotive driver load, and much higher than the wheel loads for heavily loaded freight cars. Since it seemed probable that transverse fissures were the result of the application of a relatively large number of wheel loads (more than could be expected from the number of driver loads passing over the rail) it was felt that tests should be made in order to answer the following questions:

1. Do heavily loaded freight cars have occasional wheel loads equal to or greater than the 40,000 lb. mentioned in Section 9?
2. If high wheel loads are found under freight traffic, how frequently do these occur?
3. If high wheel loads are found, what is the reason for their occurrence?

13. **Test Methods and Apparatus.**—In order to accumulate the necessary statistical data concerning the magnitude and frequency of high wheel loads, it was decided to base such determinations on measurements of average longitudinal strain at the center of the base of the rail. Since such average strain is very nearly proportional to the wheel load causing the strain, the problem resolved itself into devising a means for recording the strain under each locomotive and car wheel for the usual freight train passing over the test location.

It was decided that the recently-introduced DeForest scratch strain recorder would be the simplest method of measuring such strains, provided it would give satisfactory records under the severe impact and vibration conditions found in a railroad rail during the passage of a train. A trial instrument was obtained and used on the tracks of a local railroad in order to try it out. It was found that by making some modifications in the instrument and by introducing rubber padding for damping vibration of certain parts, satisfactory records could be obtained. Ten of these instruments were purchased and mounted on clamps which could be attached to the base of the rail at points where measurements were desired. Figure 6 shows this strain gage and its attachment to the rail.

The principle of operation of the scratch strain gages is very simple: The total strain in the rail in the four-inch gage length is recorded, without magnification, by a diamond point scratching on a chromium-plated brass strip. Movement of the strip, producing a separation of the ordinates corresponding to the passage of the various wheel loads over the instrument, is produced by a spring whose action is influenced by the variable friction introduced by the relative movement of the two ends of the instrument due to the strain being recorded. The rate of feed can be controlled by variation of spring tension and of the friction acting on the plate carrying the record strip. With proper regulation of friction and spring action it was possible to obtain records showing the strain in the rail for each wheel of a 40-car train.

This original form of the scratch strain gage was used for the tests made at Dayton, Ohio, and at Coatesville, Pa. After the completion of these latter tests, ten new instruments were built in the University shops, embodying the general principles of operation of the original instruments, but including certain changes which made them more suitable for the tests of wheel loads in service. The changes made included: (1) More rigid construction to prevent vibration; (2) use of celluloid pads coated with diamond dust

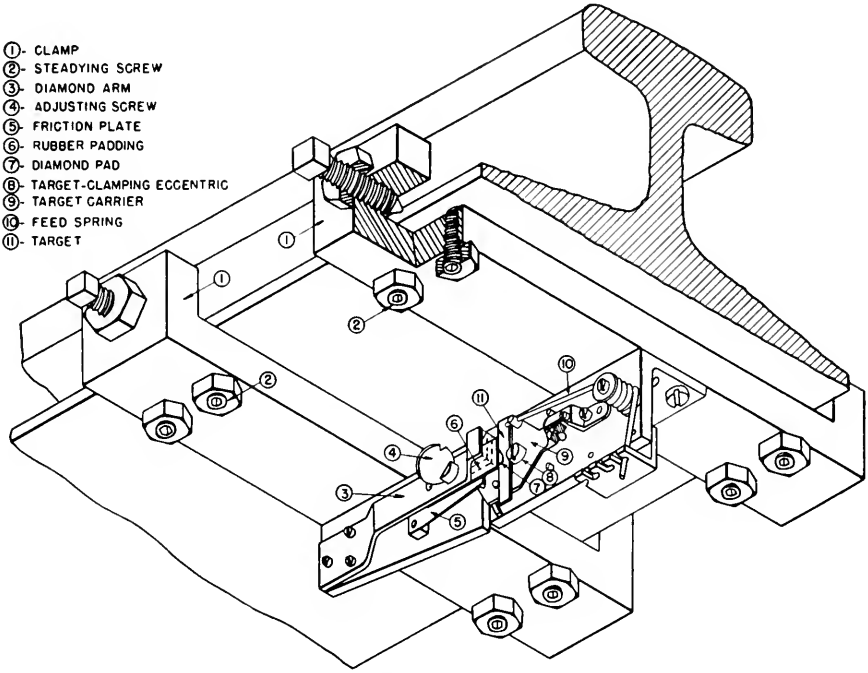


Fig. 6.—Scratch Strain Recorder.

This instrument measured the strain in the base of a rail for every wheel load which passed over it. From this strain and the measured stiffness of the track the wheel load accompanying each indicated strain was computed. This instrument is an adaptation of the DeForest scratch extensometer, and was used with Dr. DeForest's permission.

instead of the single diamond recording point; (3) strictly interchangeable parts with spare parts available for substitution in case of necessity. In most cases parts were replaceable without removing the instrument from the rail.

These ten revised instruments were used on the tests at Rome, N. Y. After the tests at Rome, 10 additional instruments were made, and all 20 were used in the tests at Matfield Green, Kans.

14. **Interpretation of Results.**—In order to determine wheel loads from the measurements of mean strain in the base of the rail, use was made of the mathematical analyses reported by Professor A. N. Talbot in the Sixth Progress Report of the Special Committee on Stresses in Railroad Track.[4] Considering a group of four adjacent freight car wheels, the bending moment under a given wheel may be reduced by the effect of adjacent wheels, but if there is a dynamic augment in a given wheel load (due, for example, to a flat wheel) then the *increase in bending moment* at that wheel will be very nearly proportional to the *increase in wheel load.* Since the measurements of strain in the base of the rail permitted calculations of corresponding bending moments, the above relationship was used for computing the dynamic increase in wheel load. Bending moments due to static wheel loads were determined from runs over the instruments at sufficiently slow speeds (5 miles per hour) to avoid dynamic effects for cars with wheels in good condition.

[4] See AREA Proceedings, Vol. 35, 1934, p. 278.

15. **Results of Tests.**—Over a period of three years, tests for frequency of high wheel loads for freight cars were made as follows:

September–October 1933.—On the B. & O. north of Dayton, Ohio, on the 130-lb. test rail laid in 1932. Tests were made at two locations, one being near the beginning of the test rail at North Dayton, and the other near the north end of the test rail at Vandalia. On this single track line a considerable percentage of the traffic consisted of loaded coal and ore cars, with some refrigerator and box cars.

February 1934.—A few tests were made using a special train containing cars with flat, badly worn, and shelled wheels. Effect of frozen railbed was also studied in these tests.

September 1934.—Tests were made on the eastbound freight track on the main line of the Pennsylvania Railroad west of Coatesville, Pa. These tests were on 152-lb. rail. Traffic consisted largely of loaded coal cars.

July 1935.—Tests were made on the New York Central Railroad near Rome, N. Y. at three locations: 1. Near Greenway, on 105-lb. Dudley rail, the track being in rather poor condition. 2. East of Rome on 127-lb. Dudley rail. 3. On 105-lb. rail on a steel bridge east of Rome. This rail on the bridge was laid with GEO construction, the ties being supported directly on the bridge stringers. The test was for the purpose of determining the effect on dynamic wheel loads of very rigid rail support rather than for

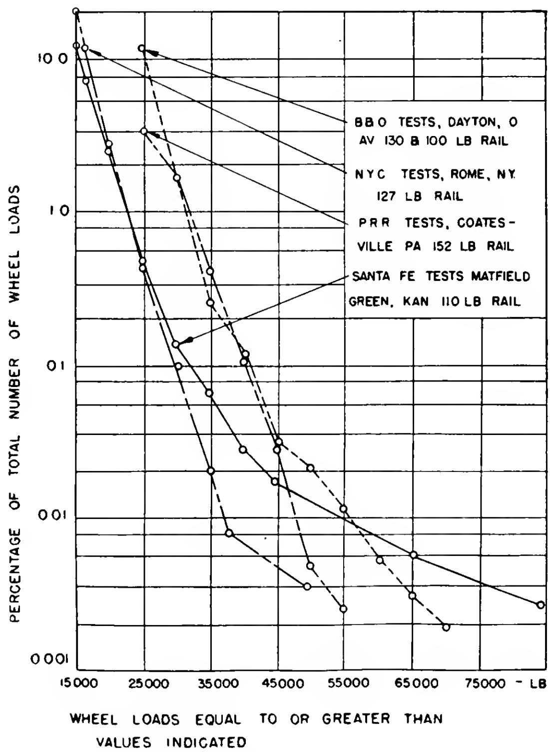


Fig. 7.—Frequency of High Wheel Loads at Four Test Locations.

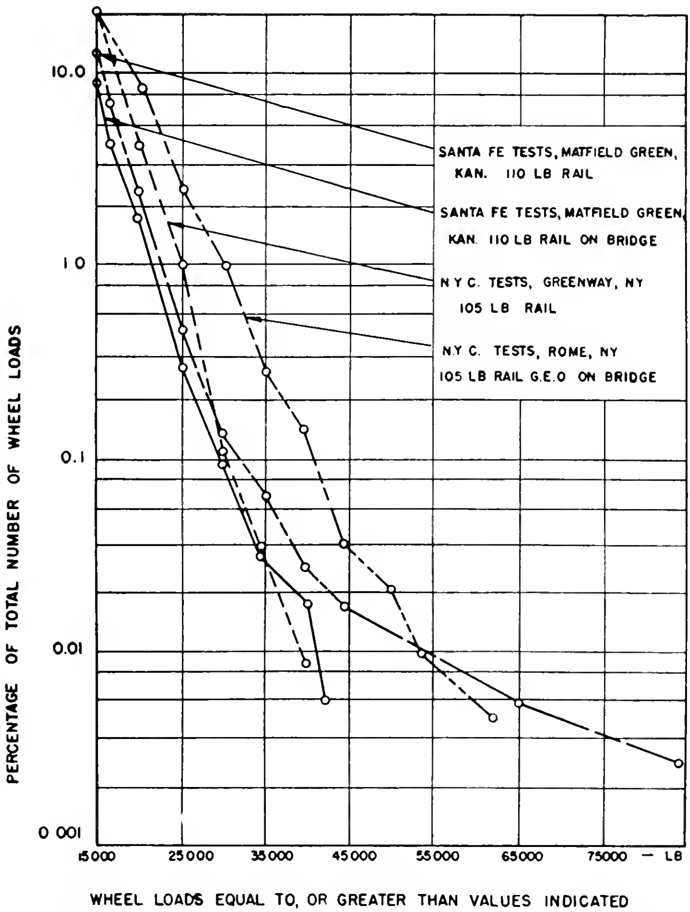


Fig. 8.—Frequency of High Wheel Loads at Sections of Track with Different Stiffness of Rail Support.

determining impact loads on a bridge. A few instruments were placed near the bridge, also on GEO track, for comparison.

Traffic over these test sections was mostly mixed freight, including refrigerator cars with some coal cars.

May–June 1936.—Tests were made on the 110-lb. test rail laid on the Atchison, Topeka & Santa Fe near Matfield Green, Kans. This is a single-track freight cut-off carrying mixed freight with many refrigerator cars and oil tanks. Tests were made using 20 instruments at two locations: (1) On normal tangent track; (2) on a ballasted deck, timber, pile-supported trestle. The bridge, in general, differed little in stiffness from the normal track.

In Figures 7 and 8 there are presented load-frequency curves, giving the results of tests on the four railroads. It will be noted that in Fig. 7 the curves for tests on the Baltimore & Ohio and the Pennsylvania railroads show good agreement, while the curves for the tests on the New York Central and the Atchison, Topeka & Santa Fe Railroads are about 10,000 lb. lower than the others. A study of the train sheets indicated that there was approximately a 10,000-lb. difference in the average wheel load for the loaded cars for these two groups of curves.

In Fig. 8 the curves for tests on the bridges on the New York Central and the Santa Fe are shown, the curves for tests on the same roads at sections not on the bridges being given for comparison. It will be noted that for the tests on the Santa Fe the curve for the bridge tests is not greatly different from that for track away from the bridge. This is to be expected, since this ballasted-deck bridge was of approximately the same stiffness as the regular track. The higher wheel loads indicated by the curve for the bridge on the New York Central were undoubtedly due to the fact that the ties were supported directly on the bridge stringers, which resulted in a very stiff track support.

16. **Conclusions.**—Based on a study of the results obtained on the above tests, including a study of many details not given by the load-frequency curves of Figures 7 and 8, but on file at the Talbot laboratory, the following statements appear justified:

1. Under heavily loaded freight cars (coal, ore, etc.), wheel loads equal to or greater than 40,000 lb. occurred on an average in these tests once for each 1,000 wheel loads passing over a given point in the rail.[5] At some points along the rail, the frequency of 40,000-lb. wheel loads was three times as great as the average.
2. For less heavily loaded cars the frequency of 40,000-lb. wheel loads was less than for the heavier loads.
3. High dynamic wheel loads may be caused by flat spots on wheels, out-of-round wheels, lack of concentricity of axle and rim of wheel, and non-uniformity of rail support.
4. From these field tests it seems that in the speed ranges of trains below 25 m.p.h., flat spots on wheels are very prominent as a cause of high wheel loads. In the range of 40 to 50 m.p.h., hard spots in the rail support seem prominent, and in the range of 60 m.p.h. and above out-of-round wheels, unbalance in counterweights and abnormally large play between rail and tie (that is, lack of uniformity of rail support) loom up as important factors. These speed ranges probably will not be the same for locomotive drivers as for freight car wheels, but adequate data on which to base a quantitative statement are not available at this time.

IV Service Records of Test Rails

By J. L. Bisesi

17. **Test Rails on the Baltimore & Ohio and Santa Fe.**—Early in the investigation of transverse fissures in railroad rails, two railroads agreed to put in test sections of rails to be observed for the purpose of determining some facts regarding the formation of transverse fissures under service conditions. They were all hot-bed cooled rails.

[5] Tests of the ratio of flexural strain to flexural load were made by Dr. R. N. Arnold in the Talbot laboratory, University of Illinois. He applied load rapidly by means of a weight falling from various heights and striking at mid-span a rail supported head up as a simple beam. To the tension side (base) were soldered a series of DeForest scratch strain gages which gave a record of strain variation along the base. From this the load applied could be determined with a fair degree of accuracy. The ratio of load to maximum base stress was found to be higher—in some cases 100 percent or more higher—than the ratio of load to base stress under static load. This was due to the resistance to sudden bending offered by the inertia of the rail.

This result indicates that, since the curves shown in Figures 7 and 8 were determined on the basis of ratio of load to base stress as given by analysis for a static load, the wheel loads shown in those figures may be somewhat too low. However, the rapidity of load application to a rail resting on ties and ballast is probably considerably less than is the case with Dr. Arnold's stiffly supported test beam.

The rails were to be rolled under normal conditions under specifications of the individual railroads and to be placed in average service with no special care or maintenance. Representatives of the test party were present at the time of rolling and laying and also each time that Sperry car tests were made on the rails in service. The rails were rolled in 1931 and 1932 by five mills as listed below.

Mill	*130-lb. Rails*		*110-lb. Rails*	
	Summer Rolling	*Winter Rolling*	*Summer Rolling*	*Winter Rolling*
A	6 heats	7 heats		
B	8 heats	7 heats		
C			10 heats	11 heats
D	7 heats	7 heats	6 heats	6 heats
E	6 heats	6 heats	6 heats	6 heats

The roads which participated in the tests were the Baltimore & Ohio and the Atchison, Topeka & Santa Fe. At the test locations, the traffic on the former is heavy as compared with that on the latter, the one moving more coal, ore, and machinery and the other more oil and refrigerator car traffic. The track of the Baltimore & Ohio has more grades and curves than that of the Santa Fe.

18. **Tests of B. & O. Rails.**—The 130-lb. rails rolled for the Baltimore & Ohio were installed in track, beginning in 1932, and the last test rails were placed in service in 1936. The test rails were distributed over the system and laid in seven locations as follows:

Toledo Division—North Dayton to Vandalia: 1,529 rails laid in February 1932 on single track, Mile Post 62.5 to 68.1.
Tippecanoe City to Troy, Mile Post 72.9 to 78.1, 1,514 rails laid between May 1934 and March 1936.

Pittsburgh Division—Layton to St. James, 1,108 rails laid December 1933 on westbound track.

Cumberland Division—Bardane to Kearneysville: 371 rails laid July 1933 on Track 2.
Kesslers Bridge to Okonoko: 1,625 rails laid August 1933 on Track 3.
Hansrote: 51 rails laid July 1933 on Track 3.
Patterson Creek cut-off: 142 rails laid March 1932 on Track 4. Service on this track was discontinued between May 1932 and Oct. 1, 1939.

No special order was used in laying the rails except that the rails from each heat were kept together. The "A" rails of the various heats, however, were all laid at the beginning and end of the test sections.

In the fall of 1933 a detailed study was made of the rails laid on the Toledo division, north of Dayton. For this study a car was constructed on which a six-volt generator from the laboratory could be mounted and driven by a propelling engine. Cables attached to the generator in the car could be run out to the end of the rails in track and the drop-of-potential test run on the full length of the rail.

The drop-of-potential tests were made on 443 rails classified as follows:

(1) 111 "A" rails.
(2) 96 rails from a heat containing a great number of shatter cracks. (Heat 50110).
(3) 119 rails from a heat containing no shatter cracks. (Heat 21660).
(4) 95 rails from a heat representing summer rollings, having few shatter cracks. (Heat 30240).

(5) 93 rails from a heat containing few shatter cracks, part of which heat had been in service 10 months longer than the other test rails. (Heat 43118).

No fissures were discovered in any of the rails tested at this time but this was not surprising since in most cases few fissures develop in rails in service during the first few years of service.

Beginning in 1934 the test rails in service on all sections on the Baltimore & Ohio were tested by means of the Sperry detector car under conditions of commercial testing in current use. In most cases the test rails were given more attention than is ordinarily given to the general run of rails. This was especially true during the years 1936 to 1939 when the double-crew method of testing was used and particularly in 1936 and 1937 when the second, or hand-test car made a drop-of-potential test on each indication that appeared on the record tape.

The cumulative record of failures in the hot-bed cooled test rails on the Baltimore & Ohio appears in Table 2. The failures found in the Sperry car tests made in 1940 are included. With reference to this table it will be noted that although the first failure found in these rails (a vertical split head) occurred in Heat 50110 in 1936, the first transverse fissure failures occurred almost simultaneously in Heats 50110 and 43118 after they had carried a traffic of 73 million tons. Etch tests had indicated that rails in these two heats contained more shatter cracks than those in other test heats. It should be noted that of the 14 vertical and horizontal split heads, all occurred in shatter-cracked heats; none in non-shattered heats. The distribution by rail letter was as follows:

Rail Letter	*Vertical Split Heads*	*Horizontal Split Heads*
A	2	2
B	1	0
C	0	1
D	2	1
E	0	2
F	1	2

The evidence from the laboratory samples of the above rails seems to indicate that a majority of these failures originated at slag or segregation streaks, although some of these failures have been found in service, which gave clear evidence of having originated in shatter-cracked areas.

No failures have been reported in the test sections on the Cumberland division at Hansrote (51 rails in Track 3) and on the Patterson Creek cut-off (142 rails on Track 4).

19. **Test of Rails on the Santa Fe.**—The 110-lb. hot-bed cooled rails laid in the tracks of the Atchison, Topeka & Santa Fe were laid southwest of Emporia, Kans. between Ellinor and Matfield Green, in 1932. This is a single track cut-off which is used exclusively for freight. In this case these rails were also laid by heats as follows:

Mill Letter	*From Mile Post*	*To Mile Post*	*Total Miles*	*Total Feet*
E	124 + 2,985 ft.	131 + 3,023 ft.	7 +	38
C	131 + 3,023 ft.	138 + 2,590 ft.	6 +	4,847
D	138 + 2,590 ft.	145 + 2,462 ft.	6 +	5,152
Total			20 +	4,757

The test rails laid in the tracks of the Santa Fe have also been tested each year since 1934 by means of the Sperry type detector car owned and operated by the railroad

TABLE 2

CUMULATIVE RECORD OF FAILURES ON BALTIMORE AND OHIO TEST RAILS

Division	Location	Track	No. of Rails	Date Laid	Mill	Heat No.	Type of Failures* I.T.F.	H.S.H.	V.S.H.	D.F.B	Million Tons Traffic at 1st failure	No. of Failures Total	Service	Etch Tests L**	T**
TOLEDO	Dayton to Vandalia M.P.62.5 to 68.1	Single	1529	2-32	D	50110	20	0	4	0	58.9	24	2	44	30
						43118	8	0	2	0	73.0	10	4	7	4
						55052	1	0	0	0	125.1	1	0	2	0
						51109	2	0	0	0	125.1	2	0	1	0
					E	16980	0	0	0	5	125.1	5	0	0	0
						17081	0	0	0	2	135(est.)	2	0	0	0
						25154	0	0	0	1	135(est.)	1	0	0	0
						19345	0	0	0	1	135(est.)	1	0	0	0
						27525	0	0	1	0	135(est.)	1	0	8	0
	M.P.72.8 to 76.0	Single	804	5-34	D	47248	1	0	0	0	100(est.)	1	0	2	0
	M.P.76.0 to 76.4	Single	53	10-35	E	27525	2	2	0	0	57.4	4	0	8	0
	M.P.76.4 to 78.1	Single	657	3-36	D	47248	1	0	0	0	50.4	1	0	2	0
PITTSBURGH	Layton to St.James	No.2	1108	12-33	A	74191	2	1	0	0	79.3	3	3	1	0
						73071	0	1	0	0	89(est.)	1	0		
CUMBERLAND	Bardane to Kearneysville	No.2	371	7-33	A	74098	1	1	0	0	92.5	2	0	7	0
						75102	0	1	0	0	92.5	1	0	2	0
	Kesslers Bridge to Okonoko	No.3	1625	8-33	A	74191	1	0	1	0	68.3	2	0	1	0
						74190	4	0	0	0	68.3	4	0	3	0
						71182	1	0	0	0	79.5	1	0	9	2

* I.T.F. denotes internal transverse fissure; V.S.H. denotes vertical split head
H.S.H. denotes horizontal split head; D.F.B. denotes detail fracture under burn

** Number of longitudinal (L) and transverse (T) shatter cracks found in one side of a six-inch horizontal slice from sample shipped to the Talbot Laboratory at the time of rolling.

company. In this time no fissured rails have been reported in this test section. There have been, however, 37 rails removed for the following reasons:

4 Crushed head
26 Curve worn
5 Stock rail
2 Kinked

This rail at the last report (January 9, 1941) had carried 118,406,000 tons of traffic. The general conclusions which may be drawn from these test rails are:

1. Transverse fissures were generally associated with shatter-cracked rail. This fact is indicated by the fact that in all cases where transverse fissures have been found in these test rails, the etch tests of these rails and other rails from the same heat have shown that shatter cracks have been present. Of the 67 failures in the test rail on the B. & O. only 9 failures have occurred in heats not shattered. These 9 failures were detail fractures under burns.

2. It is likely that in a given group of rails in service under similar track conditions and traffic, fissures will first be found in rails from heats which contain the greater number of shatter cracks. This is shown by the fact that in the rails laid on the Baltimore & Ohio the first failures were found in rails from Heats 50110 and 43118, the two heats containing the most shatter cracks, as shown by etch tests of specimens. Also out of the 67 failures in these test rails, 34 have occurred in these two heats whereas the rest are spread through 15 other heats not so badly shattered.

3. In order to start a transverse fissure a rather large number of heavy wheel loads is necessary. This was shown in the laboratory by the fact that in the rolling-load machines no fissures were produced when wheel loads were kept below 40,000 lb. In this connection it is interesting to note that transverse fissure failures have occurred in the rails of the Baltimore & Ohio where there are more heavy wheel loads but not in the rails in the tracks of the Santa Fe where there were fewer heavy wheel loads. However, etch test results indicated that the Santa Fe test rails were freer from shatter cracks than the Baltimore & Ohio test rails.

20. **Correlation of Rolling-Load, Wheel-Load and Service Tests on Rails North of Dayton.**—The development of transverse fissures in the test rail on the Baltimore & Ohio recalls the question of correlation of the various test data. This discussion is based largely on the discussion of the results of the field tests to determine wheel loads made north of Dayton in 1933. A list of some of the failed rails found in this section of track is given in Table 3, together with the amount of traffic which these rails have carried and the dates the failures were found.

Heats 47248 and 27525 were laid in March 1936 and October 1935, respectively, after having lain on the ground since they were rolled in 1932, therefore, although the failures were found in December 1938 they had comparatively little tonnage over them.

In the laboratory, the rolling-load tests were carried out in an attempt to give some estimate of the number and magnitude of wheel loads necessary to start and develop an internal fissure in a rail. A study of the data shows that the lowest recorded load which *started* a fissure in the laboratory was 40,000 lb. However, after a fissure is started it will spread under a load less than that required to start it. From a study of rolling-load test results an admittedly crude estimate is that once a fissure *started* to spread under loads of 40,000 lb. or more, then after 200,000 wheel loads of 30,000 lb. or more rail fracture *might* occur. From the records of wheel-load tests north of Dayton it was con-

TABLE 3

FAILED 130-LB. TEST RAILS - TOLEDO DIVISION, NORTH DAYTON TO TROY.

Heat No.	Defect	Tonnage, Millions	Date Found	Remarks
47248	1 T.F.*	50	Dec. 1938	Found by
27525	2 H.S.H.*	59	Dec. 1938	Sperry
50110	1 V.S.H.*	58.9	May 1936	Detector Car
50110	1 T.F.	73	Nov. 1936	Service
43118	1 T.F.		Nov. 1936	Failure
43118	3 T.F.	89.2	Sept. 1937	Found by
50110	3 T.F.			Sperry
50110	5 T.F.	109.7	Dec. 1938	Detector
43118	1 V.S.H.			Car

* T.F. denotes transverse fissure
H.S.H. - horizontal split head
V.S.H. - vertical split head

cluded that at the worst location tested 3 percent of the wheel loads might be 30,000 lb. or greater. Estimating an average wheel load of 10 tons, and remembering that the tonnage passing is that for *two* lines of rail, this would mean the passage of about 65,000,000 tons of traffic before there would be great probability of failure by transverse fissures.

Again the fact that this was a very crude estimate must be kept in mind. Wheel loads of 40,000 lb. and higher were measured on the tracks north of Dayton, and their observed frequency would lead to an estimate of 15,000 such loads under 65,000,000 tons of traffic at the "worst" location studied. This would probably be an ample number of wheel loads to *start* a fissure.

It will be noted in the tabulation that the first fissures to appear in the test rail were those in Heats 50110 and 43118 which failed in service, breaking the block signal circuit. These heats were expected to show the first failures, since they contained more shatter cracks than any of the other heats in service at that location. The failures occurred after an estimated 73,000,000 tons of traffic had passed over the track. The vertical split head in Heat 50110 was the top rail in ingot 1 of that heat. It was laid as the first rail leading to the west passing track at the Needham yards and failed after an estimated traffic of 59,000,000 tons. It is possible, however, that, due to its location, it actually carried more than the estimated tonnage and possibly was subjected to a great many more loads of high magnitude.

The failures in Heats 47248 and 27525 which occurred after only 50,000,000 and 59,000,000 tons, respectively, were in a location about 16 miles from where the wheel-load tests were made and as noted above, the rails were not put into service until several years later than the others.

Again the caution must be repeated that the estimates for probable life of shatter-cracked rail are very crude indeed, and actual tonnage carried will often vary widely from those estimates. However, the comparison of estimated and observed tonnage before failure at the Dayton location is interesting.

V The Origin and the Prevention of Shatter Cracks in Rails

By R. E. Cramer

21. **Occurrence of Shatter Cracks in New Rails.**—As pointed out in Chapter II, the available evidence indicates that shatter cracks are the major cause of transverse fissures in rails in service, and a cause of some compound fissures and horizontal split heads (horizontal fissures). It should be recognized that any other internal "stress raisers" such as large slag inclusions, as shown in Fig. 9, or blow holes, as shown in Fig. 10, will, if located in a region of high stress be equally effective in starting interior progressive fractures. As noted in Chapter II, no fissures were developed in rolling-load tests in rails without shatter cracks, although some fissures have occurred in service in rails which showed no shatter cracks in subsequent etch tests. However, in these rails it is in many cases possible that the fissure started from a single shatter crack, and that

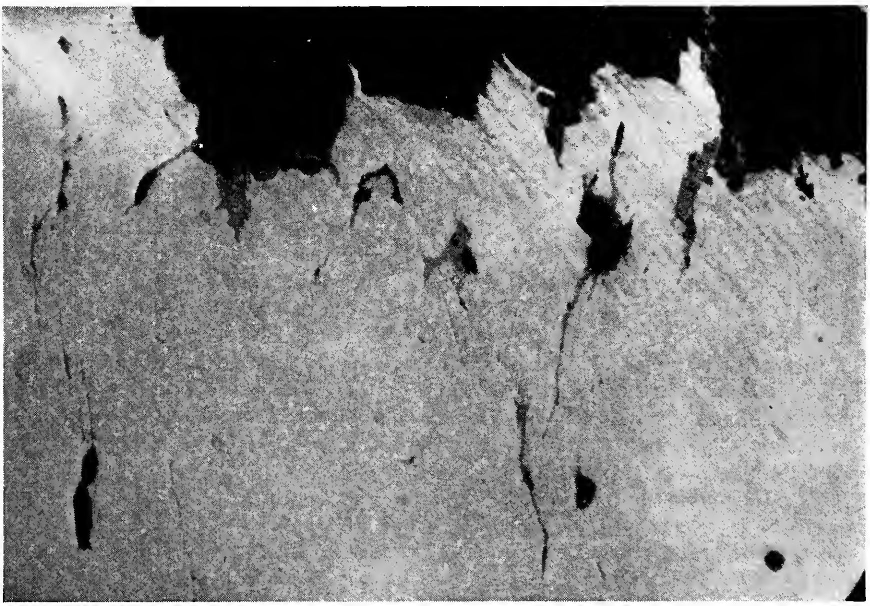


Fig. 9.—Slag Inclusions Which Caused a Transverse Fissure.
Upper side of micrograph shows the nucleus of the fissure. Large inclusions, such as are shown here, act as stress raisers, and in an area of high nominal stress may start internal fissures. Magnification 50 ×. No Etch.

the etch test specimens happened to be taken from locations in the rail which had no shatter cracks. It seems that occasionally a fissure may develop from a slag streak in the rail, although rolling-load tests of new rails which showed such slag streaks but no shatter cracks, failed to develop fissures.

As noted in Chapter II, the question was raised in connection with the early studies of shatter cracks whether these cracks were actually present in new rails, or whether they were developed by the etching process, or were caused by the change of strain in the rail caused by cutting out slices of rail for etch test. By the use of high-magnification exami-

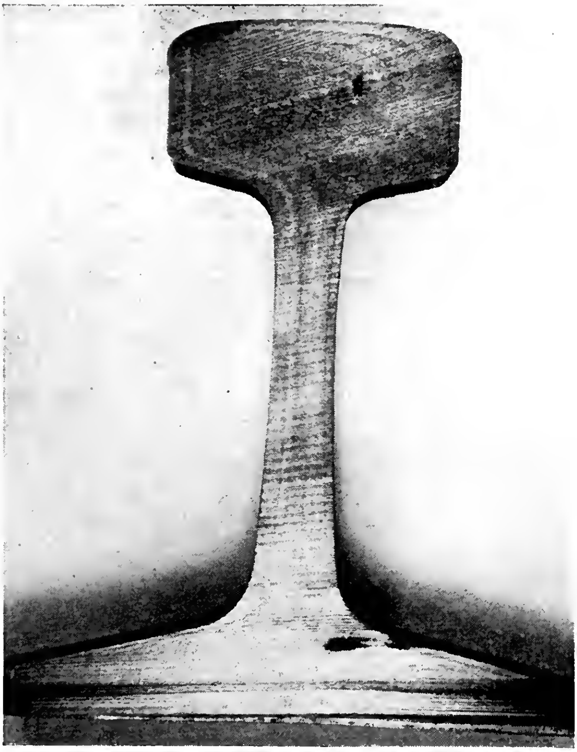


Fig. 10.—Blow Holes in Rail Head Close to Compound Fissure.

This was a "D" rail of Ingot No. 8 in a control-cooled heat. Many other blow holes were found in this rail merely by sawing. They ranged in size from that of a pinhead to that of the diameter of a lead pencil. A blow hole is defined as "A hole produced during the solidification of metal by evolved gas which, in failing to escape, is held in pockets." Such stress raisers as blow holes may cause an internal fissure, especially a horizontal or vertical split head. Specimen not etched.

nation cracks were found in unetched slices of rail. Also a piece of rail adjacent to one in which etch tests had shown shatter cracks was thoroughly annealed[6] so as to relieve any internal strain. This piece of rail was then sliced and etched, and shatter cracks were found as in the unannealed piece. This is evidence that there were some actual shatter cracks in rail as rolled, although the majority of rails rolled in American mills are free from shatter cracks.

In the earlier studies of shatter cracks in rail few data were obtained on the percentage of rail heats which developed shatter cracks. At the start of the present investigation etch tests were made of each of three rails from 99 heats of new test rails and shatter cracks were found in 45 percent of the heats of 130-lb. rails and in 33 percent of the heats of 110-lb. rails. It is to be noted that all of the first lot of test rails were hot-

[6] C. B. Bronson had previously reported similar tests. See ASTM Proceedings, Vol. 19 (1919), pp. 200–201.

bed cooled. It is not considered that these high percentages are representative of rail production in 1931, as each rolling was only one day's production, and in some cases all heats rolled the same day developed shatter cracks, while on other days no heats developed shatter cracks. It should be further noted that subsequent rollings of rails, even though hot-bed cooled, showed a smaller percentage of shatter-cracked heats.

22. **Possible Causes of Shatter Cracks.**—It was soon recognized by members of the test party that shatter cracks in railroad rails are the same type of internal cracks as flakes in forgings which have been widely discussed since the first World War. Over 100 technical papers have been written on the causes and methods of preventing flakes.

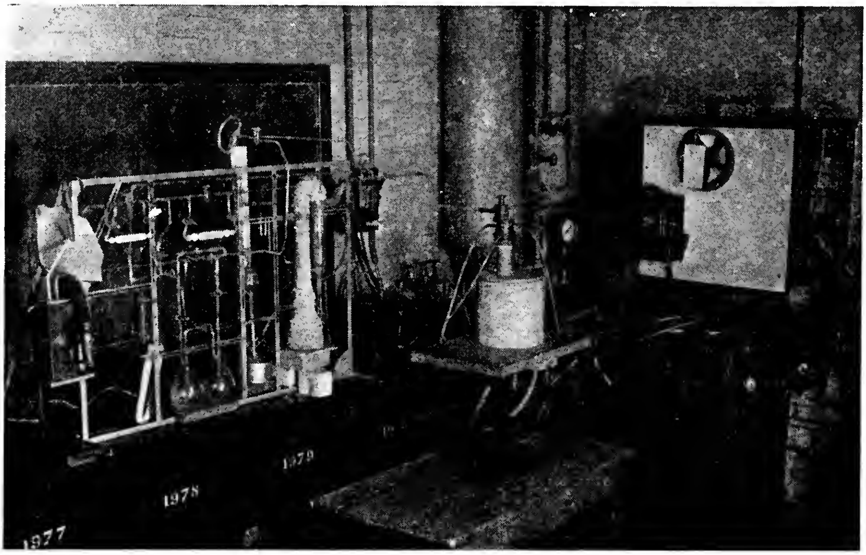


Fig. 11.—Equipment for Gas Analysis of Steel by the Vacuum Fusion Method.

A great many different causes have been suggested including the following as listed by Zapffe and Sims,[7] inclusions in the steel, refining operation, casting temperature, speed of casting, ingot size, uphill or downhill casting, quick heating in the rolling mill, excessive draft on rolling, separated ferrite, dendrites, formation of martensite, alloy content, transformation stresses, cooling stresses, brittle areas, and gas pressure.

Several metallurgists suggested that gas content of the finished rail might be a clue to the cause of shatter cracks, so in 1932 in conjunction with Dr. G. F. Smith of the Department of Chemistry of the University of Illinois the equipment shown in Fig. 11 was set up, and analyses were made of sound and shatter-cracked rails for oxygen, hydrogen and nitrogen. It was found that the oxygen and nitrogen analyses were satisfactory, but the hydrogen content of the rails was so low as to be below the accuracy of the analytical method. There was no correlation between presence of shatter cracks in the rails and the oxygen and nitrogen content. It is now understood that there would be practically no hydrogen left in the rails two years after they had been rolled, and the ⅜-in. diameter specimens were machined from the rails several months before they were analyzed.

[7] Zapffe, C. A. and Sims, C. E.—Hydrogen, Flakes and Shatter Cracks, Part III—Metals and Alloys, July 1940, pages 44–51.

From 1929 onward steel mills in the United States and Canada gave much attention to the problem of preventing shatter cracks in rails. Control-cooled rails were the subject of much study in steel mill laboratories, under service conditions and, of course, in this Rails Investigation. In view of reports from German laboratories that "flakes" had been caused in steel by treating heated steel with hydrogen, tests were made by the author of this chapter to see whether shatter cracks could be produced in a sound steel rail by treating it with hydrogen. A carbon-pile furnace in the mechanical engineering laboratory at the University of Illinois was used to heat six-inch sections cut from rails free from shatter cracks (as shown by etch test). The specimens were held in the furnace for 27 hours at 2,300 deg. F. in an atmosphere of hydrogen and then cooled in air. Typical shatter cracks were produced by this treatment.

23. **Experimental Study of Control Cooling to Prevent Shatter Cracks in Rails.**—The "flakes" sometimes found in alloy steel had been largely eliminated by the use of control cooling of the steel. Shatter cracks seem to be the same as, or at least very similar to, flakes. Control cooling of rails, then, seemed a promising method for the prevention of shatter cracks in rails, and experimental control-cooling processes for rails had been tried; and by 1935 control-cooled rails were in quite wide use on Canadian railroads. An experimental study of control cooling was planned and carried out. The tests were made in three rail mills, F, M, and D. Altogether about 450 rails and rail specimens from some 25 heats have been tested. In these tests groups of rail specimens were cooled in special individual cooling boxes, using four different cooling procedures, as follows:

1. Specimens cooled in air on the mill floor to serve as "control" specimens.
2. Specimens placed in cooling boxes at the same temperature and removed at different temperatures.
3. Specimens placed in cooling boxes at the same temperature and removed after a fixed time in the box, the rate of cooling for different specimens being varied by the amount of insulation used.
4. Specimens placed in cooling boxes at various temperatures and removed after a fixed time.

In these tests each rail specimen was placed in a wooden box about 18 in. square by 3 ft. long. This box was insulated with rock wool, and the rate of cooling could be regulated by the amount of insulation used. In this box the rate of cooling was slightly faster during the first hour than was found to be the case in commercial control-cooling containers; this was due to the absorption of heat by the rock wool immediately surrounding the rail. However, this placed the experiments on the safe side when interpreting results. Twelve such boxes were used in a series of tests. A thermocouple was attached to each rail specimen as it came from the hot saw, and the temperature observed until the rail specimen was placed in a cooling box. When a specimen was placed in a cooling box, the first thermocouple was removed and another thermocouple clamped to the specimen with a connection to a 12-point recording pyrometer which recorded the time and temperature while the specimen was in the cooling box.

The rail specimens used for these tests were full-section pieces of rail about two feet long. This length was chosen after a mathematical study of heat transfer in rails had been made by Professor W. L. Schwalbe of the University of Illinois, who showed that any "end effects" on the temperature gradient became inappreciable at a distance from the end of a specimen equal to the height of the rail. At least one of the two-foot rail specimens from each heat was cooled in air as a control specimen. Cooling in air is a little more rapid than is cooling on a hot bed with other hot rails near at hand.

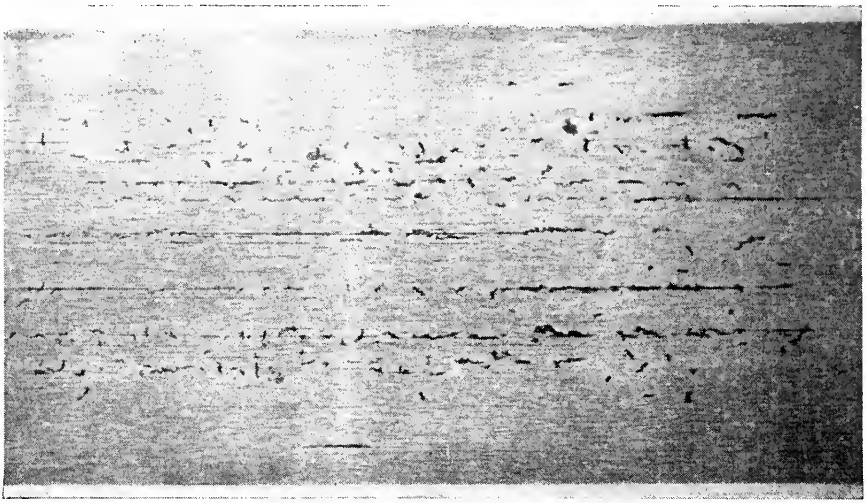


Fig. 12.—Typical Etch Test of an Air-Cooled, Hydrogen-Treated Rail Specimen.

Etch, 50 percent hot hydrochloric acid. This specimen showed 92 longitudinal and 62 transverse shatter cracks on one side of a 6-in. horizontal slice cut from the head of the rail. It will be noted that this etch test specimen showed many more shatter cracks than are shown in Fig. 1 (b), which is a macrograph of an etch-test slice from a normally-produced, hot-bed-cooled rail. Some hydrogen-treated, air-cooled specimens showed many more cracks than are shown in this Fig. 12.

After the rail specimens had cooled they were shipped to the Talbot laboratory, horizontal slices were cut from the head of each specimen, and deep etch tests made with hot hydrochloric acid. The etch tests of the air-cooled rails showed any shatter cracks present (See Fig. 12). Brinell tests were also made on some specimens.

24. **Treating Ingots with Hydrogen to Produce Shatter-Cracked Rails.**— In the earlier cooling tests it was necessary to use specimens from a large number of heats of rail steel and take the chance that some heats would develop shatter cracks in the air-cooled or "control" specimens. This was a very unsatisfactory procedure, owing to the time and expense involved. The experiments with hydrogen treatment of steel (See Section 22) suggested a way to insure a supply of shatter-cracked rail specimens for study. A method of treating rail-steel ingots with hydrogen to develop a large number of shatter cracks was developed at the Carnegie–Illinois Steel Corporation, Gary, Ind. This hydrogen treatment has been applied to most of the rails used in the cooling tests during the past years and has proved to be a valuable aid in such experiments, since in all cases when the ingots were properly treated with hydrogen the "control" specimens have developed a large number of shatter cracks during cooling in air.

25. **Method of Treating Ingot with Hydrogen.**—The ingot molds were about 90 in. high, holding about 5 tons of steel, and in most cases only one ingot from a heat of steel was treated with hydrogen. The method of introducing hydrogen is shown in Fig. 13. The hydrogen from the cylinder is bubbled through a bottle containing mercury in order to know when the gas is flowing. The rubber stopper is wired in, and the bottle tested to over 40 lb. per sq. in. air pressure. For safety it is partly buried in a box containing cleaning waste or covered with a wire screen. The bent ½-in. "double extra strong" pipe

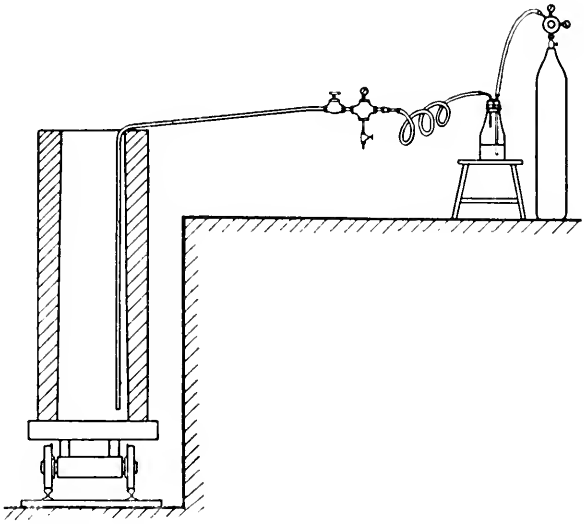


Fig. 13.—Method of Treating Ingot with Hydrogen.

extending nearly to the bottom of the mold has a wall thickness of about ¼ in. which requires considerable time to melt off as the molten metal rises in the ingot mold. The hydrogen is lighted at the end of the pipe before starting to pour the ingot and to keep the pipe open, a pressure of 15 lb. per sq. in. is used when the metal first enters the mold. As the metal rises in the mold, the hydrogen pressure is increased to keep an even flow, as indicated by the bubbling of the gas in the bottle, and the pipe is moved back and forth across the mold in the molten steel. A maximum pressure up to about 30 lb. per sq. in. is necessary, depending on how fast the pipe melts away. It has been found advisable to stop the flow of hydrogen when the metal is about one foot from the top of the mold to keep the molten metal from spattering out of the mold. The pipe is shortened by about four feet when removed from the metal, depending on how fast the ingot is poured. The time of pouring has been varied from two to four minutes and this also governed the volume of hydrogen used, the latter usually varying between 25 and 40 cu. ft. While freezing, the metal gives off considerable hydrogen which burns at the top of the ingot. In the case of one ingot the solid crust was burned through with an oxygen jet resulting in a ½-in. stream of molten steel being thrown 5 or 6 ft. high for about a half minute, showing that considerable internal pressure is developed as hydrogen and other gases are liberated during the solidification of the steel.

The use of hydrogen treatment of rails in studying the prevention of shatter cracks does not involve the assumption that hydrogen is the sole cause of shatter cracks in rails. It does involve the assumption that a control-cooling process which will prevent the very severe shatter cracking found in air-cooled hydrogen-treated rails will be effective in preventing shatter cracks in normally produced rails. This assumption appears not unreasonable.

26. **Results of Tests in Special Cooling Boxes.**—Tables 4 and 5 give the results of cooling tests of rail specimens placed in special individual cooling boxes. Figure 14 shows typical cooling curves during a test. An examination of Table 4 shows that shatter cracks were prevented in many of the box-cooled rail specimens, and that the prevention of shatter cracks is made more probable by (1) placing the rail in the cooling box at as high a temperature as is practicable, and (2) allowing the rail to remain in the cooling box for as long as is practicable. Naturally the longer the rail is left in the cooling box, the colder it will be when removed; however, it will be shown later that it is the time in the cooling box rather than the temperature of rail specimen at removal which is significant in the prevention of shatter cracks.

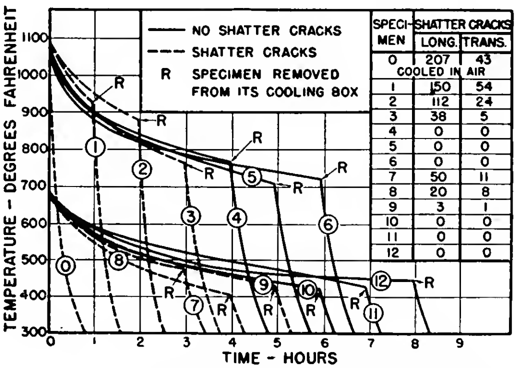


Fig. 14.—Typical Cooling Curves for Rail Specimen (2 ft. Long) in Individual Cooling Box Insulated with Rock Wool.

The practicable maximum temperature of the rail as it is placed in the cooling container is set by the tendency of the finished rail to be soft if the temperature at time of placing in container is too high. In another series of tests, described in Section 30, no appreciable change in hardness from that of air-cooled rails was found for specimens held in a furnace at 900 deg. F. for 5 and 6 hours. Rail specimens placed in cooling boxes at 1,100 deg. F. were 5 to 10 Brinell numbers softer than air-cooled specimens. Rails held in a furnace at 1,100 deg. F. were 25 to 30 Brinell numbers softer than air-cooled specimens: 900 deg. F. was chosen as an upper temperature limit for placing rails in cooling boxes. The exigencies of rolling mill practice make it impracticable to get every rail into the cooling box at precisely 900 deg. F., and for the upper limit of a temperature cycle of control cooling which should serve as a criterion for judging the effectiveness of the process in removing shatter cracks, 700 deg. F. was chosen—an arbitrary value, but not an unreasonable one. It is, approximately, the lower limit permitted in the present practice for control cooling rails.

For the lower limit of the temperature cycle 300 deg. F. was chosen. This is also an arbitrary value which was selected because it was recognized in the present specification for control cooling of rails which is in rather general use today, so the time required for the rail to cool from 700 deg. F. to 300 deg. F. is given in Table 4.

An examination of Table 4 shows that no shatter cracks were found in any rail specimen which was placed in a cooling box at a temperature of 700 deg. F. or higher, and which, remaining in the box, required 7 hours or more to cool down to 300 deg. F.

TABLE 4.

TESTS FOR SHATTER CRACKS IN RAIL SPECIMENS PLACED IN SPECIAL COOLING BOXES AT A TEMPERATURE OF 700° FAHR. OR HIGHER.

Boxes insulated with rock wool. One box for each rail specimen tested.

Heat	Specimens: Put in Box at degrees F.	Specimens: Removed from Box at degrees F.	Time in Box hours	Time to Cool from 700° F. to 300° F. hours	Shatter Cracks in 6-in. Etch Specimen: Long.	Shatter Cracks in 6-in. Etch Specimen: Trans.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air: Long.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air: Trans.
I. TESTS AT MILL F - Normally produced Rails.								
(a) 112-lb. rails								
88	900	700	less than 1.8	less than 1.8	7	0	22	0
	900	600	" " 3.4	" " 3.4	0	0		
	900	-	- -	" " 4.2	0	0		
78	900	800	Less than 1.9	less than 1.9	7	0	29	0
	900	700	" " 2.6	" " 2.6	1	0		
	900	600	" " 5.4	" " 5.4	0	0		
	900	-	- -	" " 3.4	0	0		
73	900	800	less than 2.6	less than 2.6	0	0	15	0
	900	700	" " 4.1	" " 4.1	0	0		
	900	600	" " 4.5	" " 4.5	0	0		
	900	-	- -	" " 2.9	0	0		
54	900	800	less than 2.3	less than 2.3	8	0	22	1
	900	700	" " 3.2	" " 3.2	0	0		
	900	600	" " 5.4	" " 5.4	0	0		
	900	-	- -	" " 3.0	3	0		
(b) 130-lb. rails								
70	900	800	less than 2.9	less than 2.9	1	0	16	0
	900	700	" " 3.7	" " 3.7	0	0		
	900	600	" " 5.5	" " 5.5	0	0		
	900	-	- -	" " 3.5	0	0		
91	900	800	less than 2.6	less than 2.6	20	0	24	1
	900	700	" " 3.1	" " 3.1	9	0		
	900	600	" " 5.8	" " 5.8	0	0		
	900	-	- -	" " 3.4	3	0		
64	900	800	less than 2.8	less than 2.8	6	0	23	1
	900	700	" " 4.0	" " 4.0	0	0		
	900	600	" " 7.0	" " 7.0	0	0		
	900	-	- -	" " 3.7	1	0		
69	900	800	less than 2.8	less than 2.8	16	0	20	2
	900	700	" " 3.2	" " 3.2	5	0		
	900	600	" " 5.5	" " 5.5	0	0		
	900	-	- -	" " 3.8	6	0		
II. TESTS AT MILL M - Normally produced Rails. 100-lb. rails								
2	900	800	0.2	- -	7	0	10	0
	900	700	0.6	- -	6	0		
	900	600	2.2	less than 2.2	0	0		
	900	500	4.6	" " 4.6	0	0		
	900	-	- -	" " 1.9	2	0		
	900	-	- -	" " 3.7	0	0		
	900	-	- -	" " 5.4	0	0		
4	900	800	0.4	- -	43	7	25	1
	900	700	1.1	- -	7	6		
	900	600	3.2	less than 3.2	0	0		
	900	500	5.3	" " 5.3	0	0		
	900	-	- -	" " 1.2	21	4		
	900	-	- -	" " 1.8	4	0		
	900	-	- -	" " 3.3	0	0		
	900	-	- -	" " 5.8	0	0		
6	900	800	0.5	- -	10	4	8	9
	900	700	1.3	- -	0	0		
	900	600	3.3	less than 3.3	0	0		
	900	500	6.7	" " 6.7	0	0		
	900	-	- -	" " 1.4	13	3		
	900	-	- -	" " 2.8	1	0		
	900	-	- -	" " 5.4	0	0		

TABLE 4 (Continued)

Heat	Specimens Put in Box at	Specimens Removed from Box at	Time in Box	Time to Cool from 700° F. to 300° F.	Shatter Cracks in 6-in. Etch Specimen Long.	Shatter Cracks in 6-in. Etch Specimen Trans.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air Long.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air Trans.
	degrees F.	degrees F.	hours	hours				
	III. TESTS AT MILL M - 100-lb. Rails from Hydrogen-treated Ingots.							
3	900	800	0.3	- -	280	42	167	33
	900	700	1.1	- -	264	46		
	900	600	2.5	less than 2.5	65	14		
	900	500	6.1	" " 6.1	0	0		
	900	-	- -	" " 2.1	100	14		
	900	-	- -	" " 3.9	63	4		
	900	-	- -	" " 6.6	9	0		
8	900	800	0.5	- -	29	10	40	6
	900	700	1.3	- -	8	2		
	900	600	2.2	less than 2.2	2	0		
	900	500	4.6	" " 4.6	0	0		
	900	-	- -	" " 1.5	21	5		
	900	-	- -	" " 2.6	3	0		
	900	-	- -	" " 4.0	0	0		
	900	-	- -	" " 5.7	0	0		
12	900	800	0.3	- -	20	65		
	900	700	1.0	- -	7	24	18	94
	900	600	2.9	Less than 2.9	0	0		
	900	500	7.1	" " 7.1	0	0		
	900	-	- -	" " 2.0	10	40		
	900	-	- -	" " 3.5	4	2		
	900	-	- -	" " 6.2	0	0		
	IV. TESTS AT MILL D - 131-lb. Rails from Hydrogen-treated Ingots.							
41003 Ingot 9	1100	930	1.0	- -	150	54	207	43
	1100	880	2.0	- -	112	24		
	1100	760	3.0	- -	35	7		
	1100	760	4.0	- -	0	0		
	1100	710	5.0	- -	0	0		
	1100	720	6.0	- -	0	0		
	700	470	3.0	3.5	50	11		
	700	410	4.0	4.4	20	8		
	700	430	5.0	5.3	3	1		
	700	425	6.0	6.3	0	0		
	700	430	7.0	7.3	0	0		
	700	450	8.0	8.3	0	0		
41003 Ingot 11	950	710	2.0	- -	75	40	210	90
	950	700	3.0	- -	25	16		
	950	665	4.0	1.3	3	1		
	950	640	5.0	2.1	0	0		
	950	520	6.0	4.7	0	0		
	950	530	7.0	5.0	0	0		
40159	700	465	3.1*	3.2	230	47	128	29
	700	450	4.0*	4.1	56	26		
	700	425	5.0*	5.2	42	15		
	700	415	6.0*	6.1	4	0		
	700	400	7.0*	7.1	0	0		
	700	390	8.0*	8.1	0	0		

* After removal from cooling box, specimen was cooled to 100° F. under a 3-ft. mill fan and then placed in ice water for 8 hours to repr\u00e9sent severe winter cooling conditions.

TABLE 5.
TESTS FOR SHATTER CRACKS IN RAIL SPECIMENS WHICH WERE REMOVED FROM SPECIAL COOLING BOX AT A TEMPERATURE HIGHER THAN 300° F.

Heat	Wt. of Rail	Specimens: Put in Box at	Specimens: Removed from Box at	Time in Box	Shatter cracks in 6-in. Etch Specimen		Shatter cracks in 6-in. of Control Specimen Cooled in Air	
	lb. per yard	degrees F.	degrees F.	hours	Long.	Trans.	Long.	Trans.
		I. TESTS AT MILL F - Normally produced rails.						
		(a) 112-lb. rails						
88	112	900	700	less than 1.8	7	0	22	0
		900	600	" " 3.4	0	0		
78	112	900	800	" " 1.9	7	0	29	0
		900	700	" " 2.7	1	0		
		900	600	" " 5.4	0	0		
73	112	900	800	" " 2.6	0	0	15	0
		900	700	" " 4.1	0	0		
		900	600	" " 4.5	0	0		
54	112	900	800	" " 2.3	8	0	22	1
		900	700	" " 3.2	0	0		
		900	600	" " 5.4	0	0		
		(b) 130-lb. rails						
70	130	900	800	" " 2.9	1	0	16	0
		900	700	" " 3.7	0	0		
		900	600	" " 5.5	0	0		
91	130	900	800	" " 2.6	20	0	24	1
		900	700	" " 3.1	9	0		
		900	600	" " 5.8	0	0		
64	130	900	800	" " 2.8	6	0	23	1
		900	700	" " 4.0	0	0		
		900	600	" " 7.0	0	0		
69	130	900	800	" " 2.8	16	0	20	2
		900	700	" " 3.2	5	0		
		900	600	" " 5.5	0	0		
		II. TESTS AT MILL M - Normally produced rails.						
		100-lb. rails						
2	100	900	800	0.2	7	0	10	0
		900	700	0.6	6	0		
		900	600	2.2	0	0		
		900	500	4.6	0	0		
4	100	900	800	0.2	43	7	25	1
		900	700	1.1	7	6		
		900	600	3.2	0	0		
		900	500	5.3	0	0		
6	100	900	800	0.5	10	4	8	9
		900	700	1.3	0	0		
		900	600	3.2	0	0		
		900	500	6.7	0	0		
		III. TESTS AT MILL M - 100-lb. Rails from Hydrogen-treated Ingots.						
3	100	900	800	0.3	280	42	167	33
		900	700	1.1	264	46		
		900	600	2.2	2	0		
		900	500	6.1	0	0		
8	100	900	800	0.5	29	10	40	6
		900	700	1.3	8	2		
		900	600	2.2	2	0		
		900	500	4.6	0	0		
12	100	900	800	0.3	20	65	18	94
		900	700	1.0	7	24		
		900	600	2.9	0	0		
		900	500	7.1	0	0		

TABLE 5 (Continued)

Heat	Wt. of Rail	Specimens: Put in Box at	Specimens: Removed from Box at	Time in Box	Shatter Cracks in 6-in. Etch Specimen: Long.	Shatter Cracks in 6-in. Etch Specimen: Trans.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air: Long.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air: Trans.
	lb. per yard	degrees F.	degrees F.	hours				
IV. TESTS AT MILL D - 131-lb. Rails from Hydrogen-treated Ingots.								
86371	131	500	390	3.0	21	2	160	55
		500	370	4.0	15	2		
		500	355	5.0	7	0		
		500	360	6.0	3	0		
86373	127	500	420	3.0	7	2	87	28
		500	385	4.0	1	0		
		500	380	5.0	0	0		
		500	325	6.0	1	0		
85371	127	500	385	3.0	90	15	240	65
		500	375	4.0	26	7		
		500	360	5.0	21	3		
		500	325	6.0	1	0		
41003 Ingot 9	131	1100	930	1.0	150	54	207	42
		1100	880	2.0	112	24		
		1100	760	3.0	35	5		
		1100	770	4.0	0	0		
		1100	710	5.0	0	0		
		1100	720	6.0	0	0		
		700	470	3.0	50	11		
		700	410	4.0	20	8		
		700	430	5.0	3	1		
		700	420	6.0	0	0		
		700	430	7.0	0	0		
		700	450	8.0	0	0		
41003 Ingot 11	131	950	710	2.0	75	40	210	90
		950	700	3.0	25	16		
		950	670	4.0	3	1		
		950	640	5.0	0	0		
		950	520	6.0	0	0		
		950	530	7.0	0	0		
		500	380	3.0	31	12		
		500	370	4.0	19	5		
		500	350	5.0	0	3		
		500	350	6.0	0	0		
		500	320	7.0	0	0		
		500	330	8.0	0	0		
40159	131	700	470x	3.0	230	47	128	29
		700	440x	4.0	56	26		
		700	430x	5.0	42	15		
		700	420x	6.0	4	0		
		700	400x	7.0	0	0		
		700	390x	8.0	0	0		

x Rail cooled by 3-foot fan and ice water on removal from the cooling box.

TABLE 6.

TESTS OF HYDROGEN-TREATED RAILS COOLED IN COOLING CONTAINERS AT FOUR STEEL MILLS*

Lid on container removed 12 hours after it was put on. The following table summarizes test results on 44 control-cooled rails and 26 control specimens.

Mill	Weight of Rail	Minimum Temperature of Rail degrees Fahr.		Cooling of Rail to 300° Fahr.				Shatter Cracks (Maximum No. in etch specimen)			
				Fastest Cooling Rail		Slowest Cooling Rail		In Control Specimens (cooled in air)		In any Test Rail in Container	
	lb. per yard	When placed in Container	When Lid was put on Container	Location in Container*	Time, hr.	Location in Container*	Time, hr.	Long.	Trans.	Long.	Trans.
D	127	800	---	9	13	8	16	95	23	0	0
E	112	800	---	1	7.2	8	14.6	30	16	0	0
F	131	900	370	1	6	8	16.8	150	10	0	0
F	112	780	330	1	2	8	21	92	18	0	0
G	112	750	---	1	8	8	14.4	58	14	0	0

*See Fig. 16

TABLE 7.
TESTS FOR SHATTER CRACKS IN RAIL SPECIMENS PUT INTO SPECIAL COOLING BOXES AT TEMPERATURES OF 400° Fahr. OR LOWER.

Heat	Wt. of Rail lb. per yard	Specimens Put in Box at degrees F.	Time in Box hours	Shatter Cracks in 6-in. Etch Specimen Long.	Shatter Cracks in 6-in. Etch Specimen Trans.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air Long.	Shatter Cracks in 6-in. of Control Specimen Cooled in Air Trans.
		I. TESTS AT MILL F - Normally produced rails.					
38	112	200	21	1	0	22	0
		300	21	0	0		
		400	21	0	0		
78	112	200	21	3	0	29	0
		300	21	0	0		
		400	21	0	0		
73	112	200	21	0	0		
		300	21	0	0	15	0
		400	21	0	0		
54	112	200	21	2	0	22	1
		300	21	0	0		
		400	21	0	0		
70	131	300	21	0	0	16	0
		400	21	0	0		
91	131	300	21	0	0	24	1
		400	21	0	0		
64	131	300	21	0	0	23	1
		400	21	0	0		
69	131	300	21	0	0	20	2
		II. TESTS AT MILL M - Normally produced rails.					
2	100	200	18.0	0	0	10	0
		300	7.6	0	0		
		400	12.6	0	0		
4	100	200	14.8	7	0	25	1
		300	5.4	0	0		
		400	14.3	0	0		
6	100	200	19.8	7	0	8	9
		300	8.7	0	0		
		400	14.3	0	0		
		III. TESTS AT MILL M - Rails from Hydrogen-treated Ingots.					
3	100	200	15.1	104	4	167	33
		300	6.4	8	0		
		400	11.6	0	0		
8	100	200	21.0	5	0	40	6
		300	8.5	0	0		
		400	11.8	0	0		
12	100	200	21.0	1	0	18	94
		300	8.5	0	0		
		400	13.5	0	0		
		IV. TESTS AT MILL D - Rails from Hydrogen-treated Ingots.					
86371	131	210	More than 10.0	30	1	160	55
		255	" " 10.0	14	0		
		320	" " 10.0	2	0		
		420	19.0	0	0		
86373	127	200	" " 10.0	13	0	87	28
		250	" " 10.0	1	0		
		300	" " 10.0	0	0		
		400	20.0	0	0		
85371	127	200	" " 7.0	110	7	240	65
		260	" " 10.0	19	0		
		300	" " 10.0	2	0		
		400	18.5	0	0		

27. **Is It Necessary to Allow Rails to Remain in the Cooling Box Until They Have Cooled Down to 300 deg. F.?**—The recommended standard practice now in general use for control-cooling of rails requires that they be not removed from the cooling container until all rails have cooled down to 300 deg. F. This frequently requires 20 to 30 hours before the slowest cooling rail in the container reaches that temperature. This is a source of expense in rail production.

To throw light on this question Table 5 has been prepared from the data of the series of tests made at the different rail mills. In this table are recorded the results of tests of 89 rail specimens each of which was removed from the cooling box at a temperature above 300 deg. F. An examination of this table shows that none of these rail specimens which had remained in the cooling box as long as 7 hours developed shatter cracks. It therefore seems that the tests showed that *shatter cracks were prevented in all rail specimens which were placed in the cooling boxes at a temperature of 700 deg. F. or higher and which remained in the boxes for 7 hours or longer without cooling below 300 deg. F.*

In this connection the question was raised whether the above conclusion would hold in winter weather, when rails removed from cooling containers above 300 deg. F. would be subjected to a more rapid cooling to air temperature than was the case during these tests which were mainly in the summer. To answer this question the rail specimens from Mill D, Heat 40159, on being removed from the cooling boxes were cooled down to 100 deg. F. under a 3-ft. mill fan, and then placed in ice water for 8 hours. This drastic treatment did not develop shatter cracks in any rail which had been in the cooling box for 7 hours or more. The answer to the question, "Is it necessary to allow rails to remain in cooling box until they have cooled down to 300 deg. F.?" seems to be "no," not if a rail is placed in a cooling container at 700 deg. F. or higher, and remains there for 7 hours, or longer, without cooling below 300 deg. F. So long as a rail does not cool below a certain minimum temperature, it seems to be *time in the cooling container,* rather than *minimum temperature reached which is significant.*

28. **Rates of Cooling of Rails in Commercial Cooling Containers.**—Two series of tests have been made on rates of cooling in cooling containers in use in Mills D, E, F, and G. The first series of tests showed that the rails in the lower layer of some containers cooled very rapidly—cooling from 700 deg. F. to 300 deg. F. in 3 hours or less in some cases. Since tests had shown that it was not necessary to wait until all rails had reached 300 deg. F. before removing any rails from the cooling box, it became possible to remedy this rapid cooling by better insulation of the boxes against loss of heat. Figures 15 and 16 show how such insulation may improve the control-cooling process. Figure 15 shows the cooling curves for rails in various locations in an uninsulated cooling container. One of the test rails cooled from 700 deg. F. to 300 deg. F. in 3 hours and another in 5 hours. Figure 16 shows cooling curves for rails in an insulated cooling box at the same mill. The fastest cooling rail cooled from 700 deg. F. to 300 deg. F. in 7 hours. Nearly all the cooling containers in United States mills are now insulated. The bottom of the cooling box or car is covered with a layer of insulating material, and the sides and ends are insulated to a height of two or three feet. It seems important that there should be a minimum of air space between the rails and the sides, ends and floor of the cooling box or car.

An obvious way of taking advantage of improved insulation in containers, and of the fact that it seems unnecessary that all rails cool to 300 deg. F. before the container is opened, is to allow the removal of the lid from the cooling container after some minimum time. This procedure was tried on hydrogen-treated rails at Mills D, E, F,

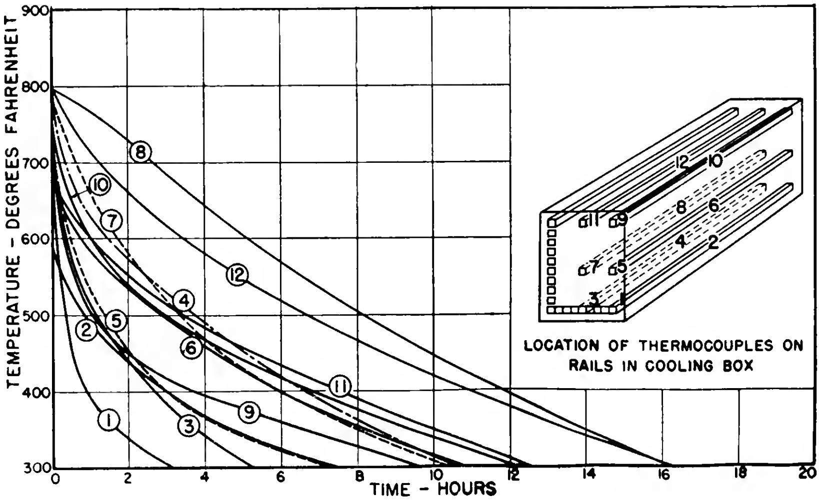


Fig. 15.—Cooling Curves for Rails in Commercial Cooling Box Without Special Insulation.

and G, using an interval of 12 hours from the time of placing the lid on the container to the time of its removal. Rails were removed as soon as it was deemed they would not suffer distortion by handling. Figure 16 shows a typical set of cooling curves, and Table 6 gives the test results. It will be noted that the air-cooled control rail specimens showed numerous shatter cracks, but that no shatter cracks were found in the hydrogen-treated rails which were control cooled using this "lid-lifting" procedure. Some of these test rails were placed in the top layer of the box, some in the bottom layer. At two of the mills the fastest cooling rail cooled to 300 deg. F. in less than 7 hours. However, *none of the control-cooled hydrogen-treated rails* developed shatter cracks. These tests give rather strong evidence of the reliability of the plan proposed, to remove the lid from the cooling container after a definite interval of time.

29. **At What Temperature Do Shatter Cracks Actually Form?**—This question is of interest, although it does not bear directly on the question of details of procedure in control cooling of rails. Table 7 lists results of tests on 49 rail specimens at three mills which were put into cooling boxes at low temperatures, and allowed to stay there for periods varying from 5.4 hours to 21 hours. It will be noted that some specimens put in at 200 deg. F. showed shatter cracks even after 21 hours in the cooling box. This seems to indicate that in those cases the shatter cracks had begun to form before the specimens were placed in the cooling box. On the other hand, the specimens put in at 300 deg. F. showed very few shatter cracks. This would seem to indicate that the actual formation of shatter cracks takes place somewhere in the temperature range from 200 to 300 deg. F. It may be noted that tests by Wishart and Swanson[8] on rail specimens placed in a furnace and reheated after they had cooled to 200 deg. F. show some evidence that the formation of shatter cracks may begin nearer to 200 deg. F. than to 300 deg. F. It is to be noted that, although shatter cracks actually form at or below

[8] Trans., Am. Soc. Metals, September 1939, p. 785, footnote.

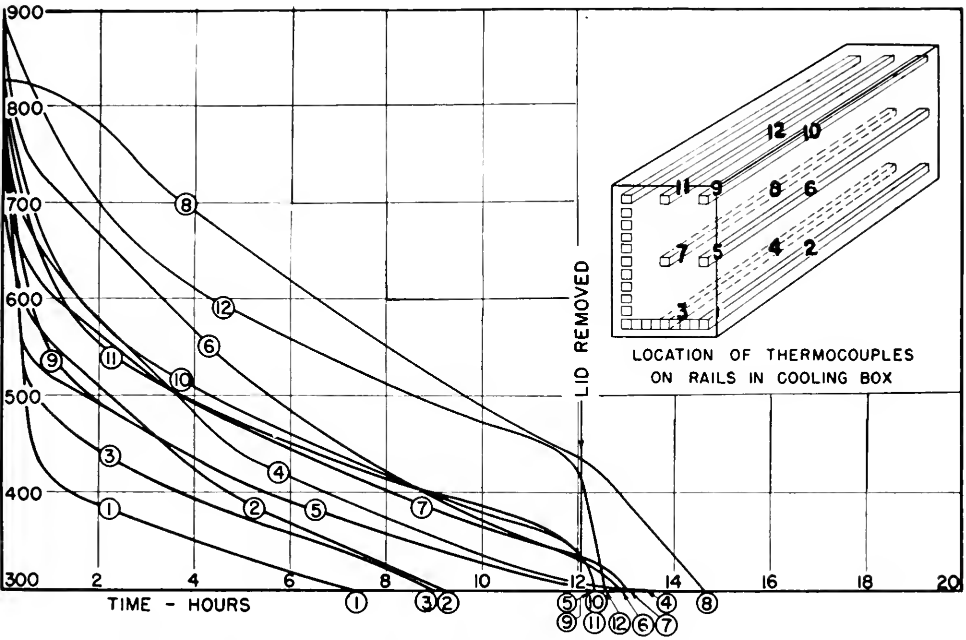


Fig. 16.—Cooling Curves for Rails in Commercial Cooling Box with Insulation Around Bottom and Ends of Box.

This test made at the same mill and under approximately the same air temperature as the test shown in Fig. 15.

300 deg. F., the rate of cooling at temperatures *above* that range determines whether or not shatter cracks occur.

Two main results of the tests of control cooling of rails may be summed up as follows:

(a) No evidence of shatter cracks was found for rails or rail specimens which were placed in the cooling container at a temperature of 700 deg. F. or higher, provided that the fastest cooling rail (usually a corner rail in the bottom row) did not cool down from 700 to 300 deg. F. in less than 7 hours.

(b) Removing the lid from the container 12 hours after it had been put in place did not develop shatter cracks in any rail for which the conditions outlined in (a) were fulfilled.

30. **Tests of Rails Held at Constant Temperatures.**—Tests on another type of thermal treatment which has been used at one mill give information on the time necessary to hold rails at various constant temperatures to prevent the formation of shatter cracks. These tests were all made at Mill D on 131-lb. rails. After the hydrogen-treated specimens were cut at the hot saws they were cooled on the mill floor to temperatures of 1,100, 900, 700 and 500 deg. F. and all but the control specimen were placed in a gas-fired furnace held at the above temperatures. The results of these tests are summarized in Table 8.

After being removed from the furnace the specimens from Tests 3 and 4 were cooled under the mill fan and then in ice water for eight hours. This accounts for the

TABLE 8

RESULTS OF ETCH TESTS OF SPECIMENS HELD FOR VARIOUS LENGTHS OF TIME AT FOUR DIFFERENT TEMPERATURES

Constant Furnace Temperatures	*Time in Furnace, Hours*	†*Number of Shatter Cracks on One Side of Six-inch Slice*			
		Test 1	*Test 2*	*Test 3***	*Test 4***
Control Spec.*	0	105 L, 45 T			
1,100° F.	1	65 L, 24 T			
”	2	5 L,			
”	3	0			
”	4	0			
”	5	0			
”	6	0			
Control Spec.*	0	160 L, 44 T	87 L, 18 T	92 L, 62 T	125 L, 50 T
900° F.	1	86 L, 14 T	26 L, 4 T	191 L, 78 T	160 L, 50 T
”	2	55 L, 8 T	8 L,	43 L, 21 T	163 L, 44 T
”	3	3 L, 2 T	0	8 L, 1 T	14 L, 3 T
”	4	0	0	0	0
”	5	0	0	0	0
”	6	0	0	0	0
Control Spec.*	0	116 L, 19 T	118 L, 21 T		
700° F.	1	85 L, 8 T	94 L, 10 T		
”	2	14 L,	29 L, 1 T		
”	3	1 L,	4 L,		
”	4	0	0		
”	5	0	0		
”	6	0	0		
Control Spec.*	0	139 L, 46 T			
500° F.	1	138 L, 57 T			
”	2	52 L, 28 T			
”	3	44 L, 5 T			
”	4	10 L, 1 T			
”	5	0			
”	6	0			

* Control specimen cooled in air outside the mill.
† Shatter cracks are recorded as the number of longitudinal (L) or transverse (T) shatter cracks on one side of a longitudinal slice six inches long.
** For Tests 3 and 4, after the specimens were removed from the furnace they were cooled under a mill fan and then in ice water for eight hours.

increased number of shatter cracks in the specimen held in the furnace one hour as compared with the number found in the control specimen cooled on the mill floor. It will be noted that the formation of shatter cracks was prevented by holding the specimens 3 hours at 1,100 deg. F.; 4 hours at 900 deg. F. and 700 deg. F.; and 5 hours at 500 deg. F. The tests also furnish further evidence that after the rails have been held a sufficient time at a given temperature, fast cooling to freezing temperatures is not dangerous.

31. **The Brunorizing Process for Rails.**—A commercial process of normalizing rails was developed by the Illinois Steel Company in 1936. Rails treated by this process are called Brunorized rails in honor of Mr. John Brunner, manager, Department of

Metallurgy and Inspection, Carnegie–Illinois Steel Corp., co-chairman of the contact committee during the early part of the Rails Investigation. An important modification in this process was made in April 1938 which includes holding the rails in gas heated containers at a temperature about 1,000 deg. F. for two or more hours before the normalizing treatment. A few heats of rails produced by the Brunorizing process before the modification in 1938 have developed typical transverse fissures in service from shatter crack nuclei but no Brunorized rails produced after the holding period was adopted have developed fissures. Laboratory tests were made of hydrogen-treated rails produced by the modified process but no shatter cracks were found while companion rails cooled on the hot bed developed many shatter cracks. Laboratory tests and service records so far available indicate that the holding period is adequate to prevent shatter cracks in Brunorized rails.

32. **The Service Record of Control-Cooled Rails.**—Mr. W. C. Barnes, engineer of tests for the AREA Committee on Rail, reports about 3,000,000 tons of control-cooled rail (rolled under contract, not including experimentally control-cooled rail) in service June 30, 1940. Up to October 1940 only three actual fissures[9] in control-cooled rail and one vertical split head had been reported to the test party. Laboratory tests showed that two of the three fissures started from large slag inclusions near the tread of the rail, and that the third started from blow holes in the head of the rail. A vertical split head had developed from a gross slag segregation surrounded by a large area of decarburized steel. All four rails were found to be free from shatter cracks. This may be considered a decidedly promising record for control-cooled rails, and gives ground for the expectation that very few, if any, control-cooled rails will develop the ordinary type of transverse fissure, originating in a shatter crack.

33. **What Control Cooling Will Not Do for Rails.**—A word of caution about control-cooled rails seems in order. Control cooling is *not* a panacea for all rail troubles. It will not prevent segregation and slag inclusions. It will not prevent decarburization of steel. It will not prevent undue wear at the tread, with consequent slivering and sometimes the starting of a progressive (fatigue) fracture. It will not prevent failures starting in the base or the web of the rail. It will not prevent failures starting from wheel burns on rail. It seems so far to be a very effective inhibitor of shatter cracks, and may be expected to reduce very greatly transverse fissure failures and compound fissure failures as the ratio of control-cooled rail to total rail in service increases.

VI Chemical Composition and Metallographic Structure of Rail Steel

By R. E. Cramer

34. **Chemical Composition of Rail Steel.**—During the investigation heat analyses were furnished the test party for all test rails. However, all the test rails showed chemical analyses within the allowable limits set by AREA specifications. Table 9 gives those limits.

During the early part of the investigation, when testing 130-lb. rails, shatter cracks were found to be more prevalent in rails of high silicon content. However, in later tests of 110-lb. rails, especially those from one rail mill which were quite high in silicon, this relationship between high silicon and shatter cracks broke down.

[9] Several broken rails had been reported as "transverse fissures" or "compound fissures", which ,on examination were found to be failures starting from the surface at a burn or at the flowed metal at an upper corner of the head of a rail. Such failures are not properly classified as fissures, which start from the inside of the head of the rail.

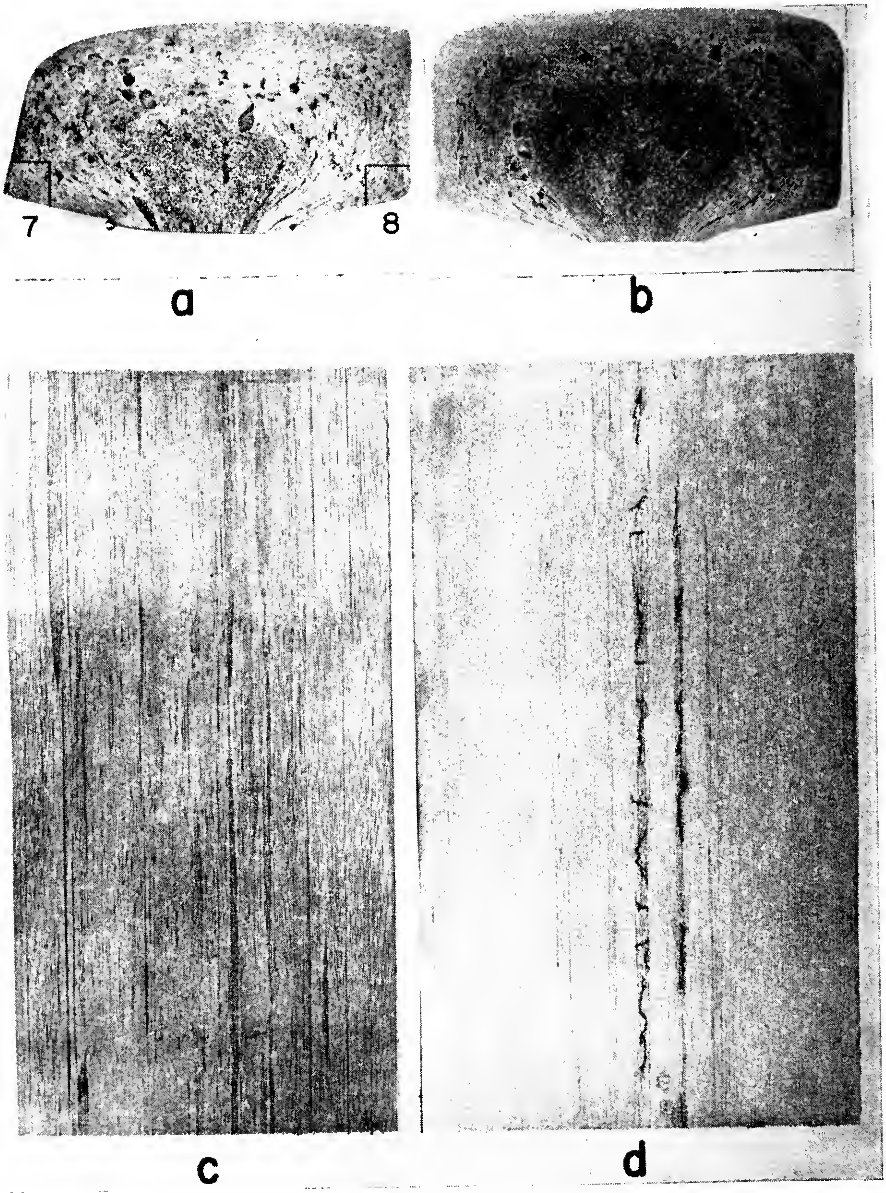


Fig. 17.—Longitudinal Horizontal Sections of Rail Heads Showing Segregation Streaks.

(a) Rail 82. Etched in acid to show segregation streaks. Numbers indicate location of tension specimens from the rail. Chemical analysis made of material in streaks in this rail.
(b) Rail 92. Etched in acid showing segregation streaks from which material was taken for chemical analysis.
(c) Longitudinal section of Rail 82. No shatter cracks shown by etch test.
(d) Longitudinal section of Rail 546. Both transverse and longitudinal shatter cracks along segregation streaks shown by etch test.

TABLE 9

STANDARDS FOR CHEMICAL CONTENT OF RAIL STEEL

Item	*AREA Standards 1931*		*As Revised 1933*	
Weight of Rail, lb. per yd.	110–120	120–140	110–120	120–140
Carbon, percent	0.67–0.83	0.72–0.89	0.67–0.80	0.68–0.82
Manganese, percent	0.50–0.90	0.50–0.90	0.70–1.00	0.70–1.00
Phosphorus, percent, max.	0.04	0.04	0.04	0.04
Silicon, percent	0.15 min.	0.15 min.	0.10–0.23	0.10–0.23

It was generally recognized that there were more shatter cracks in rails of the higher carbon content. Because of these considerations the chemical analysis of carbon steel rails was revised by the AREA in 1933 to slightly lower the carbon content, and definite limits were set on the silicon content. The changes in chemical analyses were made before control cooling was adopted by the United States rail mills.

35. **Segregation of Chemical Constituents.**—It is well recognized that it is difficult to prevent chemical segregation in ingots of the size used for railroad rails, which are around 2 ft. square by 80 to 90 in. high. Such ingots require considerable time to solidify to the center so if the molten steel is not in the ideal state for pouring, the ingots may develop segregation or pipes. Phosphorus, sulphur and carbon are the chemical elements most likely to segregate. The recent adoption of the all-ingot nick and break test should reduce to a minimum the number of piped or web segregated rails which will be put in service in track.

TABLE 10

CHEMICAL COMPOSITION OF SEGREGATED STREAKS IN RAILS 82 AND 92

Rail	*Method of Sampling*	*Chemical Content—Per cent*				
		C	*Mn*	*Si*	*P*	*S*
82	Composite sample across rail	0.79	0.88	0.06	0.035	0.026
	Sample from segregation streaks	0.87	0.96	0.05	0.100	0.067
	Increase in streaks	0.08	0.08	—0.01	0.065	0.041
92	Composite sample across rail	0.69	0.80	0.17	0.029	0.041
	Sample from segregation streaks	0.77	0.87	0.16	0.066	0.076
	Increase in streaks	0.08	0.07	—0.01	0.037	0.035

Careful consideration has been given during the course of the Rails Investigation to segregated streaks found throughout the heads of some rails. Figure 17 (a) and (b) show two examples containing very large segregation streaks. Drillings for chemical analyses were taken from the segregation streaks of these two rails using a drill 0.086 in. in diameter. For comparison a composite sample was made with a ¼-in. drill of the metal across the width of the heads midway between the top and bottom. The analyses of these samples are given in Table 10.

These analyses show a decided segregation of phosphorus and sulphur in the streaks and some increase in the carbon and manganese. To determine the effect of this composition on the physical properties of the metal in the streaks, 8 tensile specimens ⅛ in. in diameter, at the reduced section, were machined from Rail 82 which is shown in Fig. 17 (a). This rail did not contain shatter cracks in the segregation streaks as is evident in Fig. 17 (c). The method of obtaining such specimens was to etch both ends of 4½-in. sections of the rail head and to center punch the streaks which extended through the sections. The tensile specimens were then turned out using these punch marks as centers. Two control specimens, No. 7 and No. 8, were taken from the lower corners of the head which did not contain segregation streaks. The specimens were tested in spherical seated holders in an Olsen 10,000-lb. testing machine and special care was taken to line up the axis of each specimen perpendicular to the plane of the cross-head of the testing machine. Table 11 gives the results of the tensile tests.

Table 11

Tensile Test Results of Specimens From Segregated Streaks and From Unsegregated Metal in Rail 82

Specimen	*Tensile Strength, lb. per sq. in.*	*Elongation in 3 in., percent*	*Reduction of Area, percent*
Specimens From Segregated Streaks			
82–1	146,500	----	7.8
82–2	144,000	4.3	8.4
82–3	142,300	6.0	10.8
82–4	140,000	6.0	8.5
82–5	133,300	7.0	15.0
82–6	144,600	6.0	11.0
Av.	141,800	5.9	10.3
Specimens From Unsegregated Metal			
82–7	113,500	14.0	20.2
82–8	117,500	12.5	28.9
Av.	115,500	13.2	24.6

It will be noted that the metal in the segregated streaks was stronger but lower in ductility than the unsegregated metal. The results of these chemical and physical tests give some explanation why shatter cracks are often located along or radiating from segregation streaks, as shown in Fig. 17 (d). It seems that the brittle material of the streaks would be more subject to cracking than the more ductile metal surrounding the streaks and so it is not unusual to find some rails containing shatter cracks only along such streaks.

36. **Metallographic Tests of Rail Steel.**—Metallographic examination of polished specimens has been an important tool throughout the investigation. It is difficult to summarize the metallographic tests because so large a portion of this work has necessarily been of a routine nature. Metallographic testing has been used to study rails for grain size, impurities, location of cracks, decarburization both external and internal,

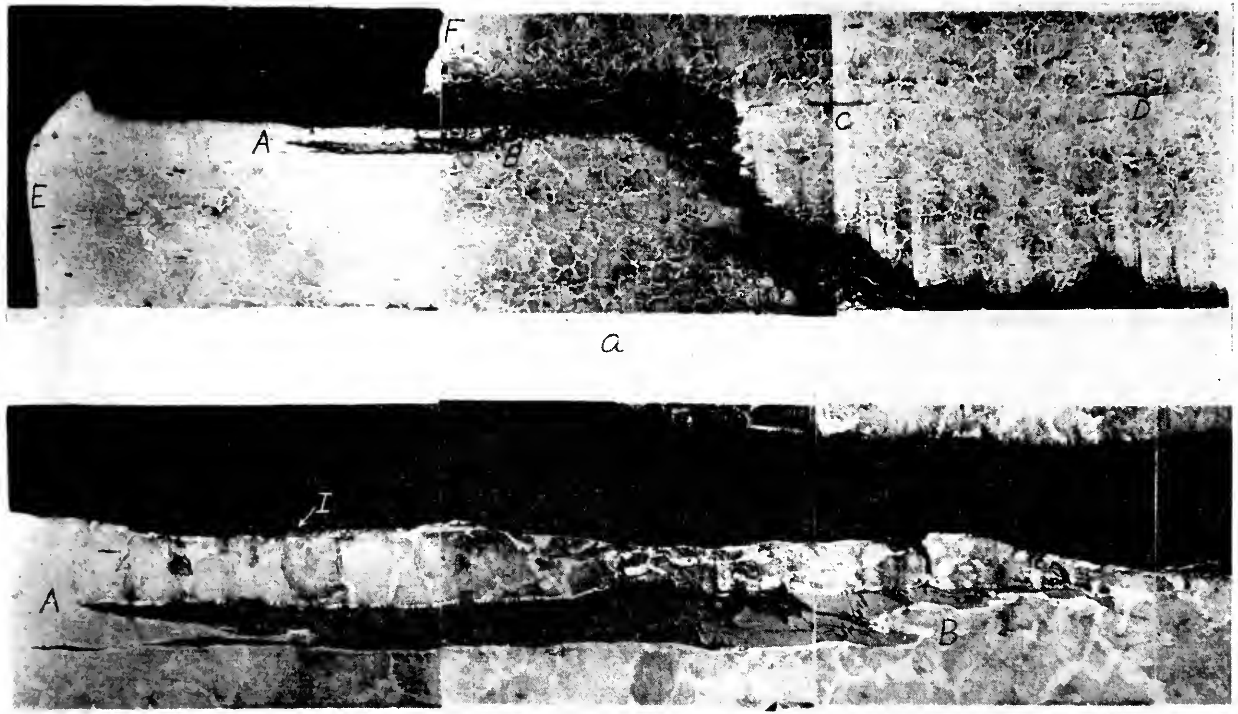


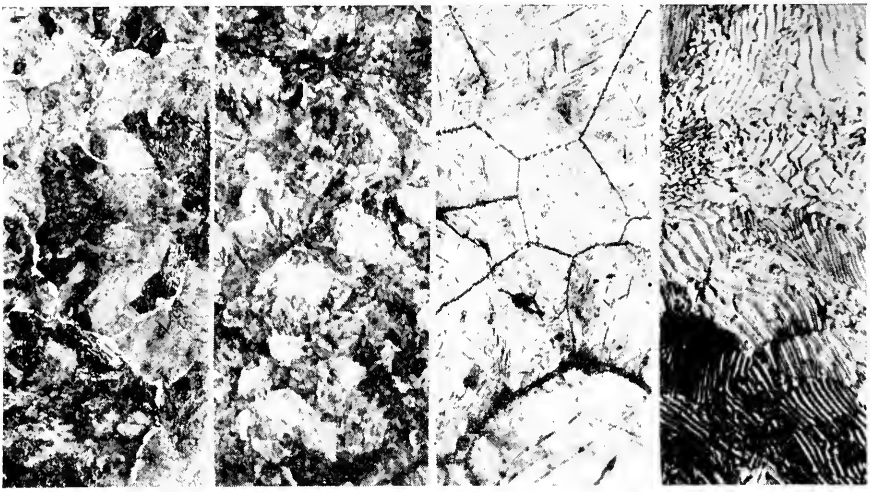
Fig. 18.—Compound Fissure in a Bessemer Rail.

a (Above)

Micrograph at point of original failure. Magnification 33 ×. Etch, 2 percent picral. A–B Inclusion just before point of original failure. C and D Inclusions in line with original failure. E and F Faces of transverse section of fissure.

b (Below)

Micrograph at Magnification of 130 ×. Etch 2 percent picral. Note ferrite band around inclusion and along edge of fracture. Note remains of inclusion at I.



a b c d

Fig. 19.—Typical Crystalline Structures of Rail Steel.
(a) Excess ferrite. Magnification 110 ×. Etch 2 percent picral.
(b) Pearlitic structure. Magnification 110 ×. Etch 2 percent picral.
(c) Excess cementite. Magnification 110 ×. Etch sodium picrate.
(d) Pearlitic structure. Magnification 1,100 ×. Etch 2 percent picral.

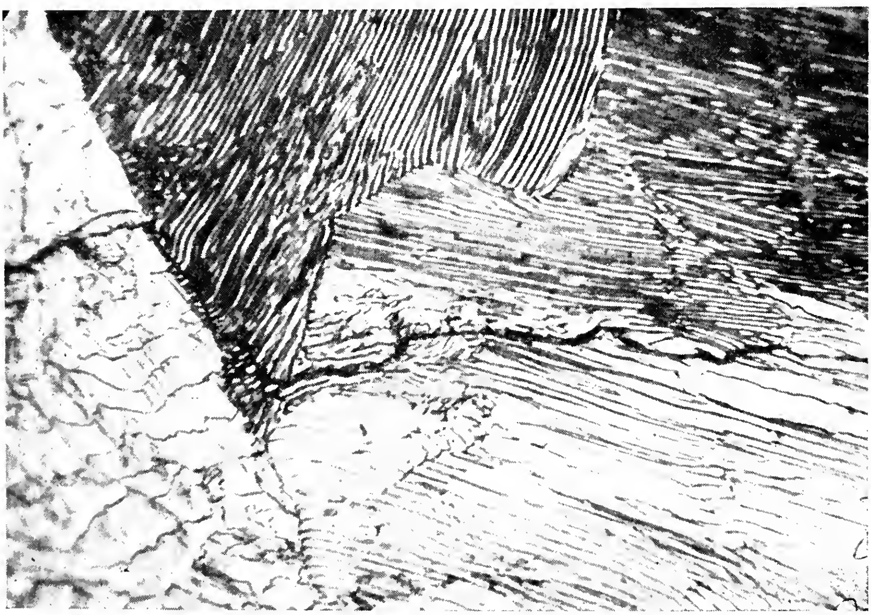


Fig. 20.—Path of Fatigue Crack Through Pearlite.
Magnification 1,500 ×. Etch 2 percent picral. Note that the crack is comparatively straight with no branches.

etc. About 1,000 photomicrographs have been taken, using magnifications from 100 × to 4,000 ×, and these are available in the files of the Rails Investigation. Most photomicrographs of the grain structures of rails have been taken at either 200 × or 2,000 × magnification, depending on whether it was desirable to show the general grain size or the nature of the pearlite within the grains. The microscope has also been used to study and photograph scratch extensometer records and to measure the radii of notching tools used to make notches in fatigue specimens.

A typical example of the use of the microscope to study failures is shown in Fig. 18. The straight longitudinal part of Fig. 18 (a) was known to be the origin of a compound fissure in a Bessemer rail. This picture is a group of three photomicrographs originally taken at 100 × magnification and here reduced to about 33 ×. The straight edge just above the inclusion marked *A–B* represents the section of initial failure. At the right end of the straight section the horizontal component of the fissure turned down in the rail

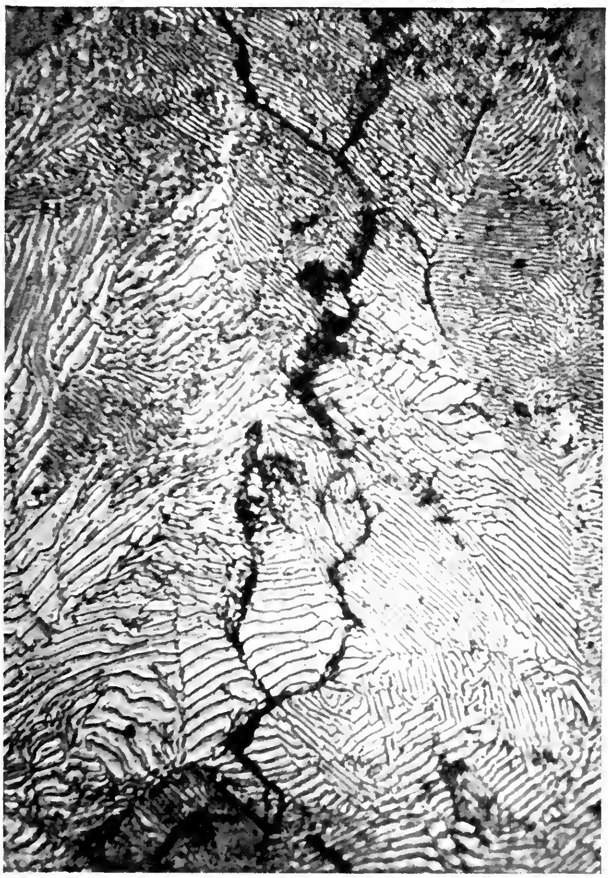


Fig. 21.—Shatter Crack in Pearlite.

Magnification 1,500 ×. Etch 2 percent picral. Note that the shatter crack is very irregular and has branches extending in various directions, indicating a shattered condition of the steel.

head. This portion of the fissure made an oblique angle with the polished surface, which makes the crack appear much wider than it would on a surface perpendicular to the crack. If a straight edge is laid along the inclusions *C* and *D* in Fig. 18 (a), it will be seen that they are in line with the edge where the fissure started, indicating that there has been an inclusion along this straight section of the fissure.

Further verification of the above explanation is shown in the lower photomicrograph marked (b) of Fig. 18. This micrograph was taken at 400 × magnification and is reproduced here at 130 ×. It shows the large inclusion marked *A–B* in micrograph (a). It will be noticed that there is a narrow band of ferrite along the edges of this inclusion. A similar band of ferrite is seen along the edge of the fracture extending the full length of this picture. Also at *I* there is a small fragment of the original inclusion which was in this space. The inclusion marked *A–B* shows numerous cracks. These inclusions are quite brittle, and would readily crack under heavy wheel loads, thus acting as possible starting points for fissures. These observations indicate that this fissure started in a horizontal direction, in or along a rather large inclusion in the highly stressed area of the rail head. This fissure as it spread developed into a compound fissure extending toward the center of the rail head.

Four typical structures of rail steel are shown in Fig. 19. Figure 19 (b) shows the structure commonly found, a pearlitic structure. Figure 19 (a) shows a structure infrequently found, in which there is a slight excess of ferrite which outlines the original austenite grains of the metal. Figure 19 (c) shows a structure fortunately very rarely found, in which there is an excess of cementite outlining the grains of the metal. This structure indicates unduly brittle steel. Figure 19 (d) is a micrograph of the typical pearlitic structure magnified 1,100 times.

Figure 20 shows the path of a fatigue crack across three pearlitic grains of steel. It will be noted that at the left of the micrograph the crack cuts across the pearlite lamellae. In the center grain it extends closely parallel to the grain boundary, while in the larger grain to the right it is between the pearlite lamellae. It has been found that in general fatigue cracks progress in a fairly straight line perpendicular to the direction of the principal tensile stress. Figure 21 shows a shatter crack in pearlite. It should be noted that the shatter crack is very irregular and has branches extending in various directions. Such cracks are well named as they represent a general shattering of the metal in the vicinity of the crack. In general it may be stated that no typical structure has been associated with shatter cracks except that they are more numerous in segregation streaks which usually contain more non-metallic inclusions than the surrounding rail metal.

VII Mechanical Properties of Rail Steel

By S. W. Lyon

37. **Introductory.**—At the inception of the Rails Investigation a program of mechanical testing of specimens cut from rails was carried out to furnish information regarding the properties of rail steel. While many of the tests that were carried out were of such a nature as to give information to supplement the findings of the metallographic, rolling-load, and other tests, the later mechanical tests, especially, were made with the purpose of enlarging the fund of data regarding the behavior of rail steel as an engineering material with, of course, especial attention to its use in railroad track.

The tests which comprised the earlier part of the program were mostly concerned with the establishment of the mechanical properties of rail steel both as found in shatter-cracked (as determined by etch tests) and in non-shatter-cracked rails. Further to delineate the difference between the various properties in shatter-cracked and non-shatter-cracked steel, specimens were obtained from the shatter-cracked rails from areas containing cracks and those adjacent in the same rails not having cracks as revealed by the etch test. The many rails tested included hot-bed cooled rails, control-cooled rails, normalized or Brunorized rails, and rails of special composition; these rails also included various weights and types of section.

When the program of the Rails Investigation was expanded to include the problem of hardening of rail ends to minimize batter[10] a great many mechanical tests of specimens cut from rails so treated were made. These tests were made on rails end hardened by 11 processes of which 6 represented mill end-hardening practice and 5 practices used to end-harden rail ends in track. Specimens were cut and tested so as to survey the mechanical properties of the steel as affected by the various end-hardening processes and also of the unhardened rail steel to give a comparison of the effect of hardening.

Besides the above enumerated more or less routine tests carried out in direct relation to the specific problems of transverse fissures and the end hardening of rails, certain special tests were made. These special tests were suggested by the major problems and are so related as to give information on certain phases of the transverse fissure and end hardening problems. Considerable effort was given to the determination of the effect of temperature, especially low temperatures, on the mechanical properties of rail steel. In connection with the end hardening of rail ends much work was done on the effect of hardness on rail steel as to tensile strength, ductility, toughness, and fatigue strength. Other special tests were also made on the effect of rolling on the toughness of rail steel.

Included in the various tests applied to specimens cut from rail steel to study the properties of rail steel were static tension tests, impact bending tests, fatigue tests, impact tension tests, hardness tests, and other special mechanical tests that will hereinafter be described. Certain of the above tests were applied not only at normal room temperature but at depressed temperatures to as low as —60 deg. F.

38. **Static Strength.**—The various studies of the static strength of rail steel will be discussed under two main classifications which included the following outlined features.

(a) Many static tension tests of specimens cut from rail heads were made in connection with shatter-cracked and non-shatter-cracked rails in the pursuit of the general problem of the cause and prevention of transverse fissures in rails.

(b) In connection with the investigation of end-hardened rails many tension tests were made of specimens cut from the end-hardened and unhardened steel in rail ends hardened by the various end-hardening processes. These tests were made to study the effect of the hardening on the steel in the rails so treated.

(a) *Static Tension Tests of Specimens from Head of Rail.*—Static tension tests were made on about 40 tension specimens cut from the heads of certain test rails in the first lot received (hot-bed cooled rails). Rails from five mills were in this first lot. These tension specimens were all from rails for which the etch test specimens showed no shatter cracks. The range of values found is given in Table 12.

Static tension tests were also made on specimens cut from the heads of rails for some of which the etch test *had* shown shatter cracks. The type of tension specimen for this second lot is shown in Fig. 22 (a). The specimens were cut so as to provide specimens from (1) the metal near the surface of rails, and (2) from the steel near the center of the cross-section of the head.

[10] A subsequent report will discuss the tests to measure batter on rails with ends unhardened and with ends hardened.

TABLE 12

RESULTS OF TENSION TESTS, IZOD TESTS AND FATIGUE TESTS OF SPECIMENS FROM HEADS OF RAILS FREE FROM SHATTER CRACKS

The test results in this table are from tests of specimens cut from rails selected from the first lot of 289 test rails sent to the Talbot Laboratory at the University of Illinois. Each of the rails from which these specimens were cut had been etch tested, and no shatter cracks had been found in any one of the rails selected, although they were all hot-bed cooled rails. Strength of steel in shatter-cracked rails is discussed in the second part (b) of Section 40, "Fatigue Strength".

Kind of Test	*Properties*	*Specimen*	*Testing Machine*	*Range of Values*
Static tension	Yield strength (0.2% offset*)	Fig. 22(a)	Amsler 100,000 lb.	63,100 to 83,200 lb. per sq. in.
" "	Tensile strength	"	" "	128,900 to 146,400 lb. per sq. in.
" "	Elongation in 2 in.	"	" "	7.0 to 9.8 percent
" "	Reduction of Area	"	" "	12.2 to 18.2 percent
Brinell hardness	Hardness number	Small block	Alpha Brinell	255 to 290
Izod impact	Energy for fracture	Fig. 22(e)	Olsen-Izod (10 ft. lb.)	1.55 to 1.64
Fatigue, reversed flexure	Endurance limit	Fig. 22(b)	R. R. Moore Type	48,000 to 55,000 lb. per sq. in.
Repeated tension, zero to maximum	Endurance limit	0.1 in. diam.	Moore-Krouse	62,000 to 70,000 " " " "
Repeated compression, zero to maximum	Endurance limit	0.1 in. diam.	Moore-Krouse	100,000 lb. per sq. in. **
Reversed shear (torsion)	Endurance limit	0.3 in. diam.	Illinois torsion fatigue machine	30,500 " " " " **
Repeated shear zero to maximum	Endurance limit	0.3 in. diam.	Illinois torsion fatigue machine	50,000 to 65,000 lb. per sq. in.

* For a description of the method of determination of yield strength by the "offset" method, see the 1939 Standards of the American Society for Testing Materials, Part I, Metals, pages 760–763, inclusive.

** Specimens from one rail only.

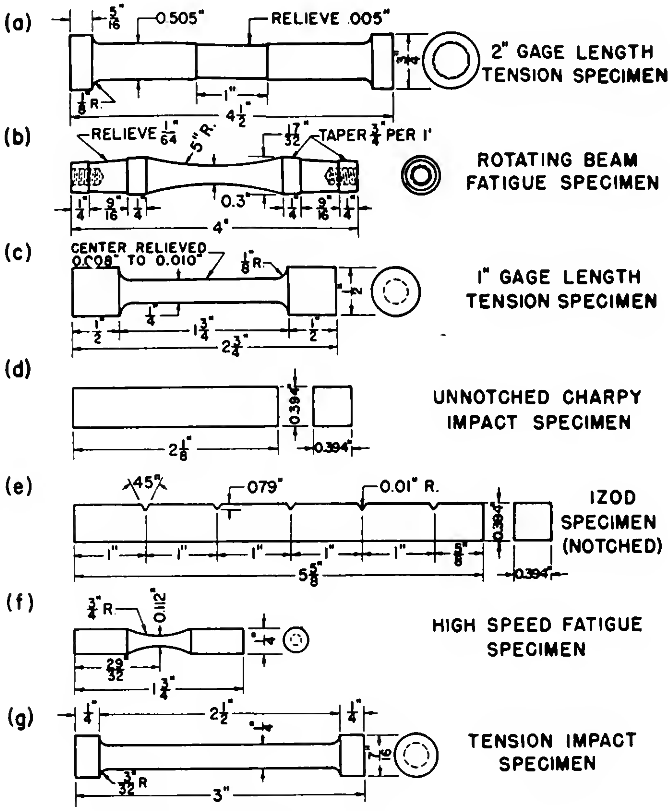


Fig. 22.—Specimens for Mechanical Tests of Strength and Ductility.

Shatter cracks, if present, are found from ⅜ to ¾ in. below the tread of a rail. Hence the difference between the physical properties of specimens from the center of heads and those near the surface of heads of rails, in one case having shatter cracks and in the other case being free from shatter cracks, should give information on the effect of shatter cracks on the strength and ductility of the metal. Figure 23 gives graphically a summary of the average results of mechanical tests of many tests on specimens from a large number of rails. It is evident that there is a distinct difference in tensile strength, reduction of area, and elongation between the steel in the center of the heads of rails in which shatter cracks were found by the etch tests, and the steel near the surface of such rails—a much larger difference than was found in rails free from cracks. The results are presented on a percentage basis so as to combine results of tests from various strength rails in the summary.

(b) *Static Tension Tests of End-Hardened Rail Steel.*—In connection with the general program of testing of end-hardened rails, mechanical tests of specimens from rails end-hardened by 11 different processes were made. Included in the mechanical test schedule were static tension tests of specimens cut from the end-hardened and unhardened rails hardened by these 11 processes. Descriptions of the 11 end-hardening processes are given in Table 13.

TABLE 13

SUMMARY OF END-HARDENING PROCESSES USED IN TESTS OF RAIL STEEL

Process No.	*Mill or Track*	*Method of Heating*	*Method of Quenching*
1	Mill	Reheated by electric induction	Warm water
2	Mill	Reheated by gas burner	Compressed air
3	Mill	Quenched from rolling heat	Water spray
4	Mill	Reheated by gas burner	Water spray
5	Mill	Reheated by natural gas burner	Compressed air and steam
6	Mill		
7	Track	Track machine-Oxyacetylene	Conduction of heat to cold metal
8	----*	---------------------------	---------------------
9	Track	Free-held oxyacetylene torch	Water sprinkler
10	Track	Automatic oxyacetylene machine	700 cc. of water
11	Track	Oxy-propane torch-------------	One pint of water
12	Mill or Track	Oxyacetylene torch------------	Compressed air

* Process 8 used with built-up ends of rails. No tests of material reported.

Figure 22 (c) shows the type of static tension test specimen cut from the end-hardened rails hardened by the 6 mill-hardening processes. The relatively shallow depth and short length of end-hardened material produced in the rail samples by the 5 track end-hardening processes precluded obtaining tension specimens for those rails.

Figure 24 is a summary of the static tension test results on the mill end-hardened rails. Each test value compared for any one process is the average of three or more test results on specimens. While tension test results were obtained from other zones of the end-hardened rails only the data obtained from the specimens cut from the portions of the rail heads adjacent to the tread of the rail were used for comparison, as these results were judged to be typical and no unusual data were obtained from the other zones investigated.

Examination of Fig. 24 shows that all of the mill end-hardened rails show increased tensile strength, elongation, and reduction of area values for the end-hardened material as compared to the unhardened steel. In view of the increased hardness of the end-hardened steel the increased ductility as shown by the elongation and reduction of area data is somewhat surprising. However, this improvement of ductility can be accounted for by the improved microstructure of the hardened steel brought about by the heat treatment imposed by the processes of end-hardening. Examination of end-hardened microstructures shown in AREA Proceedings, Vol. 37 (1936) page 645, and Vol. 39 (1938) page 816, offers substantiating evidence.

39. Energy Strength (Resistance to Impact)

(a) *Tests of Specimens from Uncracked Rails.*—Izod impact tests of notched specimens were made on specimens cut from the heads of certain test rails in the first lot of rails (hot-bed cooled) received. The range of values for energy of fracture is given in Table 12. The rails from which these specimens were cut were free from shatter cracks, as shown by etch tests.

(b) *Transverse Fissure Studies.*—When the program of mechanical testing was started in conjunction with the early work on transverse fissured rails many impact tests

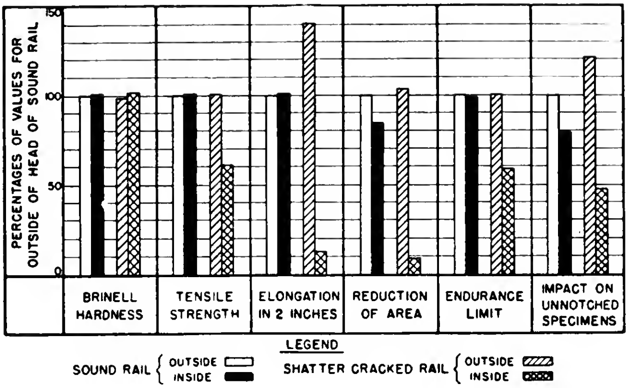


Fig. 23.—Results of Mechanical Tests of Specimens of Rail Steel.

were made on specimens cut from shatter-cracked and sound rails. The first impact tests which were made were carried out on the Charpy 223-ft. lb. capacity machine in the Talbot laboratory, using standard bending specimens with notch imposed. The resistance to fracture as measured by absorption of energy during fracture gave values, even for sound rail (1 to 3-ft. lb.), that were so small that the test was unsatisfactory as a method of differentiating between the test values obtained for shatter-cracked rails and sound rails. Consequently the unnotched specimen shown in Fig. 22 (d) was used as it provided a specimen which absorbed for sound rail steel approximately 100-ft. lb. of energy during fracture. The unnotched specimens besides providing a specimen better suited for differentiating between shatter-cracked and sound steel was also considered as giving a better measure of the toughness of the steel rather than a test of a notched specimen which shows the effect of the particular notch imposed on the specimen.

Figure 23, sixth column, gives a graphical summary of a large number of Charpy impact bending tests made on unnotched specimens machined from many rails. The specimens were cut from these rails so that impact energy strength values were obtained for the metal in the rail heads both at the outside or tread surface of the rails and of the metal within the head at the zone where shatter cracks form. The rails tested included shatter-cracked and sound rails of various weights and sections; these rails also included rails hot-bed and control cooled. Examination of the sixth column of Fig. 23 shows that while for both sound and shatter-cracked rails the metal from the inside of the head showed lower impact values this difference in the shatter-cracked rails was much more pronounced.

(c) *End-Hardened Rails.*—Included in the general program of testing of end-hardened rails, impact energy tests were made on specimens cut from the various rail samples hardened by the processes described. The impact tests served as a measure of the energy strength of these rails and were made as a part of the program of mechanical testing.

Two types of impact tests were included in the program of testing. Charpy impact bending tests were made from the hardened and unhardened material of the end-hardened rail samples; the unnotched type of specimen shown in Fig. 22 (d) was used. Besides the Charpy tests, notched Izod bending tests were made. Figure 22 (e) gives the details

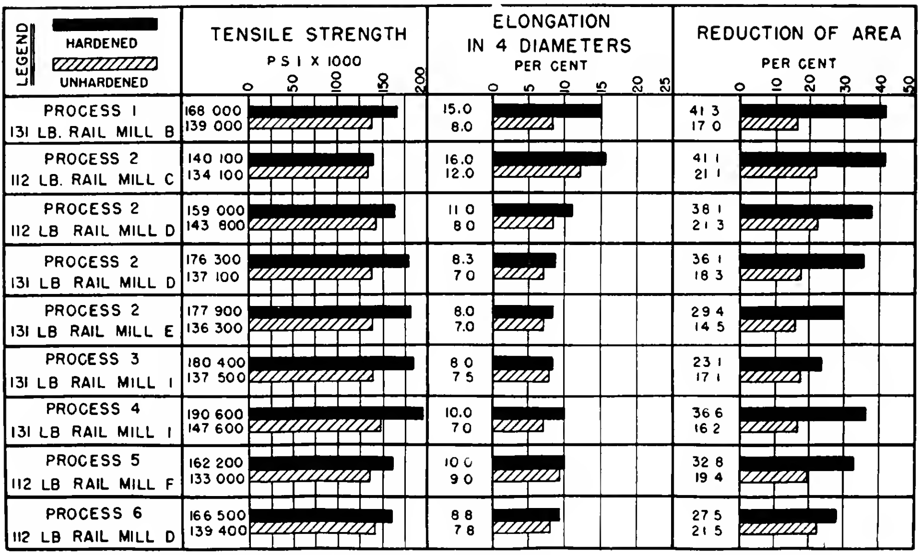


Fig. 24.—Results of Static Tension Tests of Specimens from End-Hardened Rails.

of the specimen. The Charpy and the Izod impact tests were made on the rail samples from the rails end-hardened by the 6 mill-hardening processes. As previously explained the amount of end-hardened material produced by the 5 track-hardening processes was only sufficient to furnish material for the unnotched Charpy tests. The Charpy specimens were tested on a 223-ft. lb. capacity Charpy impact machine and the Izod specimens on an Olsen–Izod machine of 10-ft. lb. capacity.

Figure 25 gives a graphical summary of the results of the Charpy impact tests on the mill end-hardened and track end-hardened rails and on the Izod tests on the mill end-hardened rails. The effect of all of the end-hardening processes was to improve the energy strength or toughness of the end-hardened material as compared to the unhardened rail steel. The increase of toughness with increase of hardness of the end-hardened steel was, as in the case of the increased ductility for the end-hardened material in the tension tests, an unexpected result. This increase of toughness with hardness can, however, be explained by the improvement of microstructure brought about by the heat treatment imposed on the steel by the end-hardening processes.

40. Fatigue Strength

(a) *Tests of Polished Specimens.*—Fatigue tests of polished specimens cut from the heads of certain test rails in the first lot of test rails received were made. These rails were free from shatter cracks, as shown by the etch test. The ranges of values for endurance limits under various ranges of stress are given in Table 12.

The metal below the surface of the head of a rail is presumably free from surface defects and, unless the rail is shatter cracked, from internal notch effects. Fatigue tests of polished specimens in which surface effects and notch effects are minimized would seem to give significant results for the metal inside the head of such a rail.

(b) *Effect of Shatter Cracks.*—At the inception of the investigation of transverse fissures in railroad rails and the accompanying problem of the effect of shatter cracks

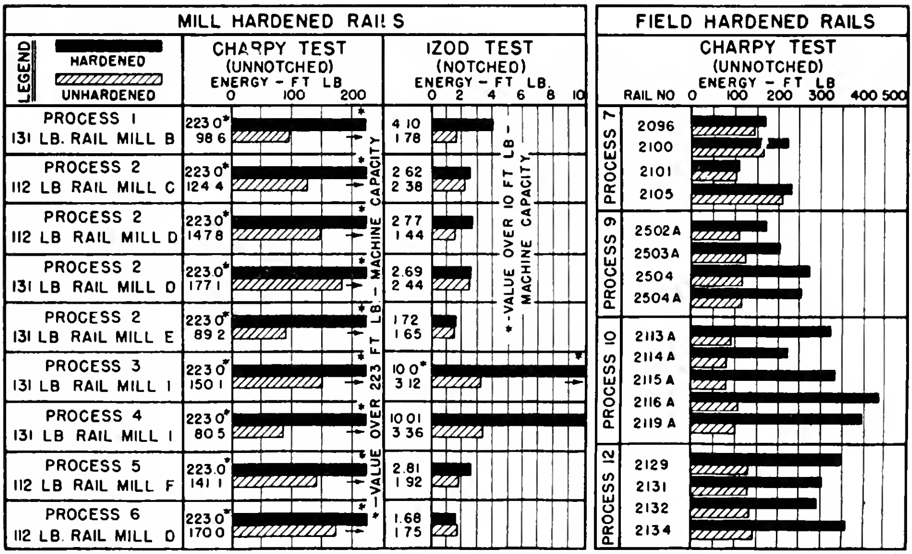


Fig. 25.—Results of "Energy Strength" (Impact) Tests of Specimens from End-Hardened Rails.

in rails, many fatigue tests were carried out on specimens cut from shatter-cracked and sound rails. The specimens were so machined as to select material from the outside metal of a rail head and from the inside metal of the head where shatter cracks are found. By testing specimens from these locations in both sound and shatter-cracked rails a measure of the effect of shatter cracks on the fatigue strength of rail steel was determined.

Figure 22 (b) shows the type of fatigue specimen used in the earlier tests. These specimens were tested in a rotating-beam type of testing machine which subjected the specimens to cycles of completely reversed bending stress. Figure 23, fifth column, gives a graphical summary of the effect of shatter cracks on the fatigue strength determined for the steel from the heads of shatter-cracked and sound rails. The rails from which the specimens were machined included rails of several different sections and weight, hot-bed cooled, box cooled, normalized, and from some alloy-steel rails. Examination of these summarized results shows that the fatigue strength of the metal from the inside of the heads of shatter-cracked rails was less than 60 percent of that of the outside metal of the same rails. As the fatigue strength of the metal of the inside of head (cracked area) was the only material appreciably weaker than the outside metal of the sound rail, the shatter cracks can be assumed to be the cause of the lessening of the fatigue strength of the material in the steel from that location.

41. **"Damage Line" for Rail Steel.**—The damaging effect of occasional high stresses on the steel in rails, caused by service loads of abnormal magnitude, was studied in connection with the transverse fissure problems. The development of high-speed fatigue machines in the Talbot laboratory and the then new "damage line" method proposed by Mr. H. J. French[11] of the International Nickel Company for determining the

[11] French, H. J.—Fatigue and Hardening of Steel, Trans. Am. Soc. Steel Treating, Vol. 21, p. 899 (1933).

effect of occasional high stresses in metals furnished a means of studying the effect of occasional overloads on rail steel. Considerable work was done on the determination of damage lines for rail steel in the shatter cracked and sound condition.

The damage-line method as used for determining the effect of occasional high stresses in rail steel can be best described by following through a typical determination of such a diagram. Figure 26 shows a graph of a typical damage-line test for rail steel. First a series of fatigue tests is run, an S–N (stress cycle) diagram drawn, and from that diagram the endurance limit of the original, unstressed metal determined. Then a number of

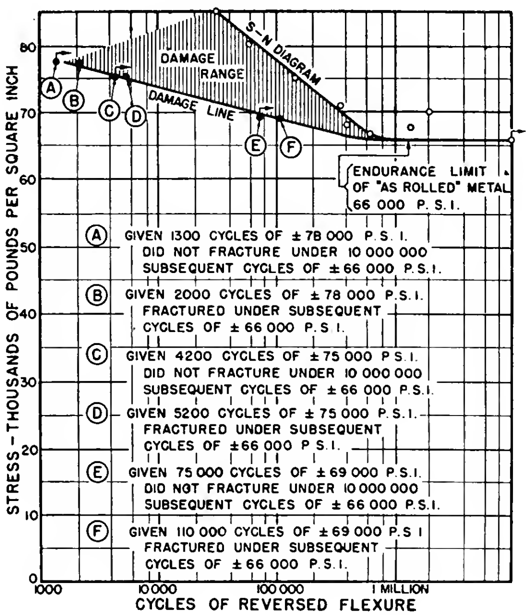


Fig. 26.—"Damage Line" Test for Specimens of Rail Steel.
Rail 1025. Hot-bed cooled. Etch test showed shatter cracks. Tested at air temperature, approximately 70 deg. F.

specimens are subjected to definite stresses above this endurance limit and are run for a certain number of cycles of stress. In Fig. 26 detailed results are shown for three pairs of specimens subjected to cycles of reversed flexure at stresses above the endurance limit of the original unstressed material. After undergoing this overstress the specimens are then subjected to cycles of stress equal to the endurance limit of the original metal. Points on the "probable damage line" are located between the plotted point of that specimen of a pair which fails under this stressing at the endurance limit of the original metal and the plotted point for the specimen which does not fail.

It has been proposed by H. W. Russell of the Battelle Memorial Institute[12] that, as an arbitrary measure of resistance to occasional overstress, there may be used the ratio $S_D : S_F$, in which S_D is the "damage line stress" for 25,000 cycles and S_F is the endurance

[12] Russell, H. W.—Damage and Overstress in the Fatigue of Ferrous Metals, ASTM Proceedings, Vol. 36, Part II, p. 118 (1936).

RAIL	THERMAL TREATMENT	TEST TEMP °F	OTHER SPECIAL FEATURES
651	HOT BED	70	SHATTER CRACKS
653	HOT BED	70	UNCRACKED
453	HOT BED	70	SHATTER CRACKS
668	HOT BED	70	UNCRACKED
1121	HOT BED	70 10 -20 -40	3% CHROMIUM UNCRACKED
1013	HOT BED	70 10 -20 -40	UNCRACKED
1014	CONTROL - COOLED	70 10 -20 -40	UNCRACKED
1025	HOT BED	70 10 -20 -40	MANY SHATTER CRACKS
1026	NORMALIZED	70 10 -20 -40	VERY FEW SHATTER CRACKS
NOTCHED SPECIMENS			
1013	HOT BED	70	UNCRACKED
1014	CONTROL COOL'D	10	UNCRACKED
1025	HOT BED	-20	SHATTER CRACKS
1026	NORMALIZED	-40	FEW CRACKS
OTHER STEELS			
SAE 1020	AS ROLLED	70 10 -20 -40	
SAE 3135	HEAT TREATED	70	

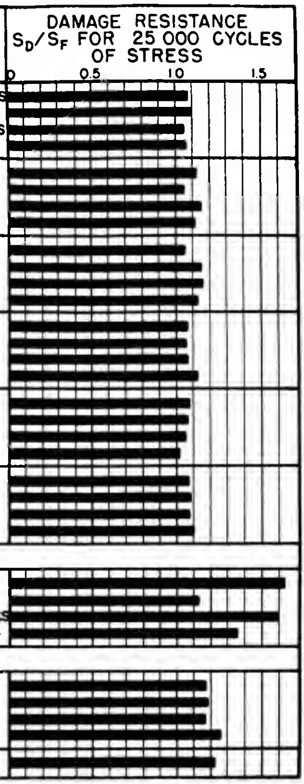


Fig. 27.—Results of "Damage Line" Tests of Specimens of Rail Steel.

limit of the original unstressed metal. In Fig. 26 Russell's ratio would be 73,000 : 66,000 = 1.11.

In Fig. 27 values of Russell's "damage resistance ratio" have been plotted from test results for specimens from various rails. Although values for these ratios for low temperature tests are shown, the items designated as run at +70 deg. F. are the ones under discussion. It will be noted that no outstanding variation of this ratio was found in rail steel (1) between specimens from shatter-cracked and from uncracked rails, (2) between specimens from hot-bed rails and from control-cooled or normalized rails, (3) between specimens of ordinary rail steel and of 3 percent chromium steel. Notched specimens showed high values of this ratio, although they developed an endurance limit only about 50 percent of that developed by unnotched specimens.

42. **Fatigue Strength of End-Hardened Rail Steel.**—In connection with the program of mechanical testing on end-hardened rails the variation of fatigue strength of the rails was "explored" by determining the endurance limits for the steel from specimens machined from the hardened steel, the unhardened steel, and from specimens obtained from the transition zone between the hardened and unhardened material. The small type of fatigue specimen shown in Fig. 22 (f), tested in a fatigue machine running at approximately 8,000 r.p.m., was used. Figure 28 gives the results of the fatigue tests

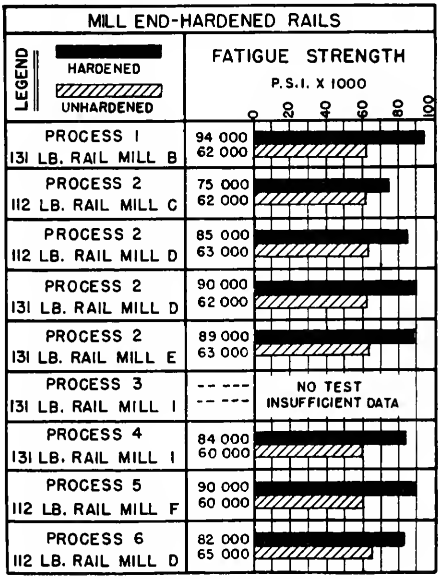


Fig. 28.—Results of Fatigue Tests of Hardened Metal from Rails End-Hardened at the Mill.

of specimens from the hardened and unhardened material from the rails end hardened by the six mill end-hardening processes. The results of the transition zone specimens are not given as no unusual results were found. Figure 28 shows that in all cases the end-hardened material gave higher values of fatigue strength than did the unhardened rail steel. These results are in line with the findings for tensile strength test results and impact test results.

43. **Hardness and its Effect on Tensile Strength, Ductility, Toughness, and Fatigue Strength of Rail Steel.**—The application of the various end-hardening processes to railroad rails to produce a hardened condition in the rail ends, thereby better to resist battering action at rail joints under traffic in track, consists essentially of the practical application of the principles of heat treatment to rail steel. Any study then, which has for its purpose the determination of the most desirable mechanical properties to be attained in the hardened material of end-hardened rails so as to best resist batter, resolves itself into a study of the effect of heat treatment on the mechanical properties of rail steel.

Consequently to provide such studies of the effect of hardness on the tensile strength, ductility, toughness, and fatigue strength of rail steel a laboratory method of study was carried out as follows: Specimens were cut from unhardened test rails, heat treated to produce any desired range of hardness, and then tested to give the desired information regarding the various properties. Tension specimens, Fig. 22 (c) were prepared and tested to study the variation of tensile strength, percentage elongation, and percentage reduction of area; also, variation of toughness[13] (Tension-Energy) by measuring the areas of

[13] The term toughness is used to denote energy required to fracture a metal.

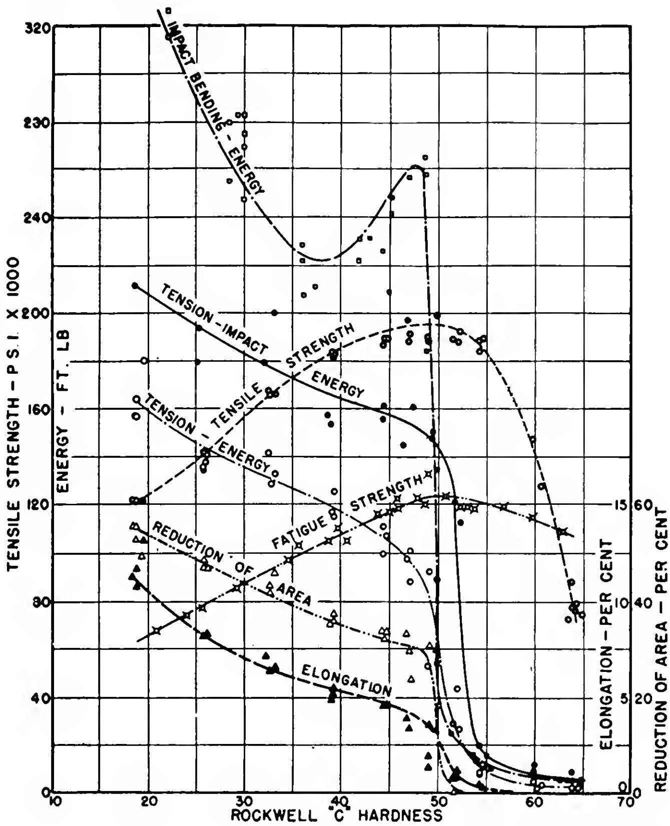


Fig. 29.—Variation of Tensile Strength, Elongation, Reduction of Area, Energy for Fracture and Fatigue Strength with Varying Rockwell "C" Hardness. Rail 1100, 131-lb.

the stress-strain diagrams was obtained. Impact bending tests of unnotched bars (Fig. 22 (d)) and impact tension tests (Fig. 22 (g)) gave data to determine the variation of toughness with hardness changes. Fatigue tests of unnotched bars (Fig. 22(f)) were also made and the data gave variation of fatigue strength with hardness. Adequate Rockwell "C" hardness readings were obtained on all specimens prior to testing.

After the various specimens were rough machined from the test rails, allowance having been made for final finish, they were heat treated and then ground to finished dimensions. The general procedure of heat treatment was to quench all specimens to obtain maximum hardness, followed by suitable draw to obtain the desired hardness.

Figure 29 presents the results of these tests. Examination of these results will show that in the hardness range, Rockwell "C" 48 to "C" 52, a rather distinct change occurs in all of the curves of the various properties shown. The tensile strength and fatigue strength curves reach their peak in this hardness range while all the curves of toughness (energy strength) and ductility (reduction of area and elongation) drop off abruptly. These results would indicate that the usable hardness of rail steel is exceeded when a hardness of approximately Rockwell "C" 50 (Brinell 465) is exceeded. It should also be noted that as the hardness decreases the toughness and ductility increase.

The above results would seem to furnish a rather direct guide for end-hardening practice in that the hardened material in end-hardened rails is a rather carefully heat-treated rail steel. It would therefore be reasonable to assume that the toughness in end-hardened material would be subject to the same limitations. In other words it is indicated that the upper limit of Rockwell "C" hardness to be attained in end-hardening practice should not exceed a value of "C" 45 (or Brinell 415). Also, as heat-treated rail steel develops good toughness for hardnesses below "C" 45 it is evident that the lower limit of end-hardening practice would not be set by toughness considerations. The rolling-load tests (and service tests) indicate that hardnesses in end-hardened rails below "C" 35 (Brinell 320) are not effective in preventing wear and batter. Briefly then, the limits of hardness seem to be set on the high end by toughness considerations and on the lower end by batter and wear considerations. The laboratory tests then indicated a satisfactory hardness range between "C" 35 and "C" 45, (approximately Brinell 320 to 415).

44. **Effect of Temperature.**—A considerable study of the effect of temperature on the properties of rail steel was made as it is a matter of common railroad experience, especially in the northern United States and Canada, that rail failures are more frequent in cold weather than in warm weather. Two general types of explanation for this have been offered: (1) Changed track conditions due to low temperatures and to freezing and thawing, and (2) changes in the physical properties of rail steel at low temperatures. It was to provide data to investigate the second of the two reasons given above that the various studies of the effect of low temperature on rail steel were carried out.

The studies which were made fall into three divisions: (1) tests of specimens cut from rail steel were tested at low temperatures and at room temperatures to determine the change of tensile strength, fatigue strength, ductility and toughness of rail steel, (2) tests at low temperatures, using the "damage line" method, to study the weakening effect of occasional periods of overload, and (3) tests to determine the effect of hardness on the toughness of rail steel with variation of temperature of testing. The first two series of tests were made possible through the very generous aid of the U. S. Air Service in allowing the use of a cold room at Wright Field, Dayton, Ohio. The third series of tests was made in the Talbot laboratory at the University.

(a) *Physical Properties of Rail Steel at Low Temperatures.*—Fatigue tests, tensile tests, Brinell tests and impact tests of numerous specimens from three rails were run in the cold room with minimum temperatures of —40 deg. F. for all tests and of —53 deg. F. for impact and tensile tests. Tests were run both on standard specimens and on notched specimens. Figure 30 shows a summary of the results of the tests, from which it will be noted that the tensile strength of unnotched specimens increased as temperature decreased to about zero Fahrenheit, and then decreased with further decrease of temperature for steel from two rails and increase in strength for the steel from the third rail. Notched tensile specimens showed decrease of strength with decrease of temperature. Fatigue strength of unnotched specimens increased with decrease of temperature, while fatigue strength of notched specimens changed but little with decrease of temperature. At the lower temperatures the rail steel tested seemed more sensitive to notch effect than at higher temperatures.

Also shown in Fig. 30 are the results for ductility and impact or energy strength. Elongation, reduction of area, Izod value for notched specimens and (most marked effect) Izod value for unnotched specimens, all show marked decrease for lowering of temperature. A high impact test value is a point in favor of a steel.

Of the three rails from which specimens were taken, Rail 1017 was a hot-bed cooled rail in which etch tests had shown shatter cracks, Rail 1018 was a companion rail slow-

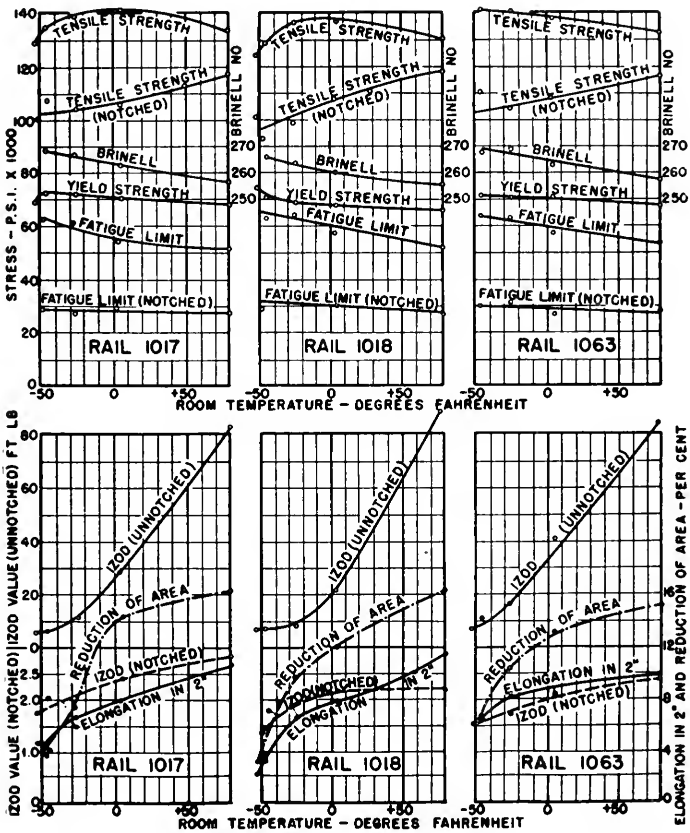


Fig. 30.—Strength and Ductility Properties of Rail Steel at Low Temperatures.

cooled, in which no shatter cracks had been found, and Rail 1063 was a hot-bed cooled rail in which etch tests had shown no shatter cracks. No outstanding differences appear between the results of strength and ductility tests for these three rails.

Summed up, the evidence of these results indicates that the general tendency is for strength properties to increase as temperature decreases to —40 deg. F. but the brittleness of the steel also increases.

(b) *"Damage Line" Tests at Low Temperatures.*—The results of the first series of tests to determine the properties of rail steel at low temperatures suggested the desirability of running fatigue tests at low temperatures using the "damage line" method to study the effect of occasional high stresses. Tests were run on specimens from several rails using this method at various low temperatures ranging from +70 deg. F. to minimum of —40 deg. F. A description of the "damage line" method is given in this report, pages 732–734, along with that of Russell's ratio which was used to evaluate the damage diagrams obtained during the low temperature testing.

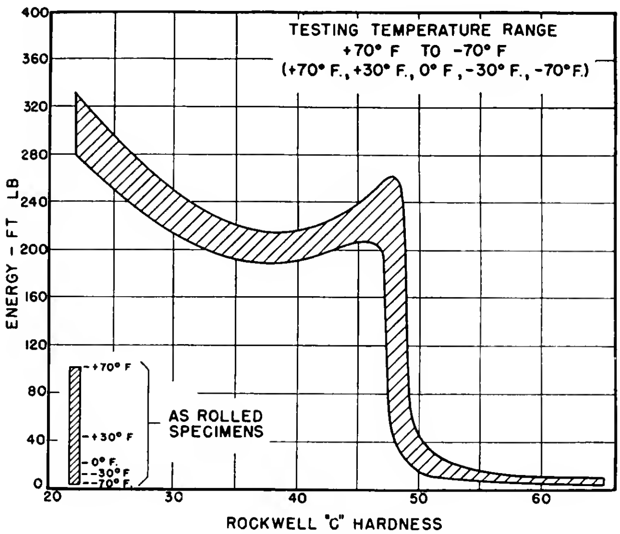


Fig. 31.—Envelope Diagram Showing the Effect of Temperature at Time of Testing on the Toughness of Rail Steel for Different Hardnesses Produced by Heat Treating.
Charpy tests on unnotched specimens.

In Figure 27 values of Russell's "damage resistance" ratio have been plotted from test results for specimens from various rails. It will be noted that no outstanding variation of this ratio was found in rail steel: (1) Between specimens from shatter-cracked and from uncracked rails, (2) between specimens from hot-bed cooled rails and from control-cooled or normalized rails, (3) between specimens of ordinary rail steel and of 3.0 percent chromium steel, and (4) between specimens tested at temperatures ranging from +70 deg. F. to —40 deg. F. Notched specimens showed a high value of this ratio, although they developed an endurance limit only about 50 percent of that developed by unnotched specimens.

(c) *Tests at Low Temperatures to Determine the Effect of Temperature on the Toughness-Hardness Relationship for Rail Steel.*—In Section 39, pages 730, 731 of this report are described tests on unnotched Charpy specimens heat treated to various hardnesses and tested to show the variation of toughness (energy strength) of rail steel with variation of Rockwell hardness. To determine the variation of this toughness-hardness relationship of rail steel with change of temperature, this same method of considering the energy developed in impact-bending tests of unnotched specimens was used as the criterion of toughness. The effect of temperature of testing was obtained by determining the toughness-hardness relationships for five testing temperatures, namely +70, +20, zero, —30, and —70 deg. F. Briefly the testing procedure consisted of bringing the specimens to the desired temperature in a bath of acetone cooled with dry ice (solid CO_2), quickly placing them in the Charpy-impact testing machine and testing them before appreciable temperature fluctuation was possible.

Figure 31 shows the effect of temperature on the toughness of heat-treated rail steel as determined by the toughness-hardness relationships obtained for five testing temperatures. The envelope, which gives the variation of toughness, was constructed by superimposing the toughness-hardness relationship curves for the five temperatures and then

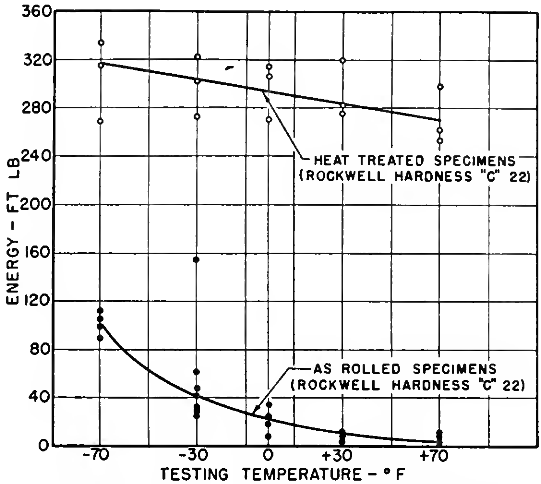


Fig. 32.—Variation of Toughness of Heat Treated and "As Rolled" Rail Steel for a Range of Temperatures from +70 to —70 deg. F.

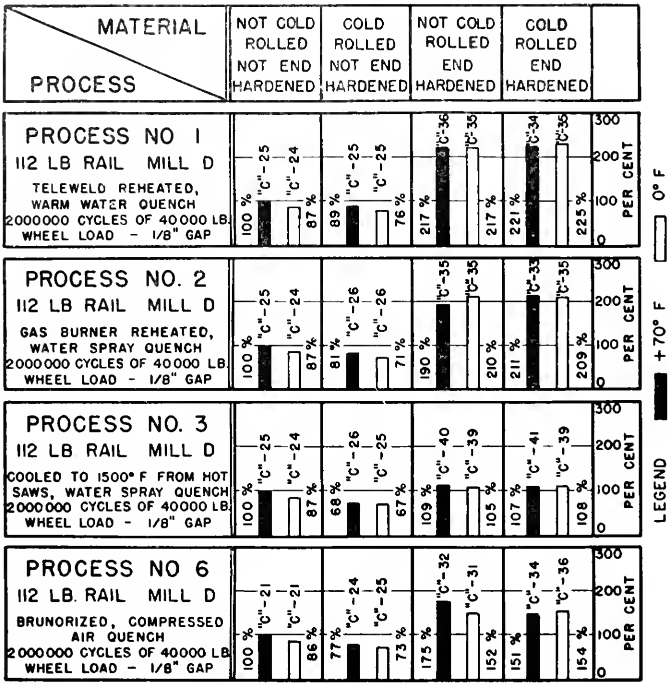
Charpy tests of unnotched bars.

enclosing all five curves. These results would indicate that the toughness-hardness relationship is not greatly changed over the range of temperature between +70 and —70 deg. F. Also, for this temperature range the envelope indicates that to have good toughness heat-treated rail steel should not exceed Rockwell "C" 47 in hardness.

In the lower left corner of Fig. 31 are shown the impact-bending (toughness) results obtained for the five testing temperatures on specimens of the as-rolled rail. Figure 32 compares these results with those obtained for the heat-treated specimens of similar hardness (Rockwell "C" 22). Examination of the curves shows that at all testing temperatures the heat-treated steel has much greater toughness than the as-rolled rail steel. It should also be noted that as the temperature at the time of testing is progressively lowered the as-rolled material loses its toughness much faster than does the heat-treated steel. These results indicate then, that the heat-treatment of the rail steel tested produced two beneficial results, namely, the toughness was much improved over that of the as-rolled steel and the effect of temperature was much less for the heat-treated material over the range of temperatures considered.

45. **Effect of Cold Working.**—Rail failures due to spalling out of metal near rail ends are occasionally encountered in service. The cause of such failures has, in many cases, been charged to the enbrittlement of the metal at the tread of the rail by cold working due to traffic. It is, also, the opinion of many that such failures occur more often during cold weather. If such failures were encountered previous to the comparatively recent widespread use of end-hardened rails, will heat-treated hardened steel at the rail ends affect the frequency of occurrence of spalling (i.e. especially of the hardened steel) after these rails have been in service for some time? It was to provide data to answer the foregoing question that the tests to find the effect of cold working on rail steel were made.

The rails from which the test specimens were obtained were from one ingot of one heat of steel. The test sections of the rail designated to be end hardened were hardened



NOTES

PLOTTED VALUES BASED ON PER CENT OF IMPACT VALUES OBTAINED FOR UNHARDENED RAIL NOT ROLLED

ALL PLOTTED PERCENTAGES WERE CALCULATED FROM AVERAGE TEST RESULTS OBTAINED FROM FOUR OR MORE SPECIMENS

Fig. 33.—Effect of Cold Rolling (in Rolling-Load Machine) and of End Hardening on the Toughness of Rail Steel as Shown by Charpy Impact Tests of Unnotched Bars.

with care by four mill end-hardening processes which are briefly described in Fig. 33. The test program provided for machining and testing of unnotched Charpy specimens adjacent to the tread of the rail samples and so cut as to include the desired test material for which the toughness determinations were to be made. The rail samples were treated so as to provide specimens to give data on the toughness of rail steel according to the outlined programs listed below.

Item	*Source of Test Specimens*	*Testing Temperatures* *deg. F.*	*deg. F.*
1	Rail not cold-rolled—not end-hardened	+70	0
2	Rail cold-rolled—not end-hardened	+70	0
3	End-hardened rail—not cold-rolled	+70	0
4	End-hardened rail—cold-rolled	+70	0

Each rail specimen was placed in a rolling-load testing machine and subjected to 2,000,000 cycles of a 40,000-lb. wheel load. Specimens were provided for testing both at +70 deg. F. and 0 deg. F. The testing procedure for the 0 deg. F. tests was as described in Section 44 (c), page 740 of this report.

Figure 33 gives a graphical summary of the results of the tests. Examination of the summary reveals that the toughness of the end-hardened steel was, as expected, greater than in the unhardened steel. The effect of testing at low temperatures was a slight reduction of toughness for the as-rolled steel as compared to the reduction for the hardened steel, but the effect was small for all of the conditions of testing listed above. The rolling reduced the toughness of the as-rolled steel but did not cause this reduction in the end-hardened material. Processes 1 and 2 were most effective in improving the toughness of the end-hardened material as compared to the as-rolled steel. From the above results it is indicated that the end-hardened material has better toughness properties to resist rolling or cold working and low temperatures than does the as-rolled material; this result was obtained for all of the four mill end-hardening processes.

VIII Non-Destructive Tests For Shatter Cracks and Fissures

By J. L. Bisesi

46. **Usefulness of Non-Destructive Tests.**—It is known that in the past rails have been manufactured from steel which developed shatter cracks or was subject to conditions which would produce them. It has been definitely established that most rails which fail because of the development of transverse fissures contain shatter cracks and it has been shown that the presence of shatter cracks is one of the principal causes (probably the principal cause) of transverse fissure failures. A large number of these rails are still in service and, while it is true that a majority of these rails will not develop fissures, many will fail before they are worn out. It is evident that a non-destructive method of detecting these potential failures in new rails would be very desirable, although the use of control-cooled rails may be expected to lessen its importance.

Detector cars have been developed for the purpose of detecting fissures and other defects in rails after they have reached a considerable size but no method of testing has yet been devised to detect the presence of shatter cracks or other small defects in new rails or in rails in service.

47. **Detector Cars for Fissures.**—Detector cars have been operated on the American railroads since 1928. The type of car which is most commonly used is the Sperry detector car which was designed to travel over the rails at a speed of five to seven miles per hour and to detect fissures and other potential failures by means of its electrical and magnetic equipment.

In connection with the use of any detector car the following condition and limitation may be noted: The sensitivity of the detector car, in its present state and in spite of the constant improvements made in its equipment, has not been brought to the point of detecting all of the small fissures and other defects which have been started in the rail.

The only test available at the present time for the detection of shatter cracks is the etch test in which horizonal slices are cut from the head of the rail and etched in acid. This test, if the slices are cut thin enough, will show up shatter cracks if they exist in the rail. Since this is a destructive test and is time consuming, only a few samples can be taken from each heat and it becomes a test of representative samples.

It would therefore be advantageous to have a non-destructive test which could be made on every rail rolled. It should be noted at this point that a search for a non-destructive test for shatter cracks is purely a research problem, and is expensive and slow and that there is a large element of chance in such a search. This chapter describes briefly various methods for detecting shatter cracks. None of these methods has proved reliable, but an account of those attempts may be of use to future investigators. In view of the element of chance and the cost of the equipment involved in making the various experiments a good deal of the needed equipment used in making the tests has been borrowed from other departments of the University.

48. **Study of Mechanical Vibration of Rails.**—One of the earliest studies and one of the studies most persistently followed in the search for a non-destructive method of detecting shatter cracks in rails has been the study of the mechanical vibrations of rails. This study has consistently been the most promising of those tried. It is known that vibrations of a body are influenced by the density of the body and it was reasoned that the density of a rail should be affected by the presence of shatter cracks.

This study has been given impetus by various investigators from time to time, notably by the work of Föppl in Germany and by one of his pupils, von Hydekampf, employed by the Baldwin-Southwark Company. In some tests made by the latter, specimens prepared from the metal in the heads of shatter-cracked rails, fissured rails and rails free from either were subjected to a torsional stress and then the stress was released. From a study of the resulting vibrations it was determined that the damping factor of the defective steel was greater than that of the sound steel and that the damping factor had some relation to the amount of structural damage in the specimen. This work, as explained above, was dependent on prepared specimens, and since this investigation is interested in non-destructive methods of testing rails, non-destructive damping tests of full section rail specimens were tried.

In the earliest experiments on the vibration of rails a device was designed to strike the rail on the side of the head, two ear phones and later other electro-mechanical devices were fastened to the other side of the rail head so that the distance from the striking device to each of the pickup devices was equal. It was thought that the presence of shatter cracks in the rail, possibly in the path between the striking device and one of the receivers would so affect the travel of the vibrations in that path that a comparison of the outputs of the receivers would indicate the difference.

These experiments led to a series of studies utilizing the longitudinal vibrations of the rail in order to obtain the accumulative effect of the shatter cracks in the rail. In these studies various means of inducing the rail to vibrate were used. These methods included mechanical impact devices and devices so designed that they would constitute a constant source of vibration of a predetermined fixed amplitude and frequency. The frequency most used was the natural fundamental of the rail specimen, although harmonics and other frequencies were studied. These devices included hammers which struck the end of the rails to give an impact, magneto-striction devices, and electromagnetic devices, the latter two giving constant impetus to the rail.

Studies of the vibrations included studies of the first wave of sound through the rail, the frequency of the natural fundamental frequency and other frequencies, the damping characteristics of the rails and the power necessary to vibrate the rails. To make these studies, methods of recording the vibrations and wave shapes on permanent records were devised. The detection devices included phonograph pickups, Piezo-electric crystals and other electro-mechanical transducers.[14] In some cases the output of these devices was passed into trick radio circuits which were used for obtaining the values for study, and in other cases permanent records were made of the output utilizing magnetic oscillographs.

49. **Mechanical Hysteresis in Cracked and in Uncracked Rails.**—Under some conditions a specimen when subjected to a stress and then to removal of the stress does not entirely recover its shape. This indicates that energy has been lost due to inelastic action during the loading-release cycle of stress. This loss of energy is known as "mechanical hysteresis". It was thought that the presence of shatter cracks in a rail might cause the rail to show greater mechanical hysteresis under such a cycle than would an uncracked rail.

[14] This term has been adopted by the American Radio Relay League to denote any apparatus for transforming mechanical vibrations to electrical impulses, or vice versa.

Rails with shatter cracks and rails which etch tests had shown to be free from shatter cracks were mounted in a testing machine and flexural load was applied and released. Delicate measurements of deflection were made both under increasing load and under decreasing load and load-deflection diagrams were drawn. These diagrams showed differences between deflection under increasing load and under decreasing load and the area between the diagram for increasing load and that for decreasing load ("hysteresis loop") measured the energy lost during a cycle of loading and unloading.

No systematic difference in the areas of the hysteresis loop for shatter-cracked rails and of the hysteresis loop for uncracked rails could be detected.

50. **Thermal Tests.**—Thermal tests for the detection of shatter cracks in a rail were based on the theory that when a heavy current was passed through a rail the shatter cracks would offer a resistance to the passage of the current and thereby cause heat zones in the rail at the location of the shatter crack. Two methods of detecting these heat zones were tried, namely, a thermopile and a heat-sensitive paint. These tests were not successful, mainly due to the fact that since laboratory etch tests have shown that when shatter cracks are found in a rail they are usually found throughout the entire length and not necessarily in definite zones in the length of the rail. Moreover, there was no sign of a sharp enough change of temperature at a crack to produce any marked difference of temperature at the surface of the rail.

51. **Acoustic Tests.**—The acoustic tests devised for the non-destructive testing of rails for the presence of shatter cracks fall in two classes. The first one tried was that in which the rail was struck a blow and the presence of shatter cracks was to have been detected by a difference in the "ring" of the rail as heard through a listening device which was attached to the rail. This crude method led to some of the tests which have been tried and which are covered under vibration tests.

The other acoustic test was designed to be used at the mill and was to have detected the noise of formation of the crack while the rail was cooling. For the purpose of making this test a bank-vault microphone was used, the output of which was brought through an amplifier to a recording device. The rail under test was supported, immediately after rolling, in slings so arranged that the support could move with the rail in cooling. These supports were insulated acoustically so that extraneous noises which would be transmitted from them to the rail and hence to the microphone were eliminated. The microphone was fastened to the end of the rail. Air borne noises were to be compensated for on the record by having another rail equipped in the same manner as the rail under test. In that way noise which occurred simultaneously in the dummy rail and the rail under test would be eliminated from consideration.

It was found in these tests that all of the noises which were present only in the rail under test were due to the cracking-off of scale from the rail while cooling. For this reason laboratory tests were made on a rail under controlled conditions.

It had been found that shatter cracks could be produced in a clear rail by heating it to a temperature of about 2,100 deg. F. in a hydrogen atmosphere and keeping it at that temperature and in that atmosphere for a period of several hours. The popping of scale as the rail cooled could be avoided by letting the rail cool in an atmosphere of nitrogen. The microphone test was tried under these laboratory conditions without success, although etch tests on the specimen indicated that shatter cracks had been formed by this treatment.

52. **Drop-of-Potential Tests.**—The drop-of-potential (electrical) test used was the same as that used by the Sperry Company on its detector cars for a final check on the rail of the indications on the record tape. A heavy current is sent through a length of rail (about 4 ft.) and the drop of potential over a length of about ½ in. is explored by means of two metal strips fastened ½ in. apart and attached to the terminals of a millivoltmeter. Above a fissure the drop of potential increases, since the area of the cross-section is somewhat reduced by the fissure, and the resistance is increased. This method had been tried previously at one of the steel mills to detect shatter cracks in new rails, but without success. It was thought, however, that if a rail were tested by this method while the head of the rail was in tension the shatter cracks might open up enough to give some indication on the millivoltmeter. The rail was stressed to 40,000 lb. per sq. in. tension at the shatter-crack zone and the drop-of-potential tried but the test gave no indication on a rail for which the etch test had shown shatter cracks.

53. **X-Ray Tests.**—Early in the investigation a rail was taken out of service on the tracks of the Illinois Central Railroad, which contained a horizontal split head that had turned down slightly to a transverse direction. This rail was sent to an X-ray laboratory for a trial of this method for the location of fissures in rail. This experience indicated that this method was very slow and the line of the fissure on the X-ray film was so indistinct that it would not have been found had the location not been marked previously. Since shatter cracks are so narrow and since they cannot be located previously, the X-ray method was not tried for the non-destructive testing for shatter cracks.

54. **Bridge Methods.**—All bridge methods are essentially null methods of comparing two conductors. The bridge is first balanced with a standard conductor in one arm and then the standard is removed and the specimen to be tested is put in the arm of the bridge. If the bridge remains balanced the specimen is the same as the standard. The bridge may be operated both with direct and alternating current, the only difference being that when direct current is used the resistance of the current is the only factor involved whereas the inductance must be considered when alternating current is used.

Various bridge methods were used to test the new rails for the presence of shatter cracks. In these tests a rail free from shatter cracks was used as the standard and the shattered rail for the specimen. The results were not successful.

55. **Magnetic Tests.**—The first magnetic test was inspired by the paper of M. Suzuki of the Japanese Railways research office entitled, "Magnetic Rail Defectoscope". His method consisted in using a U-shaped magnet to magnetize a portion of the rail. A pick-up coil covering three sides of the rail head was mounted between the legs of the magnet and it was thought that as the magnet was moved along the rail any defect would cause a change in the flux linkages and consequently would be indicated by the output of the pick-up coils. Due to the difficulty in moving this large magnet along the rail at sufficiently high speed to take advantage of the flux changes it was deemed impractical for laboratory use.

To overcome this difficulty several forms of rotating armatures were used to replace the pick-up coils. In some cases one rotating armature was placed in the leakage field near the rail and was balanced by the second armature rotating in a separate constant field.

In the other case the two armatures were located across the top of the rail head in the leakage field. Both methods are differential methods in that, while the device was made to travel along the length of the rail and approached the fissure or other defect, the first armature would be affected by the change in the field due to the defect while the other armature would still be under the influence of the unaffected field over the good part of the rail. In both of these cases when one of the armatures was passing over the defect an e.m.f. would be generated to give the indication of the defect. Also the generated e.m.f. would not be dependent on the speed of the magnet along the rail.

It was found that these magnetic methods were affected by the presence of interpoles at various places along the rail. It was also found that the generated voltages were so small that they were obscured by electrical disturbances due to the chattering of the brushes on the collector rings.

56. **Reason for Non-Success of Non-Destructive Tests for Shatter Cracks.**—Most of the methods which have been briefly described have shown promise of differentiating between rails which contain shatter cracks and those which do not, but to date none has shown any positive sign of being an absolute criterion of the difference. In some cases it has been possible to differentiate between the two conditions on some batches of rails but when the group of rails has been enlarged or when it has included two sizes of rails the test has failed. Several reasons could be advanced for the non-success of the tests tried, the principal one being that shatter cracks are exceedingly small and that the faces of the fracture, unlike those of transverse fissures or other detail fractures are interlocking. There is therefore a nearer approach to mechanical, electrical and magnetic continuity than there would be for the other defects. Due to this fact slight variations in the condition of the surface of the rail under test or of its magnetic properties, or the relative position of the rail and test apparatus or variation in the test apparatus would overcome much of the effect of the presence of shatter cracks.

Most of the tests proposed involve detecting changes in energy loss caused by shatter cracks by measuring in some way the energy applied to or absorbed by the rail. The total amount of energy lost around minute shatter cracks is so small that variations in this energy are masked by variations of energy distribution in the vastly larger mass of sound steel in the rail.

This does not mean that the search for a non-destructive test for the presence of shatter cracks is hopeless but it does mean that it would be necessary to make further investigations of the methods already used to eliminate the variables which now influence them. For the present, at least, this phase of the investigation has been discontinued.

IX Acceptance Tests For Rails—Drop Tests and Bend Tests

By N. J. Alleman

57. **Former Studies of Bend Tests for Rails.**—In 1900, when all rails were produced by the acid Bessemer process, making relatively high phosphorus steel, the drop test was introduced by the Pennsylvania Railroad as an impact test to eliminate excessively brittle rails.

After open hearth rails had been in use for several years it was thought by many engineers that the drop test did not give sufficient information regarding the reliability of a rail for service, and that some form of bend test would give a better measure of the strength, elastic properties and ductility.[15]

[15] References to bend tests are found in Volumes 12, 14 and 16 of the AREA Proceedings, on work done by M. H. Wickhorst, then engineer of tests of the Rail committee. Volumes 18 and 20 contain the results of quick bend tests reported by W. C. Cushing, chairman of the Subcommittee on Quick Bend Tests.

The results presented in a report by W. C. Cushing cannot be applied as a basis for comparing drop and bend tests. Individual results were not plotted and no comparative data on drop tests could be found. Much emphasis was placed on "elastic limit" although the methods for measuring it were not very satisfactory, when judged by present-day practice.

58. **Bend Tests and Drop Tests by the Pennsylvania Railroad.**—Through the courtesy of Vice-President C. D. Young of the Pennsylvania Railroad, a large amount of unpublished data on file at Altoona on bend testing and drop testing obtained over 20 years ago was made available to the test party. After a careful study of the data it became evident that these tests would not afford the means for getting a correlation between results of bend and drop tests, since the drop tests were made with the base in tension and the bend tests with the head in tension and since relatively few rails had failed in the drop test.

For rails from Mill A it was noted that no rail failed on the first blow in the drop test when the corresponding bend-test specimen required more than 110,000 ft. lb. of energy for fracture. Very few broke on the first blow in the drop test when the energy for fracture of companion rails was greater than 30,000 ft. lb., although six failures in the drop test were recorded on rails which developed between 80,000 and 100,000 ft. lb. energy for fracture in the bend test. Results from the other mills showed so few breaks on the first blow that they did not furnish any basis for correlation.

59. **Bend Test Rig and Test Results.**—Experiments were started in 1933 to try the bend test as a detector of shatter cracks in rails. For this purpose a bend test rig was constructed and used in a 600,000-lb. Riehle testing machine in the Talbot laboratory. This test rig is described in AREA Proceedings, Vol. 37 (1936), page 999. Test results obtained with it are given in Vol. 36 (1935), page 1078 and Vol. 40 (1939), page 664. These include results of tests of 166 rails varying in weight from 90 lb. to 131 lb. per yard. Forty-two rails contained shatter cracks, 124 being free of cracks; 115 of the rails were hot-bed cooled, the remaining 51 being controlled cooled. All of these rails had passed the AREA drop test requirements in the tests made at the mills.

Based on the results of head-down bend tests made with two-point loading and a span of 5 ft. 4 in., the following tentative minimum values of energy for fracture were suggested as a criterion for the acceptance of rails. (Values of elongation and deflection are given for information).

Rail Weight, lb. per yd.	*Energy for Fracture, ft. lb.*	*Total Elongation, percent*	*Elongation Across Break, percent*	*Deflection, in.*
130–131	100,000	35	7.5	5
110–112	75,000	35	7.5	5
100	50,000	35	7.5	5

On the basis of the above minimum requirements for energy for fracture, 4 rails not shatter cracked would fail to pass the bend test, 28 shatter-cracked rails would be rejected and 14 rails containing only longitudinal shatter cracks would be accepted.

Included in the rails tested were three rails from two different heats containing approximately 3 percent chromium and 0.30 percent carbon. These rails showed high elastic strength, but were very low in energy for fracture and deflection in the bend test. The drop test specimens passed the AREA requirements. Apparently the high elastic strength was responsible for the good values in the drop test. This high elastic strength is shown by the permanent deflection (set) after the first blow, the value being 0.70 in., whereas the set after the first blow on tests of fifty-eight 131-lb. carbon steel rails ranged from 0.94 in. to 1.16 in. It has been previously pointed out that the permanent set after the first blow is an inverse indication of the elastic strength of a rail.

However, a fact not so well recognized is that a rail of high elastic strength, but which is very brittle, may stand up well in the drop test (i.e. require several blows for fracture) because up to the limit of the elastic strength very little energy is absorbed by the specimen, most of the energy being absorbed by the springs under the anvil of the drop-testing machine.

The drop test is supposed to sort out "brittle" rails, distinguishing them from tougher ones. Apparently a distinction must be made between a tough steel and a high elastic strength steel.

From the results of these tests it was concluded that the bend test is a relatively reliable destructive test for separating shatter-cracked rails from sound rails, and that it would have many advantages over the drop test as an acceptance test for rails.

60. **Advantages and Disadvantages of the Drop Test and the Bend Test.**—Some of the advantages and disadvantages of drop tests and bend tests may be briefly summarized as follows:

1. The drop test is a "pass or fail" test giving very little indication of the relative merit of different rails which pass the test.
2. Deflection after the first blow in the drop test gives some measure of the elastic strength. The relative effect of subsequent blows is a matter of uncertainty due to the distortion of the specimen and to the fact that the springs supporting the anvil absorb an amount of energy depending on the remaining elastic strength of the test rail.
3. The bend test gives a measurement of energy for fracture not widely different from that which would be given by a single-blow impact test to fracture, with equipment to record the energy remaining in the hammer (or tup) after fracture of the specimen.
4. The bend test gives a measure of strength not determinable from drop-test data.
5. The bend test fractures a rail under known values of load and deflection (the energy for fracture is measured by the area under the load-deflection diagram). The specimen absorbs nearly all of the energy except that lost in elastic deformation of the testing machine.
6. Deflection values in bend tests of rail are on the order of six inches, using a four-foot span, making delicate deflection measuring devices unnecessary.
7. Load values are of the order of 450,000 lb. for 131-lb. rail, so that machine capacity should be about 600,000 lb.

61. **Standards for the Bend Test.**—In the spring of 1938 the advisory committee asked the test party to formulate standards for bend tests for the acceptance of rails and to submit them to the advisory committee with a view to their consideration by the AREA Committee on Rail and by the Rail Manufacturers' Technical Committee.

In November, 1938, an informal conference was held between the test party of the Rails Investigation and a subcommittee of the AREA. During this conference the limitations of the present standard drop test and certain advantages of the bend test were brought out. It was recognized that the preparation of definite specifications for acceptance or rejection of rails by the use of the bend test should be preceded by a rather elaborate series of bend tests and companion drop tests, conducted preferably at one of the steel mills in connection with regular rail rollings.

Before it would be possible to make bend tests at the mill for the purpose of establishing the minimum requirements for energy for fracture which would correspond approximately to the drop-test requirement that a rail should withstand one blow without fracture, certain additional laboratory bend tests of rails were needed in order to decide questions relative to the proper bend-test procedure. For this purpose additional bend tests were made on a few 90, 100, 110 and 131-lb. rails with lengths of span of 5 ft. 4 in. (the length used in all previous bend tests by the Rails Investigation), and also for spans of 4 ft. 8 in. and 4 ft. (The 4-ft. span is used in the drop test for rails over 100 lb. in weight). Two-point loading was used, 6 in. to either side of the center of the span. The results of these tests covering weight of rail and length of span have been published in the AREA Proceedings, Vol. 40 (1939), pages 664–671.

The load for fracture was found to vary inversely with length of span with a fair degree of consistency. Energy for fracture was found to vary with span, although varying the span does not greatly alter energy values. Deflection values increase with increasing span length, although above a span of 4 ft. 8 in. values become erratic especially on base-down (base-tension) results. This irregularity of action on the longer spans is probably due to a tendency of the head to buckle as a column when it is in compression. The only restraint to sidewise buckling is the friction of the loading block on the specimen. For tests with the head in tension the base is in compression and is wide enough to resist buckling. Buckling is more pronounced with the 90 and 100-lb. rail. In order to eliminate erratic results it seems desirable to use a 4-ft. span for the 110, 112 and 131-lb. rails and a 3-ft. span for the 90 and 100-lb. rails.

The following list will give some idea of the magnitude of values to be expected for sound rails tested on a 4-ft. span using two-point loading spaced 6 in. to either side of mid-length.

Rail Weight, lb. per yd.	*Energy for Fracture, ft. lb.*	*Load for Fracture, lb.*	*Deflection at Fracture, in.*
90	116,000	250,000	6.60
100	135,000	305,000	6.50
110	154,000	340,000	6.60
131	200,000	450,000	6.40

62. **Proposed Bend-Test and Drop-Test Study.**—Very few heats of steel are rejected at the mills on account of failure to pass the drop-test requirements. It is evident that bend tests of specimens from heats meeting the drop-test requirements will be of little value in establishing the minimum requirements for bend-test specifications. Because of the few drop-test failures considerable time will be required to obtain a sufficient number of samples for bend tests of rails from heats failing in the drop tests.

Arrangements have been made with the Bethlehem Steel Company to use a 350-ton hydraulic press in the fabricating department at Steelton, Pa., for making bend tests. A bend-test rig using central loading on a 4-ft. span has been built and shipped to Steelton, and a 400,000-lb. calibration bar has been built and calibrated. Shields for protection from flying pieces are to be constructed at the mill. Specimens for bend tests are being set aside at the mill. As soon as a sufficient number have accumulated, members of the test party will go to the mill and make the tests. It is expected that some preliminary bend tests on drop-test failed rails will be made in the near future. Tests will be made with the head down (head in tension), using a single-point loading.

X Future Study of Fissures in Rails

63. **Specifications for Bend Tests for Rails.**—Plans have been made and apparatus built for conducting a rather extensive series of tests of bend tests on rails at the Steelton Plant of the Bethlehem Steel Company. It is proposed that this work may be begun during 1941, and it is hoped that it will furnish the basis for drawing up specifications for bend tests as an alternate to or a substitute test for the present drop test.

64. **Specifications for Control Cooling of Rails.**—With the data now in hand it is planned during this year to draw up, submit and discuss detailed specifications for the times and temperatures in the control-cooled process for railroad rails, and for certain details of practice during that process.

Report of Special Committee on Stresses in Railroad Track

A. N. Talbot, *Chairman,*
C. B. Bronson
W. J. Burton
*Robert Faries
C. W. Gennet, Jr.
F. M. Graham
H. E. Hale
F. S. Hewes
G. W. Kittredge
P. M. LaBach
F. R. Layng
J. de N. Macomb
G. M. Magee
**John V. Neubert
Louis Yager, *Vice-Chairman,*
W. H. Penfield
G. J. Ray
Albert Reichmann
H. R. Safford
F. E. Turneaure
J. E. Willoughby
Committee

* Died September 8, 1940.
** Died June 4, 1940.

To the American Railway Engineering Association:

The Special Committee on Stresses in Railroad Track, cooperating with the Committee of the American Society of Civil Engineers and with the Association of American Railroads, presents the following report of progress.

During the past year the staff of the committee has continued in the work of analyzing and correlating the accumulation of data and of preparing material for publication, as well as developing apparatus and carrying on field and laboratory tests. The Seventh Progress Report has been published and other material is under preparation for publication.

Seventh Progress Report

The Seventh Progress Report of the committee is to be found in Bulletin No. 418, June–July, 1940, pages 101 to 208. The report deals with the tests of rail and rail joints made with locomotives running at various speeds and with rail and bar stresses and depressions measured by magnetic strain gages and recorded on oscillograph films. Brief comments on parts of the report seem worth making.

It was found that with the electric locomotive the averages of the stresses in the base of rail differed somewhat at the two sides of the locomotive and also at the several gage locations. It is brought out, however, that the averages of the measured rail stresses for all the driving wheels do not differ much at speeds of 5, 60 and 90 miles per hour. Average values for individual wheels may differ considerably. Speeds ranging from 5 to 60 miles per hour show only minor changes in the magnitude of the stresses for any given wheel at any given gage location. At speeds higher than 60 miles per hour wider variations in stress are noticeable for different wheels and for different gage locations; sometimes very marked changes in stress and moment under a given wheel are developed within a distance of ten feet. In the runs an increase in stress in one rail for a given wheel is generally accompanied by a decrease in the other rail for the companion wheel. It is significant that although the average stress in the two rails for companion wheels may differ little in the various runs at a high speed, the stresses in one rail may be considerably higher than in the other. At speeds of 90 miles per hour, for one gage location the left rail developed a bending moment of 205,000 in.-lb. and the right rail one of 435,000 in.-lb., corresponding to stresses of 7,500 and 15,900 lb. per sq. in., respectively, and indicating a considerable transfer of load pressure from one driver to its

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companion wheel. The analytical treatment of forces given in the report indicates how lateral forces applied to a pair of drivers may greatly modify the division of load pressure between the two wheels and the two rails. As the gages were applied only at the middle of the rail base, no information is available on lateral bending of the rail. The data regarding stresses and moments in rail served a very useful purpose as a basis of comparison in the discussion of the tests of rail joints.

The joint tests gave a great variety and extent of information which cannot be condensed into brief form. They confirmed the view that, with excellence of fit, stiffness and sturdiness of bar are accompanied by ability to develop a high joint moment ratio (that is, a high bending moment in the joint for a given wheel load as compared with the full rail), and this high joint moment ratio constitutes a proper measure of the effectiveness of a rail joint, provided the track has been tamped to fit the camber of the bars and the tie supports are normal. The best of the joints showed a joint moment ratio of 0.85 and 0.90, which are excellent showings in well tamped track. Although the vertical and longitudinal movements between rail and bar fishing surfaces are very small with closely fitting bars, opportunities for wear will be present, particularly when the position of the bearing contacts between bar and rail are such as to develop very high bearing pressures at the top fishing surfaces near the rail ends when the wheel loads are applied. Worn bars were found to give increased vertical movement between bar and rail, and the effectiveness of the joint to develop bending moment was thereby greatly diminished.

It is understood, of course, that the use of the bending moment developed in the joint as a measure of its effectiveness assumes a smooth joint and normal support—the additional moment developed when batter near the rail ends stimulates impact on the joint with resulting higher moment in the bars cannot properly be used to measure the effectiveness of a joint. It was judged that in a joint having excellence of fit little difference in bending moments would be found in the average bending moment developed at the different speeds, but at the higher speeds a wide spread of the magnitudes would occur as was the case with the full rail, due doubtless to variations in the action of the locomotive at the higher speeds, and therefore that at the high speeds greater values than those reported may be expected with more or less frequency. Attention may well be called to the inadequacy of the tests on a few joints of 24-in. length, which gave smaller moments than those found with 36-in. bars. They should not be used for comparison with the longer bars. Further tests in track made under known conditions are needed before proper comparison between long and short bars may be made.

Having equipment available, tests were undertaken in a preliminary way to find whether the testing apparatus would be satisfactory for determining the effect of a flat spot on a wheel and the effect of batter in the rail surface. While intended to be of an exploratory nature, the tests give information of interest and point to procedures that may well be followed in a more complete investigation with newly developed high frequency galvanometers. Stresses at the middle of the base of the 131-lb. rail were measured under a 4-in. flat spot on a wheel of a heavily loaded coal car. With speeds from 10 to 30 miles per hour the trend in the stress in rail was fairly definite, with a maximum as high as 25,000 lb. per sq. in. at about 21 miles per hour, as compared with a stress under the other car wheels in normal condition averaging 10,000 lb. per sq. in. The stress under the impact load is thus 2½ times that for the normal wheels. The rate of change of stress as the flat spot struck the rail doubtless was too rapid to record the full amount of the stress with the galvanometers used at the time.

To study the effect of batter in the rail surface, batter spots were ground in the rail surface both at and away from the rail ends to simulate batter developed in the rail and the joint under service. The batter irregularities were 8 and 9 in. long and the depths were about $\frac{1}{16}$ in. The stresses were measured in the joint bars and in the full rail directly under the batter spots, and while they varied widely at different wheels and locations, the measured stresses, in general, ranged up to 1½ times the stress found for normal rail conditions. Smaller batter impact effects than those found with the large flat spots are to be expected, as the batter spots have greater length and lesser depth. Grinding the 9-in. batter to a length of 36 in. without increasing the depth, to lessen the slopes of the batter spots, gave a definite decrease in the impact effect.

For the purpose of obtaining information on procedure in testing for steam locomotive counterbalance effect on stresses developed in rail and to learn the characteristics of the action of a locomotive on the given track, one day was spent in testing with a fast freight locomotive (4–8–4) that was considered to be normally well counterbalanced. Three runs were made at 5 miles per hour and 20 runs at 75 miles per hour. To make clear the methods of calculation used and as an aid to the interpretation of the test results, a condensed statement was given in the report covering the principles underlying the analysis of the forces acting on the rail and the methods of applying the analytical treatment in calculating rail stresses that may be developed by counterbalance forces. It is hoped that this statement of method of analysis and calculation of results will be found useful to young engineers who may wish to look into counterbalance problems.

No brief résumé of conclusions for these counterbalance tests seems practicable here. It is to be expected that at the speed of 75 miles per hour there will be large variations from average values, for forces other than those considered in the analysis will influence the rail stress, and the transfer of load from one driver to another evidently occurs to a greater or less extent. At the high speed the differences in stress at the several gage locations were greater than expected. With the exception of one or two wheels, in a general way the trend of the plotted points of rail stresses agrees fairly well with the direction of the analytical curves, though the test values at some wheels are definitely higher than the calculated values. One marked exception in counterbalance trend was found in the right main driver; the stresses surprisingly showed no very definite unbalance effect, the points being scattered over a wide range of stress throughout the whole revolution. The left main driver gave a definite counterbalance trend with maximum stresses up to 20,000 lb. per sq. in. at the middle of the base as compared with the average stress of 10,000 lb. per sq. in. at 5 miles per hour. As in the tests with the electric locomotive the stresses measured under the individual drivers of the steam locomotive showed an almost complete absence of general speed effect such as had been found in earlier tests of track and locomotives. The measured rail depressions under all drivers showed surprisingly good agreement with the corresponding measured stresses as plotted for half of the drivers in the last three figures and corroborated the stress relations throughout the revolution of a driver even for extreme and unexplained values. The report of the tests of this steam locomotive is worthy of careful and detailed study in making up any program of tests on the effect of counterbalance on stresses in track.

Vertical Web Stresses in 112-lb. Rail

A series of tests was conducted in May, June and July 1940 on the tracks of the Denver & Rio Grande Western Railroad near Green River, Utah. These tests were made to study the cause of the few longitudinal web cracks in the 112-lb. rail that had developed in service in less than a year. The staff of the committee had previously conducted a considerable amount of developmental work in connection with the use of the resistance strip gage and had developed a direct current amplifier for use with the strip gage that improved the usefulness and reliability of the gage and made possible a reliable static method of calibration. Six complete stress measuring units were built and used in these tests. The longitudinal web cracks had been found in the outer face of the rail web at the thinnest part of the web section, always on the outer face and mostly on tangent track. The strip gages were placed in vertical positions on the rail web, generally at 3 ¾ in. above the rail base, approximately the height at which cracks had appeared in the rails that had been replaced. Most of the measurements were made under regular scheduled freight and passenger trains, but two test locomotives were used for a day each. The records of vertical web stresses on both of the web faces for some driving wheels showed compressive stresses ranging from 8,000 to 12,000 lb. per sq. in. indicating that the wheel bearing came fairly centrally on the head of the rail. More generally, however, high compressive web stresses were found in the inner face under most driving wheels, accompanied by tensile stress of lesser amounts on the outer web face. Occasionally maximum tensile values in the outer web face under the heavy locomotive driving wheels reached 28,000 lb. per sq. in. Many values of the compressive stress in the inner face were between 25,000 and 50,000 lb. per sq. in., several reached 50,000 lb. per sq. in., and occasionally there were even higher compressive stresses. It was well established that the bearing between wheel and rail at points giving the very high compressive stresses came considerably inside of the middle of the rail head. The shiny area of the rail head surface also indicated that the wheel bearing was generally well toward the gage side of the head. The six gages were later placed on the web at different heights to determine whether eccentric loading on the rail head or lateral forces was primarily responsible for the uneven distribution. From the measurements and other evidence it is believed that the primary factor in the uneven stress distribution between the two web faces is without doubt the eccentric loading of the rail.

To broaden the scope of the work, web stresses were measured under a variety of conditions: The 1 in 40 tie plates were replaced by 1 in 20 tie plates; at one location the rail head was ground to ⅝ in. center bearing; measurements were made on 110-lb. RE rail that had been in track 5 years on which the wear had brought the wheel bearing more centrally on the rail head; and a limited number of measurements were made on a 1-deg. 40-min. curve.

In a further study of the vertical web stress problem tests were made under regular traffic on new 112-lb. rail in tangent track of the Illinois Central Railroad in Illinois in October and November 1940. Considerable general information was obtained on the web stresses developed in the rail. Measurements were also made under the following conditions: 112-lb. rail in track 4 years, 110-lb. rail in track 15 years, and 90-lb. rail in track 20 years. A study is now being made of the stresses measured in the webs of these rails. Considerable variation was found from place to place in the magnitude and nature of the stresses, and in the relation between the stresses at the two faces. Cant of rail, wear of rail head, condition of rail support, contour of wheel tread, place of contact between wheel and rail head, and other variables evidently are factors affecting the web stresses.

The information so far obtained brings out a need for further tests on the web stress problem. A program may well include tests on 112-lb. rail and 131-lb. rail on both tangent and curved track.

Service Tests of Joint Bars

In cooperation with Subcommittee 7 on Service Tests of Various Types of Joint Bars of Committee 4—Rail, observational tests have been continued on the test stretches of joint bars on the Pennsylvania Railroad and the Atchison, Topeka & Santa Fe Railway. A report of these tests is included in the report of the Committee on Rail.

Additional information on the service tests of joint bars was given in the chairman's address at the 1940 convention. (Proceedings AREA, Vol. 41, 1940, page 659).

Rolling-Load Tests

Rolling-load tests of rail joints have been continued in the rolling-load machine at the laboratory of the University of Illinois. A report on the tests completed up to March 1940 was given in the chairman's address at the 1940 convention. (Proceedings AREA, Vol. 41, 1940, page 665). Further tests have corroborated the findings given on page 668.

Testing Equipment

Developmental work on electrical measuring and recording instruments is being continued by the staff. As a more thorough knowledge of the operation of the apparatus is obtained, it has been found possible by skillful changes or by simplification to add measureably to the effectiveness and ease of operation of the equipment. At the same time the staff is keeping well informed on developments in the art of making tests.

THE SPECIAL COMMITTEE ON STRESSES IN RAILROAD TRACK,
A. N. TALBOT, *Chairman.*

Report on Stresses in Railroad Track*

An Address by A. N. Talbot
Chairman of the Committee on Stresses in Railroad Track
Professor Emeritus, University of Illinois

The report of the Special Committee on Stresses in Railroad Track, beginning on page 753, contains a short review of the Seventh Progress Report.† It also has a statement of work done in measuring vertical stresses in the web of rails on the Denver & Rio Grande Western Railroad and Illinois Central Railroad, and refers to the report on Service Tests of Joint Bars and to the chairman's report on the rolling load tests of rail joints.

Instead of giving further explanation of the report, it appears to be preferable to use the available time of the committee in reporting in brief form on the tests of vertical stresses in rail made on the D. & R. G. W. R. R. and the I. C. R. R. in 1940.

Tests of Vertical Stresses in Web of Rail

In January 1940 the maintenance department of the Denver & Rio Grande Western discovered cracks in the web of 112-lb. rail which had been laid only eight months. At various rails along a stretch of five miles of main line single track, a horizontal crack had started on the outer face of the web and extended into the web sometimes as far as three-fourths of the web thickness. The crack occurred near the thinnest part of the web, about 3¾ in. above the base, and had a length up to, say, 14 in. Rails having such a crack were replaced with new rails. Investigations made by the engineer of tests of the railroad and the mill representatives failed to find defects or abnormalities in the rails where the cracks appeared.

As the appearance of such cracks seemed to be a new phenomenon and information on the cause was not known or not available, the railroad asked for assistance and the Association of American Railroads arranged for the research engineer of the Engineering Division and the staff of the Committee on Stresses in Railroad Track to conduct tests in the early summer in an effort to find the sources or cause of the trouble. In the fall tests were also made on the Illinois Central in Illinois. This report presents some of the principal results and findings of the tests on the two railroads. To keep within the specified limits of time details of the tests will be omitted, only parts of the tests will be referred to, and the consequent incompleteness will probably not give a full understanding of the tests.

1. Combination of Bending Stress and Direct Stress

Preliminary analyses of the problem suggested a bending action in the web of the rail, developing high compressive bending stresses, which in connection with the direct vertical stresses might result in excessive compressive stresses at one face and lower compressive stresses or even high tensile stresses in the other face. The cracks found were presumably fatigue cracks progressively developed. Before discussing the test results it will be well to consider possible causes of bending action in the web. Two sources came to mind as possible ones, (a) eccentricity of wheel bearing on the rail head and (b) application of a lateral force by the wheel at the rail head. See Fig. 1.

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* This address, presented on March 12, 1941, supplements the report of the Committee on Stresses in Railroad Track appearing on page 753.

† Seventh Progress Report of the Special Committee on Stresses in Railroad Track, Bulletin 418, June–July, 1940, pages 101 to 208, and also pages 139 to 246 in the monograph or special report section of this issue of the Proceedings.

(a) *Eccentric wheel load.*—For a concentrically applied wheel load the resulting vertical stress would be uniform over the thickness of the web. The length of web resisting the vertical pressure in any event is not known definitely nor is the law of variation from uniformity of stress along its length, but for present purposes an equivalent or effective length of resisting section may be assumed to apply to all the conditions. Without considering what the effective length of the resisting section is (including the variations in magnitude of stress along that length), it is seen that a central load may be expected to give a uniform stress over the thickness of the web, which may be termed the direct stress. (See upper half of Fig. 1). An eccentric load will give in addition a bending moment at any horizontal section with a magnitude of Pe, where e is the eccentricity of the bearing load with reference to the vertical axis of the rail section. This

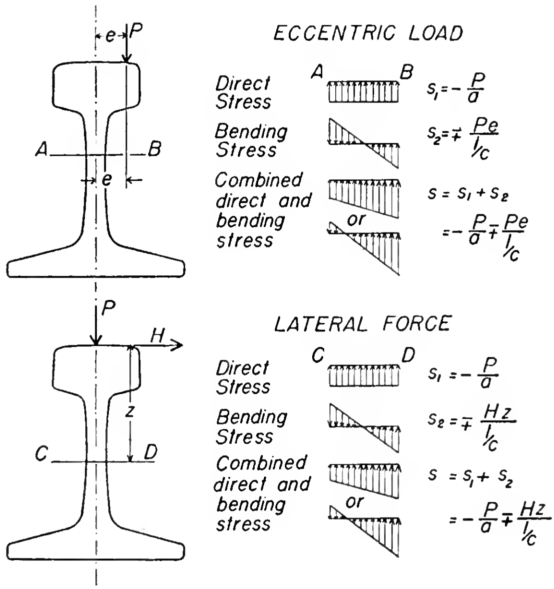

Fig. 1. Bending Stress and Direct Stress

bending moment will be resisted by the thickness of the web acting as a beam for whatever resisting length may be developed. These resisting lengths for both direct stress and bending stress may be assumed in a manner that will give the calculated stress immediately under the wheel load. It has been found that the length of the section resisting the direct load is considerably shorter than the length of the section resisting the bending moment, perhaps 10 in. in all for the former as compared with 30 in. or more for the latter. For both resisting sections the stress is a maximum at the wheel point and decreases each way from this point. The effective or equivalent length of resisting section for either the direct stress or the bending stress may be worked out from the stresses at the opposite faces of the web recorded on clear stress records. The discussion under the heading, "5. Notes on the Distribution of the Direct Stress and the Bending Stress Along the Length of the Web," gives more definite information on this matter.

The combined direct stress and bending moment stress may be written

$$s = s_1 + s_2 = -\frac{P}{a} \mp \frac{Pe}{\frac{I}{c}} \qquad (77)$$

where s_1 is the direct stress, s_2 the bending stress, a the effective area of the horizontal section resisting the direct load, and $\frac{I}{c}$ the section modulus for the effective bending length. It is seen from the formula that the stresses at the faces of the web may be either both compressive or one compressive and the other tensile.

To put the formula in words: Calling compressive stress minus and tensile stress plus, the combined direct stress and bending stress given by the formula may be stated to be the algebraic sum of (1) the compressive direct stress due to the wheel loading considered as distributed uniformly over the thickness of the web and for a length that may be called the equivalent or effective bearing section length and (2) the compressive or tensile bending stress found from the bending moment due to the eccentricity of loading or other applied forces as calculated with a section modulus based on the equivalent or effective length of the section which resists bending. The combined bending and direct stress is scaled from the stress record of the film.

It may be added that in evaluating the stress records of the tests the magnitude of the direct stress at a wheel is taken as one half the algebraic sum of the measured stresses at the two opposite web faces. The magnitude of the bending stress at either face under the wheel is plus or minus one half of the algebraic difference of the measured stresses at the two opposite web faces.

(b) *Lateral force at the rail head.*—Considering the vertical wheel load to be applied centrally as in the lower half of Fig. 1, a lateral force H will produce a bending moment of Hz at a section z below the point of application of H. The combined direct stress and bending stress may then be taken as the algebraic sum of the two stresses, found in a way similar to that given for the case of eccentric loading just discussed. With a lateral force acting, the form of the formula will be the same as that for eccentric loading, but the magnitude of the bending moment will vary with the distance z to the resisting section taken, and the effective length of the section resisting the lateral bending of the web probably will be greater for the larger values of z.

It is apparent that a combination of the two sources of bending, eccentric loading and lateral force, is possible. The assumptions for both cases used are not fully accurate or complete but constitute an approach to solutions. The analyses, assumptions and formulas should be considered as preliminary in their nature and roughly approximate; they are presented in an effort to give a conception of the relation between forces and stresses. A single laboratory test made with central loading indicates that the stresses at a horizontal section toward the bottom of the web are much smaller accordingly than those at a section near the top. This test and other observations indicate that for both direct stress and bending resistance further investigations must be made to secure fully acceptable analyses and formulas.

It may be noted here in advance that the test results indicate that eccentricity of bearing is the principal source of the bending stresses.

2. Principal Tests with 112-lb. Rail on the D. & R. G. W. R. R.

The tests on the D. & R. G. W. R. R. were made on the main line single track east of Green River, Utah. The track appeared excellent and in very good condition. Double-shouldered tie plates on ties machine adzed before rail laying gave reasonably uniform rail cant, ranging from 1 in 35 to 1 in 50. The crushed slag ballast was well tamped and in general the ties were well seated in the ballast. The position of the shiny area on the rail head showed that the general wheel bearing was toward the gage side of the rail.

The locomotives making these records were largely 3700 class (4-6-6-4, mallet type), giving perhaps two-thirds of the records, with the other third divided between the 1700 (4-8-4) and 1600 (4-8-2) classes. Driving wheel weights ranged from 33,000 to 37,000 lb. Three runs were obtained with locomotives of the 1800 class (4-8-4). In addition two locomotives were used to make special test runs, locomotive 3700 and locomotive 1804.

The principal test measurement (a variety of other measurements was made at different times and places) was that of the stress in a vertical direction on the outer face and the inner face of the web of the rail. The mid-point of the gage lines was placed at the thinnest part of the web, 3¾ in. above the base of the rail. The measurement was made by carbon strip gages (1-in. or ½-in. gage length) applied directly to the two opposite faces of the web. By means of the apparatus developed by the staff of the committee the stresses at these places were recorded on films by an oscillograph near by. In Fig. 2 are plotted vertical stresses measured in both inner and outer faces of the rail web at one gage location for the 3700 class locomotives westbound in regular traffic. The figure is given as an example of the distribution of stresses at the several driving wheels for a number of runs.

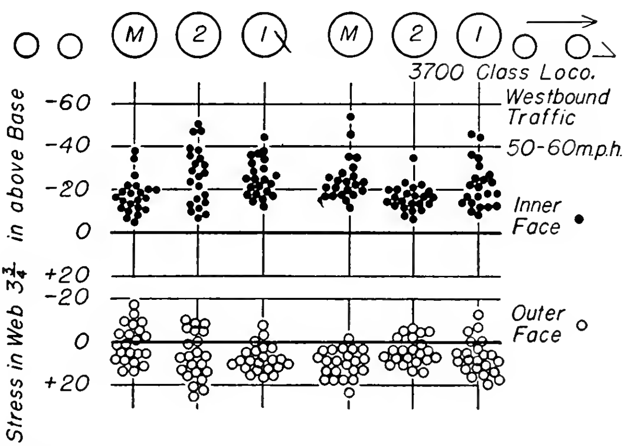

Fig. 2. Vertical Web Stresses at One Gage Location. D. & R. G. W. R. R. 112-lb. Rail

The place or location on the track at which a gage or gages were placed is termed a gage location and is given by naming with it the distance along the track from a reference point together with the words north or south rail for the rail on which it was placed. In the tests to be first discussed 13 such gage locations were used on a stretch of tangent track with a descending grade to the west giving conditions conducive to fast speeds in the westbound direction.

To give some idea of the meaning of the magnitudes in vertical web stresses, certain statements may be made as derived from a study of the test results and a consideration of probable values from an analytical basis. It may be said that the part of the measured stress at the wheel point attributable to direct stress may be expected generally to range from 8,000 to 14,000 lb. per sq. in. compression, this direct stress being calculated by taking half the algebraic sum of the measured stresses on the two opposite web faces. With ordinary bending in the web, the larger measured compressive stresses on the inner face at the wheel point may run to 25,000 or even to 30,000 lb. per sq. in. and still be considered moderate with respect to common conditions of track and rolling stock—this without any reference to whether these values exceed the fatigue resistance of the metal. With higher bending in the web, values of compressive stresses on the inner face as great or greater than 40,000 lb. per sq. in. may be considered high or very high. Tensile stresses on the outer face at the wheel point as great as 15,000 lb. per sq. in. must be expected at times under ordinary operating conditions, and values of 25,000 lb. per sq. in. were found at reflex points in a few instances. As already stated the algebraic difference between the measured stress and the direct stress will be the bending stress, either compressive or tensile.

Brief comments on the various test results will now be made. It should be pointed out that in this report all stresses referred to are those produced by the driving wheels of the locomotives. Two gage locations called gage location 21 ft. south rail and 10 ft. south rail were on new rails at points where a crack had been reported in the replaced rails. A third one was called 99 ft. south rail. At these three gage locations on the south rail many excessive vertical compressive stresses were found in the inner face of the web under regular traffic. The speeds of westbound trains ranged from 50 to 70 miles per hour. Of about 350 records of stresses from driving wheels at the inner face of web at these three gage locations, 14 percent were above 35,000 lb. per sq. in., 6 percent were above 45,000 lb. per sq. in., and 1 percent was as high as 55,000 lb. per sq. in. Where compressive stresses in the inner face as high as 35,000 lb. per sq. in. occurred, the corresponding stress in the outer face was generally tensile, and usually as the compressive stress in the inner face rose, the tensile stress in the opposite face also increased. The tensile stresses in the outer face were as high as 25,000 lb. per sq. in., with about 8 percent of the values between 15,000 and 25,000 lb. per sq. in.

At three other gage locations, two on the south rail and one on the north rail, with 150 stress records on a face and regular traffic, about 2 percent were greater than 35,000 lb. per sq. in. compression, but in general the stresses were much smaller than at the three gage locations discussed above. The tensile stresses at the outer face ranged up to 15,000 lb. per sq. in.

With locomotive 3700 westbound used as a special test locomotive (heavy mallet type) high vertical stresses on the inner face were found at gage location 10 ft. south rail at the speeds of 50 and 65 miles per hour. Nearly all the vertical stresses on the inner face of the web of the south rail at this gage location were greater than 25,000 lb. per sq. in. compression, 10 percent of the records were between 25,000 and 35,000 lb. per sq. in., 30 percent between 35,000 and 45,000 lb. per sq. in., 35 percent between 45,000 and 55,000 lb. per sq. in., and 20 percent above 55,000 lb. per sq. in. In magnitude and frequency the values here given for this gage location and this locomotive are the highest found in the tests. They are all on the inner face. On the outer face the tensile stresses were frequent but not of large magnitude.

At this same gage location on the south rail, for the 5 runs with this test locomotive at 5 miles per hour no stress on either face of the web under five of the driving wheels exceeded 20,000 lb. per sq. in. For the fourth driving wheel all of the values on the inner face were between 35,000 and 40,000 lb. per sq. in. compression.

On the north rail at gage location 10 ft. north, for the high speeds, the higher stresses were smaller in magnitude and much smaller in percentages than was the case on the south rail; sometimes the compressive stress was greater on the inner face and sometimes on the outer face. On the contrary for the speed of 5 miles per hour the higher compressive stresses on this north rail were greater in magnitude and greater in frequency than those on the south rail at the same speed.

With test locomotive 3700 at another location on the south rail (gage location 48 ft. south rail) for both high and low speeds the values of the vertical web stress were relatively low, all below 25,000 lb. per sq. in.

For test locomotive 1804 (a modern 4-8-4 passenger locomotive) at speeds of 5, 50 and 70 miles per hour (4 runs at each speed) no individual wheel on either south or north rail gave a vertical compressive stress in either inner or outer face of web as great as 30,000 lb. per sq. in. Of 232 records of stress on the two web faces at the three gage locations 17 values were between 25,000 and 30,000 lb. per sq. in. Only one of these stresses was on the outer face. The numbers in this group of stresses were fairly well divided among the three speeds. Compressive stresses of these amounts are not considered to be unduly high. It was found that the mean stress of the two faces for each driving wheel was in the neighborhood of 10,000 to 12,000 lb. per sq. in. compression. The stresses in the outer face were almost always compressive, only 3 out of 180 values being tensile and these having relatively small magnitude. The records on which the above statements are based included those at gage locations 10 ft. south rail, 10 ft. north rail and gage location 48 ft. south rail, the values at the three gage locations being quite similar. The results show that the vertical stress records for this locomotive were low or moderate and uniform and reasonably similar for the three gage locations. They may be contrasted with the values for locomotive 3700 at the same three gage locations.

3. Tests with 112-lb. Rail on the Illinois Central

The tests on the Illinois Central were made on double track main line at perhaps 32 different spots in three main groups several miles apart at places south of Mattoon and one group north of Gilman, Ill. The 112-lb. rail south of Mattoon had been laid four months and that north of Gilman had been in track for about four years under fairly heavy traffic. The track was in fairly good condition. Most of the ties were not new. The cant of the rail, intended to be 1 in 40, varied more or less from place to place and was mostly about 1 in 25. The records were taken under regular trains. The locomotives were almost wholly 4-6-2 and 4-8-2, with driving wheel loads ranging from 30,000 to 33,000 lb. The speeds ranged from 60 to 80 miles per hour for passenger trains and 30 to 55 miles per hour for freight trains.

Measurements were made on the 112-lb. rail at six gage locations on the left rail and 17 on the right rail, six of which were opposite those on the left rail. Perhaps 500 driving wheel records of vertical stresses were made for each face of the web of the rail. Some of the general findings of these tests are as follows:

1. Generally the high compressive stress was on the inner face of the web—perhaps there were three values on the outer face of about 30,000 lb. per sq. in.

2. Of these 500 records on the inner face, only four values are above 45,000 lb. per sq. in. compressive stress, three being for one run of passenger locomotive 2458 and one under the main driver of passenger locomotive 1135 pulling the Panama Limited train. On the two other runs locomotive 1135 gave only one stress as high as 22,000 lb. per sq. in.

Of the 500 records six values of the compressive stress at the inner face were between 40,000 and 45,000 lb. per sq. in. and six values between 35,000 and 40,000 lb. per sq. in.

4. It is seen that a vertical compressive stress higher than 35,000 lb. per sq. in. at the inner face was rare, occurring in only about 3 percent of the total inner face stress records made by driving wheels.

5. Vertical web compressive stresses between 25,000 and 35,000 lb. per sq. in. were found in about 8 percent of the records, only 2 percent occurring at the outer face. Considering the opportunities for eccentricity of bearing, the number of values in this group may be called very moderate.

6. The tension values in the outer face were relatively small. Very few were above 15,000 lb. per sq. in., and only one was as great as 20,000 lb. per sq. in.

4. Additional Tests on Both Railroads

The foregoing relates to 112-lb. rail presumably laid with a cant of 1 in 40. To learn something of the effect of other conditions like wear and cant and centralized bearing, tests were made on the D. & R. G. W. R. R. (a) with the 112-lb. rail canted 1 in 20, (b) with the rail ground for a short length to give central bearing on the rail head, and (c) tests were also made on 110-lb. rail that had been in service and had become worn.

With the 1-in-40 tie plates replaced with 1-in-20 tie plates on new 112-lb. rail at one gage location where many of the vertical web stresses in inner face had been found to be very high and also at one gage location where the vertical web stresses had been found to be moderately high, the web stresses were materially modified. At the inner face the compressive stresses were greatly decreased, and stresses at the outer face were changed from tensile to compressive. In many cases there was reversal of stress on the two faces from the original values. It was apparent that the change in cant of rail had made a significant change in position of wheel bearing on rail head. The results give definite evidence that eccentricity of bearing of wheel on the rail head was a principal source of the high compressive stresses originally found at the inner face.

To secure fairly central bearing of wheel, a 112-lb. rail was ground through a length of 4 or 5 ft. so as to leave a slight ridge ⅝ in. wide at the middle of the head. The effect was to markedly modify the stresses on the web faces. The test was made with locomotive 3700 which had before given very high compressive stresses at the inner face. The stresses at this face were materially decreased and those at the outer face became compressive stresses of small magnitude, only 3 out of 180 values being tensile. It was also found that certain wheels that had given high lateral bending stresses in the base of the rail did not continue to produce this effect.

Tests were also made on 110-lb. rail laid in 1935 and worn somewhat so that it more nearly fitted the average wheel tread contour. At the inner face 10 percent of the values were between 25,000 and 32,000 lb. per sq. in. compressive stress, and none was higher. This decrease in web stress as compared with the 112-lb. rail doubtless results from more nearly central bearing of wheel on rail. On the outer face the stresses were evenly spread between 13,000 lb. per sq. in. tension and 13,000 lb. per sq. in. compression. A few tensile stresses were recorded for the inner face. The appearance of the head of the rail also indicated smaller eccentricity of wheel bearing than did the new 112-lb. rail.

On the I. C. R. R. tests were made at six gage locations on 110-lb. rail laid in 1924. The rail had become worn and canted to some degree and thus more nearly fitted the usual coning slope of wheel treads. The condition of the track varied from place to place. At four of the six gage locations the vertical stresses on both faces of the web were moderate, generally under 20,000 lb. per sq. in. compressive stress. Frequently the compressive stress in the outer face was greater than the corresponding stress in the inner face. At two other gage locations opposite each other, a number of compressive stresses were found between 25,000 and 35,000 lb. per sq. in. Of these higher values those on the right rail are at the inner face and those on the left rail are at the outer face. As these higher values on the two rails were found to be simultaneous, it is seen that the wheel bearings on the right rail must have been inside of the middle of the head and at the same time those on the left rail were outside of the middle of the head. For these tests on 110-lb. rail the highest compressive stress was 41,000 lb. per sq. in., and 3 percent ranged between 30,000 and 40,000 lb. per sq. in. The few tensile stresses recorded were small and they occurred on either face of the web.

Also on the I. C. R. R. tests were made at three gage locations on 90-lb. rail laid in 1920 and still carrying the regular traffic. This rail had considerable head wear and but little batter at the rail ends. The web stresses were not high. Two compressive stresses of 29,000 and 33,000 lb. per sq. in. were recorded—all the other 58 stresses on the inner faces were smaller. Small tensile stresses were found on either face; the highest was 15,000 lb. per sq. in. It may be noted that the head of this uncanted rail was worn to an inward slope approximating average wheel contours. It is apparent that the worn shape of the head has a strong influence in preventing the occurrence of high web stresses.

To show variations that occur in track, reference may be made to the conditions at two gage locations a rail length apart on 110-lb. rail on the I. C. R. R. laid in 1924. The ties were not in good condition, and shims had been placed under the outer end of the tie plates of the right rail for two rail lengths, making the gage a little tight and resulting in a cant of 1 in 25 on the right rail and 1 in 20 on the left rail. Under these conditions the web stresses were quite moderate.

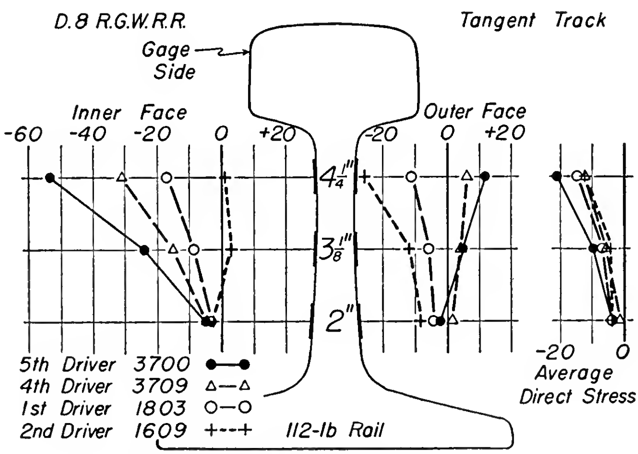

Fig. 3. Range of Measured Vertical Web Stresses

To find the relative magnitude of the vertical web stress at different heights on the web, strip gages were placed one above another on the two faces and simultaneous values obtained. Fig. 3 shows stresses measured at gage lines with centers at 2, 3⅛ and 4¼ in. above the rail base at a gage location on 112-lb. rail on the D. & R. G. W. R. R., made by a wheel for single runs of four locomotives. The diagram shows something of the range in the web stresses found under regular traffic conditions. The higher compressive stresses decrease rapidly from the uppermost gage line to the lowermost gage line. In general the web stresses do not reverse sign from the upper to the lower portion of the web. The direct stresses shown at the right were calculated from the measured stresses at opposite faces of the web. Similar measurements of stresses made at other gage locations, one on 112-lb. rail and one on 110-lb. rail on the D. & R. G. W. R. R. and still another on 112-lb. rail on the I. C. R. R. (two of them made with two gages and one with three on a face), gave similar decreases in magnitude of stress from the upper gage to the lower one or similar trends. It is apparent that the decrease in stress from above to below is greater accordingly than would be accounted for by difference in thickness of web. Perhaps the greater length of the effective section resisting web bending to be expected at the bottom gage as compared with that at the top gage, or some similar action in the web, will be found to explain the change in magnitude from top to bottom of web.

5. Notes on the Distribution of the Direct Stress and the Bending Stress Along the Length of the Web

A further discussion may help to give a clearer understanding of the variable relation between the direct stress and the bending stress at and away from a wheel load.

The measured vertical stress at any point in a web stress record may be considered as made up of (1) a compressive direct stress and (2) a bending stress due to the flexure in the web. The division of the measured stress between direct stress and bending stress may be made by the method of calculation given under the heading "1. Combination of Bending Stress and Direct Stress." A study of many records indicates that the magnitudes of the direct stress along the web varies from a maximum at the wheel point to a small amount at points averaging perhaps 5 in. in front of and behind the wheel point and that the form taken by these stress values along the web approximates a straight line. This variation of direct stresses along the length of the web is similiar to that found in the laboratory test with a concentric load on a rail. The records of the tests indicate that in general the compressive direct stresses at the wheel point had magnitudes of 8,000 to 14,000 lb. per sq. in.

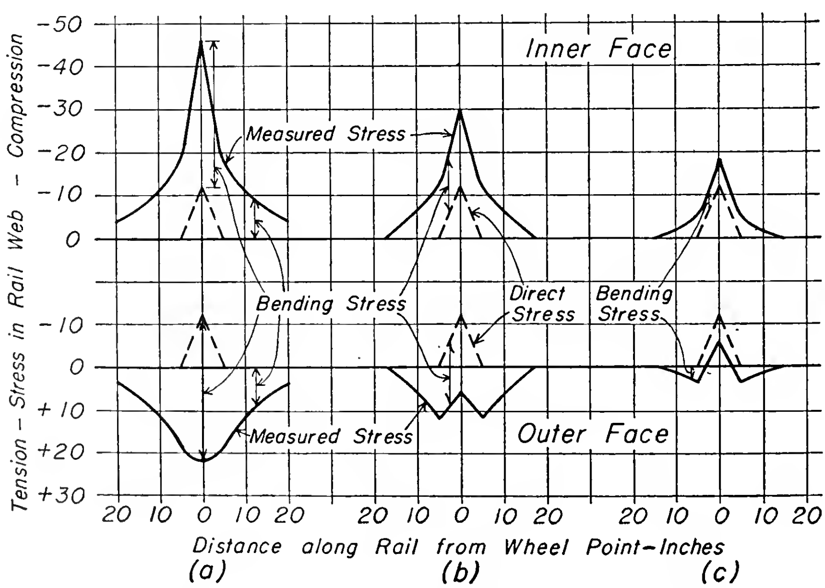

Fig. 4. Forms of Measured Vertical Web Stresses in Rails in Track

Three representative forms of the vertical stress records showing inward bending of the web at a pair of opposite gage lines having their centers 3¾ in. above the rail base are given in (a), (b) and (c) in Fig. 4. A compressive direct stress of 12,000 lb. per sq. in. at the wheel point for each face has also been plotted, and the direct stress has been taken to decrease as a straight line to zero at points 5 in. before and behind the wheel point.

The bending stresses developed in the web (compressive and tensile) will also vary from the wheel point along a distance 15 to 20 in. in front of and behind the wheel point. The scaled vertical distance from a point on the stress record to one on the line representing the corresponding point for the direct stress or to the horizontal axis of the diagram beyond any direct stress will represent the magnitude of the bending stress at any given distance from the wheel point, the stress being compressive at the inner face and tensile at the outer face. The resulting lines representing the bending stresses would have a curved form from a maximum at the wheel point to a joint 15 to 20 in. each way.

Taking first the form at (a), the stresses measured at the inner face of the web (top diagram) are compressive all along a distance 20 in. in front of and 20 in. behind the wheel point, and the stresses at the corresponding points on the outer face (bottom diagram) are tensile. The stresses shown are 46,000 lb. per sq. in. compressive at the inner face and 22,000 lb. per sq. in. tension at the outer face when the wheel is over the gage, both compressive and tensile stresses decreasing at points away from the wheel point. Subtracting the plotted direct stress from the total measured stress at any point, it will be seen that the bending stress (either compressive or tensile) is a maximum at the wheel point and decreases each way. The length of web resisting bending may be three or four times that resisting the direct or bearing load. The form at (a) is typical for stress records having relatively large bending stresses.

In (b) of Fig. 4 a different relation is seen to exist between stresses at inner and outer faces within the 10-in. length having direct stress. The effect of the direct stress here is to reflex the stress record and form a notch in the record for the outer face and thus to develop a higher tensile stress at the reflex point 5 in. away than is found at the wheel point. Examples were found when the stress at 5 in. from the wheel was 25,000 lb. per sq. in. tension and that at the wheel point only 10,000 lb. per sq. in. Away from the reflex points forward and backward the measured stress is almost wholly a bending stress, compressive on one face and tensile on the other face. The length of web resisting bending is somewhat shorter than found in (a). Records similar in form to (b) are found when the bending stresses have medium magnitudes.

In (c) of Fig. 4, in front of and behind the reflex points where the direct stress is too small to be noticeable, the measured stress again is almost wholly a bending stress, compressive on one face and tensile on the other face. However, between the two reflex points the stress record of the outer web face crosses from tension to compression, and at the wheel point the compressive stress at the outer face may have a magnitude as great or greater than the tensile stress at the reflex point. The form at (c) is representative of the large number of stress records having moderate or low vertical bending stresses in the web. As the eccentricity of wheel bearing approaches zero the notch of the record for the outer face may be expected to approach the part of the diagram representing direct stress.

The diagrams in Fig. 4 are explanatory of most of the forms of the vertical web stress records. As will be seen, they apply to inward bending of the web, but by reversal they will apply to outward bending. Naturally there may be variations from these forms. Cant of rail, wear of rail head, wheel contour, and other variations will change conditions in different ways. Thus, with outward bending of the web, tensile stress may be found in the inner face and compressive stress in the outer face. The length of the web thickness resisting the direct stress and also the length and the distribution along the web useful in resisting the bending moment will vary from that indicated on the diagrams. Stresses at horizontal sections of the web lower than 3¾ in. above the base may have different bending moments and different resistances than those here discussed. The diagrams however will be useful in interpreting the varieties in the stress records.

6. Comments on Some of the Results

To summarize the main results of the tests:

The position of the centroid of wheel bearing on the rail head evidently exercises a most importance influence on the magnitude of the vertical bending stresses developed in the web of the rail; eccentricity of wheel bearing is doubtless generally the principal source of the bending action found in the tests. These bending stresses may be considerably greater than the stresses called direct stresses. It is evident that the amount of the cant of the rail and also the shape of the worn top surface cause marked differences in the position of the wheel bearing and thus will affect the magnitude of the vertical stresses in the rail web. The larger rail cants decreased the web bending stresses materially. Worn rail heads giving greater inward slope to the running surface likewise decreased the bending stresses, and thus the higher compressive stresses were decreased.

It is apparent that even under good track conditions and under ordinary operating conditions of wheels of locomotives and cars, variations in eccentricity of wheel load bearing are to be expected. Minor imperfections of rail alinement and surface, differences in cant and wear of rail, wear and variations in tread of wheels and in bearings and other parts of rolling stock, shifting of wheel flange to and from gage side of rail, hunting and wandering of wheel on rail due to coning and other causes, inherent variations of locomotive forces at the two sides for different locomotives and different speeds—all must be expected. The position of the bearing contact of wheel on rail is dependent upon wheel contour (worn or not), actual cant of rail under loaded conditions, wear of rail section, position of wheel flange with respect to gage side of rail as the wheel continues its hunting along on the rail incident to coning of the wheel, and other causes. What is needed is the nearest practical approach to conditions giving moderate bending stresses in the web. Such modern improvements as machine adzing of ties with high-grade equipment should be given credit for improved conditions. Excellence in design and maintenance of rolling stock is very important.

In addition to eccentricity of wheel bearing, the existence of large lateral forces applied to the top of the rail by the wheels of locomotives and cars even on tangent track may develop large bending moments in the rail web. That such lateral forces may even exert extremely high bending action in the rail web is of course apparent in the downward and inward bending when rail is kinked by imperfect locomotive counterbalance, and of course lesser counterbalance effects will contribute in lesser degree to bending in the web without visible effects.

In the tests on the D. & R. G. W. R. R., vertical compressive stresses of considerable magnitude were found under the wheels on the inner face of the web and tensile stresses of lesser magnitude on the outer face. These larger values were found on the left rail at the high westbound speeds with regular traffic. Locomotive 3700 (4-6-6-4) used for tests on one day, gave many high stresses on the left rail at the higher speeds westbound and much lower stresses on the right rail, while at speeds of 5 miles per hour the high stresses were found on the right rail and moderate stresses on the left rail. Locomotive 1804 (a newer 4-8-4 passenger locomotive) at both slow and fast speeds gave moderate or small stresses on both rails, uniform and reasonably similar for the same three gage locations.

The principal source of the high web stresses on the D. & R. G. W. R. R. is evidently eccentricity of wheel bearing at the surface of the rail. Change in cant of rail, use of central ridge for the bearing surface for the wheel, and brightness of rail surface near the gage side corroberate this conclusion.

With 112-lb. rail on the I. C. R. R. the higher of the compressive web stresses found were moderate in magnitude (except for 4 values) and relatively infrequent, and the tensile stresses were usually relatively small. Although laid with tie plates with inclination 1 in 40, the greater cant of the rail in track, mostly 1 in 25 at the gage locations, contributed to moderation in web stresses. In 110-lb. rail laid in 1924 and worn and canted in a way to conform toward the usual wheel coning and with appearance of head indicating small eccentricity of wheel bearing, moderate web stresses were the rule. In 90-lb. rail laid in 1920 and having the rail head worn to an inward slope approximating 1 in 17, even though one rail web was vertical and the other canted only slightly the web stresses were all moderate or small.

Although many vertical web stresses of considerable magnitude were recorded in the tests of 112-lb. rail on the track of the D. & R. G. W. R. R., the actual percentage of high compressive stresses developed in the passage of all the driving wheels of the locomotives is not great, and the percentage of the higher tensile stresses coupled with alternations of compressive stresses of considerable magnitude on the outer face of the web (where the cracks had formed) is even smaller. It is not thought that the high compressive stresses developed in the inner face of the web, alternating on that face perhaps to zero or to small tension, bear any known relation to the formation of cracks in the outer face. The number of repetitions of alternating tensile and compressive stresses found in the outer face greater than 15,000 lb. per sq. in. is small, seemingly insufficient to cause the development of fatigue cracks. As to the magnitude of the higher values of stress, at the inner face of the web a few compressive stresses of 60,000 lb. per sq. in. and a few tensile stresses of 30,000 lb. per sq. in. were found, though these were not necessarily alternating or made on the same run, and no cracks had been found on the inner face. At the outer face a few tensile stresses between 25,000 and 30,000 lb. per sq. in. (including high tensile stresses 5 in. ahead or behind a wheel at reflex points) were found and also a few compressive stresses of similar magnitude, though their occurence was not in a way to form cycles of stress. Reversals of this magnitude are so infrequent that they can hardly by themselves explain the formation of cracks. It is evident, however, that higher stresses are frequently developed in the web of the rail in service than had been supposed and in many cases these vertical web stresses are relatively higher than the longitudinal bending stresses existing elsewhere in the rail. Faster speeds or indifferent conditions of equipment would have increased the web stresses. Whether other sources of strains in the rail were present and superimposed on the measured stresses is not known. This matter is worthy of further investigation.

Two suggestions are made in conclusion:

(1) That further tests and investigation be made on the occurrence and the sources of high vertical stresses in the web of rail on both tangent and curved track for both 112- and 131-lb. rail.

(2) That a comprehensive investigation be made of the fatigue resistances of the metal in the web of the rail, together with other conditions that may contribute to the formation of cracks.

PROCEEDINGS

PROCEEDINGS

Report of the opening session of the convention on Tuesday morning, March 11, 1941; the closing session on Thursday afternoon, March 13; and other business not related to the presentation of the committee reports

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Opening Session, Tuesday Morning, March 11, 1941

The forty-second annual convention of the American Railway Engineering Association was called to order at 9:55 a.m., on March 11, 1941, in the Grand Ball Room of the Palmer House, Chicago, by Vice-President F. L. C. Bond, vice president and general manager, Central Region, Canadian National Railways, Toronto, Ont.

Vice-President Bond: This is the forty-second annual convention of the American Railway Engineering Association. It is now declared open for business. This convention is likewise the annual meeting of the Construction and Maintenance Section, Division IV —Engineering, Association of American Railroads, the sessions being concurrent.

The first order of business is the reading of the minutes of the last annual meeting. Inasmuch as these minutes have been printed and a copy has been furnished to each member, unless there is some objection, the reading of the minutes will be dispensed with. Any objections? As there are no objections, the minutes stand approved as printed.

Address of Vice-President Bond

In calling the convention to order this morning it is with a heavy heart and a deep sense of the responsibility which devolves upon me owing to the calamity which has befallen our Association through the loss of our revered president, George S. Fanning, to whose memory appropriate reference will be made before beginning the routine functions of the convention.

In substituting for our late president I will endeavour, as far as in me lies, to give the convention an account of his able stewardship during his term of office—his aims and accomplishments on behalf of the Association.

Efforts to Improve the Association

In accepting the highest office which the Association could bestow, Mr. Fanning considered it a position of trust and responsibility, which called for the application of all the resources at his command, and which he gave unsparingly, particularly to the solution of the more difficult problems which came to the fore during his term as president, and measures designed to improve the effectiveness of the Association.

This is well illustrated by the means he adopted in an effort to carry out one of his chief aims as your executive officer—an improvement in the proceedings of our convention, and the manner of presenting the committee reports. Firm in the conviction that much could be done if his ideas were placed before the committees in a convincing manner, he set for himself the task of attending at least one meeting of each committee. While he was unable to carry out this plan in its entirety, nevertheless Mr. Fanning succeeded in presenting his message in person at the meetings of 14 committees—no doubt a far greater number than has ever been visited in a year's time by any other president of our Association.

However, he was by no means content even with this record, and, to insure that his views would be presented before the remaining committees, he wrote to the chairmen, setting forth what he had proposed to say, and asked that his letter be read at committee meetings. I take the liberty of quoting extracts from one of these letters:

> Many observers feel that our proceedings are too dull, with too much evidence of the "steam roller," and with too little discussion. The reasons for this are perhaps, first, that our time is limited, and, second,—and probably much more important—that our committee reports are so thoroughly worked over, and there is nothing generally which the member on the floor can find to criticize if he had read them.
>
> However, there is something else which I think the committees can do, and that is, make the presentation of their reports to the convention more interesting. The present practice is either to read all or part of the printed report, or simply to refer to it by bulletin and page number. What I think we should have, to introduce each subcommittee report, is a snappy statement of the high lights of the report, presented in as striking a way as the subcommittee chairman can command. . . . . . .
>
> Our reports, as printed in the bulletins, should be thorough, and, in being thorough, they occasionally may have to be dull, but in the presentation of the reports on the floor of the convention, let's forget the thoroughness and get away from the dullness.

I am sure our committees have taken our late president's suggestions to heart and that our convention this year, and those which follow, will be made more interesting and more valuable in consequence.

In centering his attention on the presentation of the reports, Mr. Fanning did not overlook the fact that presentation is the instrumentality for stimulating discussion from the floor of the convention. Again we find evidence of his initiative in a circular letter which he wrote in his capacity as chairman of the Engineering Division, Association of American Railroads, to the chief engineers of the member roads, suggesting a critical examination of the committee reports by members of their staffs, and discussions of the same from the standpoint of the experiences and practices of the individual railroads. I sincerely hope that discussions originating from this source will be given freely during the sessions which follow.

Increased Usefulness of Association

The administration of your president has been marked by an expansion of the Association's usefulness and prestige. In his capacity as chairman of the Construction and Maintenance Section of the Engineering Division he took an important part in broadening the scope of the research activities carried on for the solution of problems assigned to our standing committees, as evidenced by an increase of $25,900 in the allotment of funds for such work by the Association of American Railroads during 1941, as compared with the appropriation for 1940. The success of his efforts to this end may well be ascribed to a practical view of matters bearing on research, which inspired confidence in the soundness of his judgment and advice.

Among the projects recently authorized is the investigation of the relation of track to equipment—particularly the effect of locomotive counterbalancing, in which your Association in its capacity as a unit of the Engineering Division, is participating jointly with the Mechanical Division. President Fanning had an active part in the conferences leading to the development of the general plan of this work, and to the formation of a joint committee to administer this important project.

The resignation of Dr. A. N. Talbot as chairman of the Special Committee on Stresses in Railroad Track, effective with the close of this convention, has created a primary problem to which your president and members of the Board of Direction have given a great deal of thought. After nearly three decades, during which our knowledge of track and its behaviour as an engineering structure has been tremendously expanded under the leadership of Dr. Talbot, your board is now confronted with circumstances that differ widely from those that were presented when he started his classic experiments in 1913. Instead of one research project, your Association is now carrying on a variety of important investigations with funds provided by the Association of American Railroads. Furthermore, it has at its disposal the services of a research engineer who was engaged four years ago for the special purpose of taking an important part in the research work of the Engineering Division.

Value of Coordinated Research

In view of all the circumstances, your board is convinced that the advantages of coordinated administration of this research work would be more readily attained by having the research engineer's office serve as a clearing house for all, or nearly all, of the research work carried on for your Association. Accordingly, for the purpose of insuring an effective contact between your Board of Direction and the research engineer, your board has adopted a change in the committee organization, effective with the close of this convention, which I will describe briefly:

The Special Committee on Stresses in Railroad Track has been replaced by a new committee, which, in recognition of its broader responsibilities, will be known as the Committee on Research Administration. This committee will:

> Exercise general supervision over such research work of the Engineering Division as administered by the research engineer, insofar as it relates to assignments of AREA committees or work that falls within the scope of the Association's activities.
>
> Review the requests of the standing committees for research appropriations; service and submit them to the Board of Direction with appropriate recommendations.
>
> Initiate arrangements with universities and others when the need for cooperative investigations is indicated.

It should be understood that the acts of this committee will be subject to such review as must be exercised by the Committee on Research of the Engineering Division by reason of its responsibilities for the research work of the division.

Among the more formidable activities of the Association during the past year has been the continuation of the work of revising the trackwork plans on which the initial steps were taken in 1939. This is an exacting task, which has involved the generous cooperation of the manufacturers of frogs, switches and crossings, and which, when completed during the present year, will result in a marked improvement as well as a simplification of practices in this phase of railway engineering. The Committee on Track, which is charged with the responsibility for this work, will present tomorrow morning, as a part of its report, 50 of the new plans for your consideration and adoption.

While on the subject of committees, I wish to direct your attention to the report to be offered this afternoon by the Committee on Cooperative Relations with Universities, the first report to be presented by this committee since its restoration to activity by action of the Board of Direction a year ago.

You are also reminded that the Committee on Rules and Organization, which, for certain reasons, submitted no report in 1939 and 1940, will come before the convention on Thursday afternoon with an extended compilation of rules, which will be duly submitted.

In accordance with a suggestion made by President Fanning shortly after the last convention, the current progress report on the investigation of fissures in railroad rails has been preprinted in Bulletin 423, rather than withhold publication until after the convention. I am sure that perusal of the report will greatly enhance the value of Professor Moore's presentation tomorrow afternoon.

Association's Finances

The finances of your Association are in sound condition. The revenues for the calendar year of 1940 were substantially the same as those in 1939, but the expenditures were greater in the amount of $2,181.64, due primarily to an extraordinary outlay of $1,785.93 for the publication of the trackwork plans, and an increase of $651.31 in the expense for publications other than these plans. However, in spite of this, the revenues exceed the disbursements by $1,814.62.

An analysis of the expenditures of the Association over a period of several years discloses a marked uniformity in the outlay for the various accounts from year to year, except in that for publications. It follows without demonstration that as the work of our committees increases or decreases, as measured by the number of printed pages of reports, our disbursements for printing are subject to comparable variation.

In general, therefore, it may be said that the value of the work of our committees bears some relation to the size of our printing bill, inasmuch as we know that our committee members and chairmen have made it their practice to weigh carefully the intrinsic value of the matter which they submit for publication. This is a point that we should keep constantly before us.

Junior Memberships

Further details of the affairs of our Association are contained in the reports of the secretary and the treasurer, which there is no reason for me to anticipate at this time other than to make special reference to the change in our constitution, which became effective last June, for the purpose of establishing a junior grade of membership, the object and nature of which should be sufficiently apparent.

We look forward to a continuing response from those younger members of our profession who are resolved to equip themselves for their chosen vocation and who can appreciate the incalculable benefits and opportunities thus placed at their disposal.

The response so far has been encouraging, but it is only a beginning. I will take this occasion to welcome most heartily all those junior members who are attending the convention; you will find a helpful brotherly spirit everywhere in evidence; you are to feel quite at home, and we would like you to show your active interest by taking your part in the discussions.

In conclusion, may I remind you that, on March 16, 1940, you entrusted the affairs of the Association to the late George S. Fanning. You knew that his administration as president would present problems of more than ordinary consequence; but his record, and unfortunately I must add, his posthumous record, speaks for itself. It proves beyond question that you chose wisely. His achievements are both an inspiration and a challenge to those who follow.

Vice-President Bond: The next order of business is the report of the secretary and the treasurer. I will ask Mr. Lacher, the secretary, to present these reports.

(The secretary commented briefly on these reports, which appear in full on pages 791 to 801, inclusive.)

Vice-President Bond: You have heard the reports of the secretary and the treasurer. What is your pleasure?

Past-President Hastings: I move their adoption.

(The motion was seconded, put to a vote and carried.)

Vice-President Bond: I will now ask Mr. Hastings if he will kindly enable us to pay a tribute to the memory of our president who is not with us today.

Tribute to George S. Fanning

During the closing hours of the 1940 convention many of those who are here this morning witnessed the installation of the new president of the Association. I had the privilege and honor at that hour of handing to George Stokes Fanning the symbol of office, the gavel he was to use throughout the year. Surely none of us thought then that when we came to another convention, after a year had rapidly rolled away, we would not find George Fanning in the chair. Here we are this morning and Mr. Fanning is not here. On January 2 this year he put down the cares and burdens of life, gave up its joys and sorrows and went on out into that which lies beyond and endures through all eternity. We take this moment to honor his memory. How insufficient words seem to be at such a time; we feel within us the urge of things that cannot be expressed, and yet we try to express them in order that the world may know we are not devoid of feeling and may know that this great engineering association is concerned in the human things, the principles of love and friendship, the things of life that are the first things and the things that endure. The poet Longfellow said in a familiar verse:

> Life is real, life is earnest,
>   And the grave is not its goal,
> Dust thou art to dust returnest,
>   Was not spoken of the soul.

Mr. Fanning lived a life that was real and a life that was earnest. He put himself unselfishly into all the walks of life wherein he trod, and the engineering profession, the railroad industry, civil and social life are all better because he was here and contributed to the ongoing of all. I had the privilege of having a close warm friendship with Mr. Fanning, as well as the professional and association contacts; his kindly counsel and earnestness of purpose I cherish in memory.

I do not here recount to you his work with this Association, you know of it, the records of the Association record it for posterity. We miss him now, we will miss him in the years to come, but to look at the record of such a life and personality should be a challenge to all of us as we face the future.

The passage of time this past year has cut deeply into the ranks of those that this Association has honored and who have by their work helped to make the Association what it is. In addition to Mr. Fanning, there passed on during the year Past-President Storey, Past-President Downs, Past-President Neubert, Past-President Irwin, Director Faries and others. These losses are keenly felt; they should make us pause amid the confusion, strife and uncertainty of the present day and realize that indeed "Life is real and life is earnest"—it should be spent in service and right living, for it is all too short. Surely when we contemplate the worth and influence of the lives of those who have gone on, we should feel that life is real and life is earnest, and that we ourselves should so conduct our living and our thinking, our walking and our striving in line with those immortal words of Bryant, when he wrote:

> So live, that when the summons comes to join
> The innumerable caravan, which moves
> To that mysterious realm, where each shall take
> His chamber in the silent halls of Death.
> Thou go not, as the quarry slave at night,
> Scourged to his dungeon; but sustained and soothed,
> By an unfaltering trust, approach thy grave
> Like one, who wraps the drapery of his couch
> About him, and lies down to pleasant dreams.

Mr. Bond, I have the honor, on behalf of the Association, to hand to you this morning the president's plaque, the gift of the Association to its president, and to ask you to present it to Mrs. Fanning. The inscription on the plaque reads:

"The American Railway Engineering Association here records its appreciation of George Stokes Fanning for his able administration of the office of President 1940-41. With his winning personality and the power to lead, with unfaltering courage and his keen mind and his will to do, he served well."

Vice-President Bond: Mr. Hastings, on behalf of Mrs. Fanning, I accept this plaque in trust and for transmission.

For a few moments of silent remembrance, I will ask you to stand.

(Silent tribute)

Vice-President Bond: As stated previously, this Association also functions as the Construction and Maintenance Section of the Engineering Division of the Association of American Railroads and, as such, reports to the vice-president of operations and maintenance, Mr. C. H. Buford, who is with us this morning.

Mr. Buford, I know our members are very happy to hear from you; any remarks instructions, or reprimands will be equally welcome. (Applause)

Address of C. H. Buford

Vice-President, Operations and Maintenance Department
Association of American Railroads, Washington, D. C.

When Mr. Bond invited me to talk to you today, there was doubt in my mind about being able to accept his kind invitation. I am glad things worked out so I can be with you, because there are things I wanted to say to your group concerning the current railroad situation.

The members of the American Railway Engineering Association, which is the Engineering Division of the Association of American Railroads, are directly responsible for the construction and maintenance of almost all the railroad mileage of the North American continent. Your problems are increasing with the modern trend toward higher speeds and larger locomotives. The successful operation we have today is a credit to the manner in which you have done your work.

I am glad to know that the cooperative work of the Engineering and Mechanical divisions is being continued. The Board of Directors of the AAR has authorized an expenditure of about $115,000 for the joint study of counterbalance and its effect on track. This authorization is a tribute to Professor Talbot and the committee appointed by him to carry on the work. This committee has the full support of the general committees of the Engineering and Mechanical divisions, and I am confident that the results of its efforts will add another star to the crown that rightfully belongs to Professor Talbot in recognition of his many years of leadership in improving the railroad plant in this country.

The officers of the AAR appreciate the way in which you have handled the activities of its Engineering Division during the past year. The address of your presiding officer and reports of the various committees show that your work is being handled in an excellent manner and is in competent hands. In view of this, there is no need for me to repeat what you already know. Instead, I want to talk with you about the general railroad situation.

Transportation and the Defense Program

Railroad transportation is important in peace time. In this changing world and in our efforts to strengthen the defense arms of our nation, more people are realizing just how important it is. The increasing need for transportation in this country is causing apparent concern to some writers and others who are referred to as "transportation experts." It is fuel for the flame of a small group who openly or in their hearts hope for government ownership of the railroads. This group usually plant their feet firmly on what happened in 1917 and 1918. They ignore the lessons the railroads learned from that experience and the improvements that have been made since then, and they point a finger of doubt at the railroads' ability to handle business resulting from the national defense program.

As railroad officers, you will hear of some of these things; therefore, I want to review briefly what happened in 1917 and 1918, the changes that have taken place and what the railroads are prepared to do in the future.

What was the situation immediately preceding the last World War, and what were the underlying causes of the transportation difficulties at that time? In 1916, there was no strong central railroad organization with authority to meet any transportation emergency. With the increase in business due to the war in Europe, some difficulties were encountered and an effort was made to set up an organization to handle the situation. The Railroad War Board, created immediately after America entered the war, did some excellent work, but due to conditions beyond its control, it had little chance to function effectively. These conditions are covered and confirmed in the reports of the director general of railroads and in the annual report for the fiscal year 1919 of Brigadier General Frank T. Hines, who was the chief of transportation service of the United States army. I shall not give in detail the many difficulties listed, because they all add up to one thing: Railroad cars were used for storage instead of for transportation purposes.

No Basis for Comparison

Some people who analyze the railroad situation today apparently assume that conditions in the railroad industry are the same as those which existed in 1917 and 1918. The difference in the conditions then and now is the underlying cause of the erroneous conclusions that some investigators reach. There is no basis for a purely statistical comparison of the two periods, and there is no justification for the assumption that the same difficulties will arise again.

Today, the railroads have a strong central organization that is authorized to act for them in any emergency. This organization—the Association of American Railroads—has been working with the army, the navy and shippers over a long period of years on plans designed to avoid any possibility of transportation difficulties which might arise. The railroads are at least 20 years ahead in their planning, and a few facts in regard to this might be of interest to you.

Take the port situation: Late in 1917, practically all the Atlantic ports were congested; thousands of cars loaded with overseas freight were held back in the country because all yards near the ports were full of loaded cars that could not be unloaded. On June 11, 1918, an export control committee was organized and was successful in cleaning up the accumulation, and thereafter regulated the movement in a satisfactory manner.

On November 15, 1939, the Car Service Division of the Association of American Railroads established its Port Control Office. This organization was created due to increasing export movement caused by the war in Europe. Since its establishment, there have been months when the movement through the Port of New York was almost equal to the movement through this same port during the last World War. Yet, there has been no congestion, and at this port, as well as at all other ports in the United States, cars are being unloaded, on the average, within the tariff-free time. The manager of port traffic has an advisory committee of competent railroad officers and works with the railroads and ocean shipping agencies in bringing about this satisfactory condition. The free flow of commerce through the ports has been accomplished by cooperation, and it has not been necessary to use the embargo and permit system which can be employed to arbitrarily control any emergency.

Desired Results Being Obtained

The creation of this port control agency was not an accident. It was the carrying out of a plan that has been in existence for years—a plan designed to prevent conditions such as existed at the time the federal export control committee was formed in 1918. It has been effective and has obtained the desired results. It is now in a position to handle promptly any emergency that might develop at any port in the United States.

Under the Railroad Administration during the last World War, some arbitrary measures were used. Orders regarding maximum loading of cars were issued, and higher per diem rates were established. These steps were taken to increase the effective use of cars for transportation purposes. Some people say that the railroads should reinstate these restrictions; that it is necessary because there has been no improvement in the length of time that cars are in the hands of shippers. We have a record of the time shippers hold cars for loading and unloading, and detention is measured pretty well by the demurrage account. If shippers had held cars as long in 1939 as they did in 1920, they would have paid over 14 million dollars more for demurrage than they actually did pay in 1939.

Prompt Unloading Essential

Another situation we are watching closely is the large construction jobs being done for the army and the navy. Our last report was for projects totaling more than $1,150,000,000. Cars were being unloaded in an average of about a day and a half. Spot checks made at various industries indicate that a good job is being done in unloading cars promptly. There is no need at the present time for any kind of restrictions on shippers, and we do not want to place any. We believe the mutual interest of carriers and shippers will make it possible to get the desired results by cooperation, and we will continue our present plan unless conditions necessitate a change. I hope those of you here today who have charge of maintenance work will resolve to do as well in using equipment as shippers are doing, and after making that resolve, you will arrange for current checks of cars under load with company material to see that a good job is done.

About the largest shipper in our country today is the United States government. The Army, the Navy and those engaged in national defense work are moving large quantities of materials. During the last World War, shipments for the government caused a lot of trouble. The indiscriminate use of priorities for shipment with no place to unload the cars was the principal source of trouble. Plans were made and are in effect now to avoid this. The Car Service Division of the ARR has a Military Transportation Section. The manager of the section, with a competent staff, is located in the office of the quartermaster general of the United States army at Washington, D. C., and is the contact for all railroads in looking after the transportation needs of the army and the navy. It has not been necessary to resort to any form of priority in movement of any business for the government, and we do not think any priorities will be needed.

During the last World War, there was no organization of railroads and shippers. We now have 13 regions in the United States where there is a Shippers' Advisory Board cooperating with the railroads in each area. These regions are represented in a national board which looks after the interest of shippers in the United States. Each board in the group furnishes advance quarterly estimates of the prospective carloading in its territory. These estimates are the best forecast for future loadings that have ever been devised, and are valuable to the Car Service division in its efforts to maintain an adequate car supply for all sections of the country.

I will not take up more of your time in outlining things that have been done to avoid the sort of transportation difficulties that were encountered in 1917. The lessons we learned then have not been forgotten, and are a valuable guide for setting up safeguards for the future.

Facilities Are Adequate

After a careful analysis, I am convinced that the main line, yard and terminal capacity of our railroads is more than adequate for any business that will develop as a result of the national defense program. The only increase that may be needed will be in equipment. The need for equipment is directly related to the business to be moved, and this problem has given us the most concern. We have set up the machinery to provide a continuous and accurate flow of information on future business. Our estimates have indicated that the defense load will not exceed eight percent of the average commercial load.

Recently Mr. Ralph Budd, transportation commissioner of the Advisory Commission to the Council of National Defense, made public estimates of increased traffic for the years 1941 and 1942. These forecasts were based on estimates of increased production furnished by the Bureau of Research and Statistics of that body, covering commodities representing about 60 percent of the total carload traffic originated by the railroads.

The Bureau of Railway Economics translated these estimated increases in production into terms of carloads and arrived at estimated carloads for 1941 of 39,780,237, or an increase of 9.4 percent over 1940. The estimate for 1942 was 42,293,982 cars, or an increase of 16.9 percent over 1940.

Of course, the average weekly carloading does not mean much from a standpoint of car supply. Carloadings throughout the year vary from week to week. The peak loading occurs in the fall, usually in October, and the railroads figure on cars to handle that peak. Many thousands of cars have to be put in condition for this peak load, and ordinarily have no other loading throughout the year. To the extent that loading can be increased during the off-peak weeks, cars can be used that are otherwise idle. The defense program will call for fairly uniform shipments, and will not cause the same percentage of increase in the normal peak weeks that will occur for the other weeks of the year. This tendency to flatten out the loading curve will facilitate the movement of a large part of the increased loading without the need for additional cars.

Sufficient Cars in Sight

There are sufficient cars in sight now to take care of the loading this year, and others are being ordered as needs warrant. More cars will be purchased or rebuilt as earnings increase. The equipment purchases that are being reported to us indicate conclusively that the railroads were serious when they assured those whom they serve and the government of the United States that they would "meet to the full the demands of commerce and the needs of national defense."

The railroad industry has set up machinery to enable it to cope with an emergency. It has given satisfactory service during the peak loading periods of the past two years. It will be in shape to handle all business that may develop this fall, and will continue to be ready at all times to meet the demands of commerce. Still there are those who question the railroads' ability to do the job, and I would like to point out several things that may have given them this impression.

In the early stages of the defense program, a certain industry was behind in its shipping schedule and reported to the Procurement Department of the Army that it was short on cars. Investigation showed that the industry's track was filled with empty cars. Another industry also was behind schedule and wired the Procurement Department numbers of two cars that supposedly had been shipped. Investigation showed that the cars had not been loaded and the empties had just been spotted. One of the cars was shipped two days after the report that shipment had been made, and the second car was shipped four days later. Facts in cases of this sort are obtained by wire and given to the Procurement Department by the manager of the Military Transportation Section. Such excuses only serve to embarrass the industry making them.

Unnecessary Refinements

Here is another thing that might cause some people to think that the railroads do not have sufficient equipment. There are hundreds of different sizes of box cars when the inside length, width and height are considered. A car placed on a shipper's order may be one inch too narrow to fit the particular boxes he loads. Plenty of wider care are available, but are too wide because he does not want to do any blocking. Consequently, there is a shortage of the particular size car wanted. Cars are turned down because the length varies as little as two percent from the actual length desired. These cases are rare and are not really car shortages, although some people regard them as such. I mention these cases because someone may hear a shipper say he could not get a car, and without knowing all the facts, assume it was due to a shortage of equipment.

There is one thing in connection with transportation that is causing a great deal of concern to a lot of people at the present time. This has to do with the winter wheat crop which will be ready for movement in a few months. Of course, much can happen to a gain crop in a short while. Because of the fact that most of the storage space is now filled with grain carried over from previous crops and that there is at present a prospect of a good crop of winter wheat, serious thought is being given to what will be done with the grain when it is harvested. The Department of Agriculture is studying the matter and will probably find a solution.

Railroads are interested because the movement of the winter wheat crop is normally a major problem in car supply. We will have sufficient cars to move the crop, but cannot hope to provide cars for storage purposes. It is absolutely necessary that proper facilities be supplied for storing the grain, because cars will not be spotted for loading unless they can be unloaded at destination. To handle it otherwise would only tie up cars that will be needed by other shippers of important commodities. I am confident that the problem will be solved, and mention it simply because it is the only thing I know of at this time that might be troublesome.

Avoid Hysteria

On previous occasions, I have urged that people avoid hysteria in connection with our defense efforts. We are under terrific pressure to speed up production, and some people get excited and become hysterical under such conditions.

Your continued work with a railroad requires that you do not become hysterical under pressure, because railroading is necessarily a pressure business. You are well-fitted to think clearly in these strenuous times, and I hope you will lose no opportunity to correct any loose talk you hear about the railroads and their ability to cope with any transportation situation.

Vice-President Bond: On behalf of our Association, I want to thank you for that interesting and instructive address. We know you are here at some personal inconvenience, and we appreciate it all the more.

Report of the Tellers

(Presented Wednesday Afternoon, March 12, 1941)

We, the Committee of Tellers, report the following as the result of the count of the ballots:

For President:

F. L. C. Bond	934

For Vice-President:

W. F. Cummings	911
Scattering	18

For Directors (Three to be elected):

F. S. Schwinn	563
E. T. Howson	519
B. R. Kulp	425
J. F. Pringle	376
W. B. Irwin	262
R. R. Cummins	209
H. A. Aalberg	183
L. C. Frohman	173
H. F. Brown	153
Scattering	2

For Nominating Committee (Five to be elected):

A. E. Perlman	596
C. H. R. Howe	594
J. A. Lahmer	569
A. D. Kennedy	504
Miss Olive W. Dennis	446
H. F. King	428
E. W. Caruthers	417
R. D. Garner	413
D. B. Thompson	342
M. J. J. Harrison	336
Scattering	9

Respectfully submitted,

The Committee of Tellers,

R. C. Bardwell, *Chairman*
J. C. Bradley
W. T. Dorrance
R. N. Foster
H. L. McMullin
R. A. Morrison
F. E. Morrow
A. B. Pierce
W. C. Pinschmidt
H. E. Silcox
R. M. Stimmel
D. C. Teal
J. N. Todd
R. E. Warden
J. B. Wesley
A. R. Wilson

Closing Session, Thursday Afternoon, March 13, 1941

Vice-President Clarke (in the chair): Is there any further business to come before the convention?

W. G. Nusz (Illinois Central): I would like to present a resolution:

Be it Resolved, That the American Railway Engineering Association, in convention assembled, express its thanks to C. H. Buford for his constructive address at the opening session of our convention and for his cooperation with our Association throughout the year in his capacity as vice-president, Operations and Maintenance Department, Association of American Railroads. I move its adoption.

(The motion was seconded, put to a vote and carried.)

D. J. Brumley (Illinois Central): I have the following resolution:

Be it Resolved, That the American Railway Engineering Association, in convention assembled, extend its appreciation to the National Railway Appliances Association for the constructive exhibit of materials and equipment applicable to the construction and maintenance of railway roadway and structures, presented concurrently with the convention, which exhibit has added much to the educational value of our meeting.

I move the adoption of the resolution.

(The motion was seconded, put to a vote and carried.)

E. M. Hastings (Richmond, Fredericksburg & Potomac): I would like to offer the following resolution:

Be it resolved, That the American Railway Engineering Association, in convention assembled, record its appreciation to Hon. Clarence F. Lea for his constructive address at our luncheon, which address emphasized to our members the problems involved in the framing of legislation to provide equality of opportunity to the railways and other agencies of transportation. I move the adoption of the resolution.

(The motion was seconded, put to a vote and carried.)

Vice-President Clarke: If there is no further business to come before the convention, I will ask Past-President Wilson and Past-President Brumley to please conduct President-Elect Bond to the rostrum.

(President-Elect Bond was escorted to the rostrum.)

Vice-President Clarke: I will ask Past-President Campbell, I believe the oldest past president here and who was president when I became a member of this Association, to install President-Elect Bond.

Past-President Campbell: My dear Mr. Bond, it is my privilege to notify you that, as expressed in the election returns, the American Railway Engineering Association has elected you to be its president during the ensuing twelve months.

Your qualifications for this high position are so eminent and obvious that it is unnecessary to elaborate them. There is an additional reason why this Association delights at this time to so honor you.

The jurisdiction and the membership of this Association extend far beyond the limits of the United States. From time to time it has delighted to give recognition and honor to Canada through the membership from that neighboring country, so that we have had the pleasure of being presided over by a president from that land.

Therefore, by the authority of the American Railway Engineering Association, I declare you to be its duly elected president for the ensuing twelve months and, as the emblem of your authority and jurisdiction, I have the honor to present to you this gavel. (Applause)

(President Bond assumed the chair.)

President Bond: Mr. Campbell and Gentlemen: I am indeed very much moved by the kind, flattering and, to a certain extent, neighborly remarks of our past-president, Mr. Campbell, with whom I have had the pleasure of being associated at intervals over a comparatively long period of years. In my earliest recollections of the AREA I remember Mr. Campbell.

In accepting the highest office at the disposal of this distinguished and able Association, I am sincerely conscious of the high honor and the distinction which you have thus seen fit to bestow.

It is also with a very deep sense of the responsibility which devolves upon me, following as I do a long line of distinguished predecessors who in turn have each felt their responsibility and their obligation to do all in their power to promote the welfare, the continuing and the progressive welfare of our Association. But my feeling of unworthiness is relieved when I look around at the Board of Direction and also the membership from whom we have always received the most able and helpful advice.

Any change naturally involves a certain amount of a bump, and it is with sincere expressions of regret that we note the retirement of our friends Mr. Geyer, Mr. Layng and Mr. Brennan, who have been so active on the Board committees and whose work has always been of outstanding eminence and ability.

We also have to note the new vice president, Mr. Cummings, and we also have Mr. Howson, Mr. Kulp and Mr. Schwinn, who have been elected to the Board of Direction. May I ask those gentlemen to kindly stand so that we can see whom we have elected? (Applause)

I would also like to pay my sincere tribute to our very able secretary. Following the tragedy that met us during the past year, I cannot pay tribute too high to the able assistance which I personally and we all received from our secretary. (Applause)

The final registration is as follows: For 1941 we had 692 members and 526 guests, making a total of 1,218. Last year we had 719 members and 483 guests, making a total of 1,202. That means we had 16 more this year than last, although there are fewer members this year and more guests.

I have to explain that a good many of your members from your neighboring country to the north have found it exceptionally difficult to attend this year and, on their behalf, I will ask you to excuse those who are not here because I think you will find that they had ample and abundant reasons for not being able to get to the Association meeting.

If there is nothing further, I will now call the meeting adjourned.

(The meeting adjourned at four-five o'clock.)

Federal Regulation of Transportation

An Address Presented Before the Annual Luncheon on March 12, 1941

By Hon. Clarence F. Lea
Chairman, Committee on Interstate and Foreign Commerce,
National House of Representatives

I am going to speak to you on the subject of "Federal Regulation of Transportation." I recognize I am speaking to men who are familiar with the mechanics of construction and operation of railroads. I think of an engineer as a man who devotes himself to planning and constructing useful things that better serve people. I think of him as carrying out plans that overcome the handicaps of nature. He adds to the sum of human comfort and advancement. I think of a railroad engineer as a man who has designed a modern terminal with its freight and car-handling devices and arrangements, who has defied the broad and turbulent stream and over it constructed a magnificent bridge on which people and materials pass in rapid safety and comfort. He has thrown the steel rail lines across the desert, laid them along the banks of the plunging mountain stream imbedded in narrow and tortuous canyons. He has designed locomotives that pull their great loads from the four corners of the republic across the valleys and along the very rim of the jagged peaks of our greatest mountains, to the other side of the continent. He is a constructor, a builder, a benefactor. His job is never ended. There is something new yet to be done, another improvement to be made, another purpose to be accomplished.

So far as the federal government is concerned, it has staked its future relation to transportation upon a policy of regulation. Under a policy of regulation founded on intelligent treatment of our carriers with fairness and according to the economic worth of their services, the interest of the government and all our transportation agencies lie parallel with the interest of the people of the nation. The success of that policy is dependent upon public understanding and support.

Authority to Regulate Commerce

Outside of the taxing power given to the federal government, there is probably no other one clause in the Constitution which more directly concerns the economic affairs of the country than that provision which gives Congress authority to regulate commerce with foreign nations and among the several states.

The Articles of Confederation, under which this nation functioned prior to the adoption of the Constitution, had many weaknesses, one of which was: It had no control over interstate commerce, no authority to promote it or to protect it against unfriendly action of the individual states.

The people who had self-sacrificingly and heroically cooperated to bring the Revolutionary War to a successful conclusion soon thereafter found themselves in unhappy disagreement with each other. Some of the states were attempting to restrict or bar the commerce of their sister states in favor of their own. Retaliatory legislation with bitter resentments followed.

In recent times, a barge load of potatoes merely passing up the Danube River to an interior country was subject to a tax by lower states through which that river flowed. So before the Constitution, an ox-drawn wagon bringing firewood from Connecticut to keep Old New York warm could not pass over the boundary line of that state until it had paid its toll at a custom house. A charge was made in New York on products entering New Jersey and other states. In a feeble effort of retaliation, New Jersey imposed a tax on the New York lighthouse maintained at Sandy Hook. Similar irritations, with resulting sectional hatreds, created a compelling demand for a new federal government. The bitterness of these trade difficulties developed to the point where representatives of some states went so far as to assert that they would rather ally themselves with a foreign country than with some of their sister states.

Common Interest in "Regulation of Trade"

On January 21, 1786, a General Assembly of Virginia appointed commissioners to meet with such commissioners as might be appointed by other states "to take into consideration the trade of the United States; to examine the relative situations and trade of the said states; to consider how far a *uniform* system in their commercial regulations may be necessary to their common interest and their permanent harmony; and to report to the several states, such an act relative to this great object, as when unanimously ratified by them will enable the United States in Congress, effectually to provide for the same."

This action was followed by the Annapolis convention which met September 11, 1786, and the Virginia resolution was given the concurrence of Virginia, Delaware, Pennsylvania, New Jersey and New York for the same purpose. New Jersey, in appointing its commissioners, suggested the consideration of "other important matters" which was the course followed by the constitutional convention. As a result of the action of these states, the constitutional convention assembled and our Constitution was finally written and ratified.

Regulation of commerce by the federal government was designed to provide a system of uniform regulation, or rules, governing commerce for the whole nation to lift regulation above the petty, provincial and retaliatory action of the individual states. It was intended to encourage, protect and make commerce free. In a few words written into the Constitution, Congress was given authority to regulate commerce with foreign nations and among the several states.

On December 14, 1795, the House of Representatives created a standing Committee on Commerce and Manufacturers. That committee is the original predecessor of the persent House Committee on Interstate and Foreign Commerce. That was 91 years before the Interstate Commerce Act was written. Part of the work of that committee was to exercise jurisdiction under the clause authorizing Congress to regulate commerce.

More Power to Federal Government

The original thirteen states reluctantly yielded to the federal government the powers that were necessary to make it virile and effective. The constitution took from each state its absolute power to control interstate commerce within its borders. In the main, it gave that power to the federal government. It intended to deprive the states of the power to hamper and harass the commerce of their sister states and bring it into federal protection and regulation. It gave to this commerce the freedom of the protection that the federal government could give. It relieved each state against the burdensome and destructive action of every other state. This clause of the Constitution was established to promote and protect commerce. That is still the legitimate end of federal regulation. We deliberately seek liberty of commerce within the restraints of law rather than license without the restraint that the forty-eight states could impose.

The Constitution was written when transportation and communication were difficult. There were no railroads, no motor vehicles, no steamboats, no airplanes, no modern highways, no telegraphs, no telephones, radios, electric or pipe lines. There were no great industrial enterprises. America was an agricultural country. Only five percent of the population lived in cities. The farm was an economic unit of production, manufacture and consumption. It had little dependence on the markets of other states. There was no mass production. The modern corporate system of doing business was then practically unused. The financing of great business enterprises through the widespread sale of their securities on market exchanges was not part of the economic life.

The new government under the Constitution did not hasten to assert its powers over commerce. Placing the power of control of interstate commerce beyond the destructive hands of the states in itself largely accomplished the protection that was needed in the early days of the republic. Congress passed only minor acts as to such commerce prior to the Civil War. It is said that in over seventy years preceding the Civil War only about twenty cases involving the interstate commerce clause reached the Supreme Court. The first great step in federal regulation was taken when the Interstate Commerce Act was passed in 1887.

Changes that Led to Interstate Commerce Act

Someone reviewing the history of the exercise of power under the interstate commerce clause states that it was not until the Interstate Commerce Commission was created "that the sleeping giant" of federal regulation was awakened. That statement was probably justified. A more compelling reason, however, for regulation arose out of the economic changes coming with the decades following the Civil War.

As the nation advanced from its primitive to its modern conditions, these changing developments brought into sharper conflict the original division of state and federal powers as established by the Constitution. It was rail transportation with its lines running across state boundaries serving the needs of this newly developed economic world that first obviously emphasized the new interstate relations.

As the rail lines advanced, 10,000 communities in the United States welcomed their advent with brass bands and barbecues. The rail lines offered these communities the best known transportation, a spreading market for their products, a new day for their community. And so it was. Today when we travel over some sections of our country, we may see abandoned roadbeds or rusty rails. They are reminders of the days of daring enterprise, of progress and decline.

The Civil War was followed by a marvelous period of railroad construction and expansion, including over-expansion and in many cases improvident duplication of facilities. Abuses in financing operations were notorious and unjust discriminations and rebates grew up that affected shippers, roads, industries and sections. These abuses created the demand for federal regulation and reflect the type of regulation adopted. The general purpose of the early legislation was to protect shippers, communities and the public against the established abuses of railway operations. Reflecting this purpose, the original Interstate Commerce Act was directed principally at requiring rates to be reasonable, and the prohibition of unjust discriminations, rebates and monopolistic agreements.

The last 25 years have seen a great change in our transportation system. At the conclusion of the World War, the Panama Canal was an open water route from the Atlantic to the Pacific and made intercoastal water transportation available to over one-half of the population of the country. Three million miles of highways, many of them paved, made a net-work over the nation. Thirty-two million motor vehicles are operated on these highways including several million trucks. Twenty-five years ago these roads were only feeders and not competitors to the rail lines. Today, they are substantial competitors of every form of transportation. The pipe line and the airplane have entered the transportation field in a substantial way. A division of the traffic and a competition of rates with a long depressed business period in recent years have all been problems for our carriers and the country.

Changing Economic Conditions

In that quarter of a century, regulation has taken a more embracing form. The old abuses have been largely eradicated. Changing economic conditions have made the carriers themselves objects of a protective care of the government. Regulatory protection is no longer confined to the public as against the carrier. Now, without deserting the public, regulation gives the carrier protection against abuses that may injure or destroy him. Surplus facilities, present and potential intensive competitive conditions, and a long depression have emphasized the need of coordination of facilities and of placing the game of competition under fair rules.

The owners of transportation facilities, including their security owners, are entitled to that just consideration that the government should give to ownership everywhere.

Regulation does not place on the government the obligation to support unwarranted or improvident investments nor to maintain a transportation unit after it has lost its economic value to transportation needs. The public should be concerned, however, in the maintenance of useful facilities and securing a fair return to their owners. The maintenance of our transportation system on the basis of private ownership ultimately depends on a showing that an investment in such facility is reasonably secure and offers a fair return.

We have had abandonments and reductions of rail service to an important extent. We have the threat of gradual elimination of more branch lines and then more important lines. A degree of such abandonments is inevitable and undoubtedly, in some instances, necessary. There is a danger, however, that abandonments may occur based on the ill-experience of an unfortunate period, where the maintenance of such lines under proper regulation might be warranted from the longtime viewpoint.

The Test of Economic Regulation

The test of economic regulation for the next ten years depends upon how successfully it may preserve useful transportation, prevent its substitution by a less qualified service and so stabilize the industry that sources of funds for continuing operations and replenishment of capital shall not dry up. In other words, the desirable remedy is to put the carriers on a self-supporting, healthy basis.

If this end shall be accomplished, the responsibility, to no small degree, must rest upon the Interstate Commerce Commission as our regulatory body. Its members are men of high ability, integrity and purposes. They should be given the benefit of every aid that might contribute to the success of their work. Their task will call for enlarged responsibilities, greater initiative and new approaches to some of their problems.

People who use a railroad want it to give efficient service at reasonable prices; the laboring man wants it to give employment; the farmer and producer want it as an outlet to their market. Some local communities want it to be their principal taxpayer. The rail lines have served those purposes fairly well.

The original motive for the construction of the railroad was the hope of a secure and profitable investment. The weakest point in our transportation system of recent years has been the inability of a large number of our railroads, of our shipping lines and of our commercial highway carriers to keep red off their balance sheets. The long depression affected transportation lines much as it has all business. The common carriers, however, had less opportunity to reduce fixed charges and adjust outgo to income than most lines of business.

Though regulated, we cannot expect to relieve our carriers in periods of depression as well as in periods of prosperity from sharing the fate of the country they serve. If that were the only trouble, the problem would be less difficult.

Notwithstanding many increases of cost, railroads have introduced new methods and modernized equipment and have given more efficient service on reduced charges during the last two decades. Special speed for emergency freight has been provided. Tracks have been improved, rolling stock supplied, schedules reduced, and cost lowered with additional accommodations to the shippers. Passenger trains have been streamlined and air conditioned. The fact that all this has been done in the face of the depression, a proportionate reduction of traffic and increased competition, must be recognized as an accomplishment creditable to railroad management of this period.

If it be true that we have excess transportation facilities that must be discarded, that some must perish and some survive, then the problem of regulation is to see that the conditions under which some survive and others perish must be under fair rules of competition, in other words, under a system of rules which, as nearly as possible, will permit the carrier economically justified to survive and leave failure alone to those not economically justified.

To boil down the situation we have these facts: We have a newly developed, highly competitive situation between various transportation agencies which calls for coordination to protect our national transportation system and conduct it under fair rules of competition. In the second place, we have a need of regulation so exercised that each of these agencies within its legitimate field may receive a fair and just reward for the useful service it is performing to the nation. These purposes must be among the objects of federal regulation if we are to face the situation candidly.

Transportation Policies

In the Transportation Act of 1940, Congress wrote a declaration of a national transportation policy. It is provided that the Transportation Act must be enforced with a view of carrying out those policies. This is the first broad declaration of a national policy for transportation that has been written in the laws of our country. It is the most modern statement of the purposes of regulation that has so far found its expression in our federal laws.

Several purposes are declared. One is a purpose to provide for fair and impartial regulation of all modes of transportation. Heretofore we had some carriers regulated, some unregulated and different agencies regulated by different authorities. This new act, with the exception of air transportation, places all our transportation agencies under the unified regulation of the Interstate Commerce Commission. That was a conception of necessary regulation that the great Judge Cooley had when he was made the first chairman of the Interstate Commerce Commission 54 years ago. This is a step in the evolution of regulation of historical importance. Without any claim that we have reached an ideal state of regulation, this is one step that materially advances that time when we may hope to give regulation its best test as to whether or not it can master the complicated problems of Federal coordination of transportation.

This declaration of policy further declares a purpose to recognize and preserve the inherent advantages of each mode of transportation. Each new mode of transportation brought under regulation conjured up some grounds to fear it might be a stepchild to regulation. It found some grounds to claim it should be immune from the powers of regulation to which its competitors were subject.

Each government agency exercising regulatory powers resisted the surrender of those powers even where such surrender was manifestly required for the purpose of unifying regulation or coordinating the transportation agencies of the country. Each agency, with limited exceptions, seemed to regard itself as a particular partisan advocate of its branch of the transportation service and thinks of our transportation system pretty much in the narrow limits of its own interest.

America, as a whole, cannot be expected to devote itself to preserving any uneconomic unit of transportation. To do so would simply be against the rules of progress. Progress has an immutable rule of change from the old to new and better methods. All capital is conscious of that uncertainty that attaches to every investment.

Manifestly, the railroad has some advantages over other carriers. It is equally true that the truck and the bus and the ship and the pipe line and the air carrier each offers superior advantage under some circumstances for its class of transportation. Those inherent advantages are manifestly of benefit to the nation. They give it service;

they contribute to the comfort of the public; they aid economic advancement. The country is rightly interested in the inherent advantages in each of these types of carriers. Each of these agencies competes for and shares the transportation business of the country. Our federal regulatory authority has charge of the regulation of their rates. We have entrusted the commission with the burden of their regulation with a view of preserving the inherent advantages of each.

It must be recognized that as between these various types of carriers there will be a broad field where competition in service may prevail. There will be a field in which competition in both prices and services will prevail. There will be cases where the proper adjustment of rates will give the traffic to one carrier instead of the other. The fundamental principle underlying these distinctions is based on the just principle of the value of the service rendered. There is no injustice in that principle. The difficulty of administering this principle, it must be conceded, is great.

Must Visualize All Agencies

In attempting to preserve the inherent advantages of each method of transportation, we must visualize all the agencies of transportation as included in the transportation system of the United States, each having its useful function in performing its part, which should not be obnoxious to the other agencies of transportation.

Another declared purpose of our regulation is to promote safe, adequate and efficient service as a duty of the carrier to the public.

Another purpose is to foster sound economic conditions in transportation and among the several carriers. This purpose is consistent with the modern trend of regulation. Once regulation had in mind only the protection of the users of the railroad. In the face of modern conditions, we must recognize the importance of maintaining sound economic conditions among the carriers themselves. The transportation agency, to fully perform its service to the public, must be well and soundly financed. The public has an interest in seeing that justice is done to the carrier. Regulation in attempting to protect the carrier has a right to insist that his operations shall be conducted with a degree of economy, prudence and integrity that is conscious of responsibility to the public. In other words, regulation as it has developed reaches out and recognizes a much larger field of the public interest than was recognized a half century ago.

Still adhering to the purpose of regulation assigned fifty years ago, this declaration of policy commits regulation to the maintenance of reasonable charges without unjust discriminations, undue preference or advantages. Then again, recognizing the need of carrier protection, the declaration of purpose commits regulation against unfair or destructive competitive practices. The carriers are entitled to protection against cut-throat methods of competition. There is a further declaration of purpose to encourage fair wages and equitable working conditions. This is the statement of the just relations that should exist between employer and employe. Then this declaration concludes by asserting that the end of this regulation is to develop, coordinate and preserve a national transportation system by all these agencies to meet the needs of commerce and our national defense.

Like all the rest of us, carriers live off their income.

Rate regulation goes to the heart of the problem of coordination; to the question as to what units of transportation shall survive; and it is the primary factor of regulation that affects the balance sheet. Regulation is neither the cause or the cure of many transportation ills. Transportation has all the problems common to the business world and its public relations besides.

Certain general principles are applied under which rates are fixed. The primary principle is that all rates must be reasonable—reasonable to the carrier, reasonable to the public and reasonable as between competitors. The carrier feeling that he has a rate less than is reasonable has a right to seek the aid of the commission, if necessary, to give him that reasonable rate to which he thinks he is entitled.

In many cases, a carrier foregoes that reasonable rate to which he might be entitled and voluntarily proposes a lower rate in order to meet competition, or to develop industries on his line, or to enable the traffic to move. If a carrier fails to secure the profit from transportation that he would expect, he may content himself with a meager profit rather than lose his traffic. It may even be that in the zeal of competition, in the contest for traffic, he will even forego any profit and any practical advantage to himself in order to keep the traffic from his competitor. In those cases, a competitor carrier can invoke the aid of the commission to protect him against unfair competition.

What the carrier might ordinarily regard as a reasonable rate may be so high that it prohibits the commodity from reaching its market. Regulation may permit the carrier to reduce his rate in order that the traffic may move.

There have been many cases where the lack of competition has led to unreasonably high rates and other cases where excessive competition has led to unreasonably low rates. Fortunately; excessive rates are much less frequent than in former times. The present keen competition between the rail, buses, trucks and other agencies of transportation have reduced excessive rates formerly due to the lack of competition. Legitimate regulation, as I see it, will tend to put rates on a more just basis where practicable and attempt to eliminate artificial influences that unjustly impose either excessively high or unfairly low rates. For instance, as I see it, just regulation will not permit of excessive rates because of the lack of competition nor should it tolerate cut-throat rates because of excessive competition. Reasonable rates of economic carriers must be protected wherever possible if we are to have effective coordination.

Another consideration in rate making is the value of the service rendered to the shipper. It is a practice practically world-wide to classify freight and fix rates with reference to the value of the service given. The principle is of importance from the standpoint of industries affected and also from the standpoint of preserving our transportation system. There may be two cars of equal load in the same train. One may carry a low grade freight, the other a high class freight. The car with the high class load may pay a tariff twice that of the low grade car. The low grade freight helped carry overhead and the carrier was better off on account of carrying it, but if forced to haul all freight at an equal rate, he could not operate. The high grade freight makes possible the cheap transportation of the low grade freight. It enables some producers and industries to get into markets they otherwise could not reach. It enlarges the opportunity of different sections to reach the central markets; it tends to strengthen the nation economically; it helps upbuild industries in communities that thereby give greater support to the carrier; it tends to enable the carrier to continue in business. This principle of freight regulation must necessarily apply to all types of carriers.

One of the first things we must recognize in rate regulation is that rates are and must necessarily be largely based upon necessary expediency. There is no possibility of reducing a sane rate structure to arbitrary provisions and preclude the consideration of the circumstances of each particular case.

So, under our system of regulation, when all is said and done, we must turn to the Interstate Commerce Commission and trust much to its members to whom the serious responsibilities of regulation must be confided. Theirs is an unspectacular work, the plodding burden of responsibility. We cannot ask them to be supermen, but it does not appear to me to be beyond the possible that our rate structure may yet be greatly improved to the advantage of our carriers and the country.

Some day, perhaps twenty or thirty years from now, the nation will reach its final verdict on regulation. It may be proclaimed a failure, it may be proclaimed a success, it may be decided to be a necessary method, but of an indifferent success. I trust the final verdict will pronounce it a satisfactory method of preserving our transportation system and doing justice to the carrier and the public. To me, the only course available at the present time is to support and improve our system of regulation.

Water Transportation

The original Interstate Commerce Act covered regulation only of common carriers by railroad or partly by rail and partly by water when under a common control with a railroad. In the recent Transportation Act, for the first time in the history of our country, Congress placed water regulation under unified control with our other principal transportation agencies. In doing this, Congress took a step that was absolutely essential to coordinate our principal transportation agencies into a national transportation system.

Water carriers transport a substantial amount of our commerce. They are important competitors with the regulated agencies. There can be no just effective system of regulation where a substantial part of the carriers are unregulated and free to follow their own desires as to their methods of competition. I am confident that the water carriers will, within a few years, recognize that federal regulation is desirable for their own welfare and will contribute to the stabilization and betterment of the industry.

Board of Investigation

The Transportation Act of 1940 provides for the appointment by the President of a Board of Investigation and Research to investigate and report to Congress as to the relative economy of our different transportation agencies, with a view of determining the service for which each type of carrier is best fitted. It is also the duty to investigate the extent and effect of public subsidization of rail, motor and water carriers; also the extent and effect of taxes imposed upon such carriers. This board is authorized to investigate any other matters it deems important for the improvement of transportation conditions.

In substance, this board is to have the responsibility of making a thorough investigation to furnish basic information which should be useful in working out the coordination of our transportation facilities and moulding these various agencies in one consistent rounded-out national system of transportation. The creation of this board recognizes the need of preserving the inherent value of each type of transportation and coordinating them to each other for the benefit of the nation. A thorough, impartial and courageous investigation of the type authorized may make a useful contribution toward the ultimate solution of our confused transportation problems.

The combined carrier agencies of the United States in their speed, service and efficiency constitute the greatest transportation system in this world. It is one of the great institutions of America. In the course of its evolution, it has reached a stage where it needs more complete and more practical coordination in order that it may reach out in fuller dimensions and serve the transportation needs of this country. It needs stabilization with a fair reward based only on the economic value of its services. There is only one agency that can accomplish this task . . . the government of the United States.

REPORT OF THE SECRETARY

March 1, 1941.

To the Members:

Judged by all ordinary standards, the American Railway Engineering Association carried on its work in a thoroughly satisfactory manner during the period covered by this report. The term "period" is used advisedly because it designates the calendar year in the report on finances; the Association year (from the end of one convention to the close of the next) in dealing with committee work, publications, etc.; and the 12 months from March 1, 1940 to March 1, 1941, in the report on membership.

To sum up—the accounts of the Association for the year ending December 31, 1940, showed an excess of receipts over expenditures of $1,814.62; there was a moderate increase in the net membership; and an appreciable increase in the number of pages of printed matter published in the bulletins, Proceedings and the Manual supplement. As has been demonstrated previously, the prosperity of the Association, like that of the railroads, varies from year to year with general business activity. The current high level of railway traffic is therefore a favorable condition. However, it is not an unmixed blessing, because the underlying cause of the "defense" boom, namely, disturbed world conditions, has had its adverse effects on the Association, as exemplified by complete loss of contact with members in certain "liquidated" countries, resignations and delinquencies of members in other foreign countries due to unfavorable exchange rates, and a decline in publication sales.

Finances

As will be seen in the financial statement which appears on a following page, and in the summary shown below, the outcome of the operations for the calendar year of 1940, was much better than had been anticipated in the budget. An expected deficit of $2,210 was turned into a net gain of $1,814.62, owing to the fact that the receipts were about $1,100 more than had been anticipated and because the projected progress in the revision of the Portfolio of Trackwork Plans was not realized.

	1940 Budget Estimate	*1940 Actual*	*1939 Actual*
Receipts	$27,130.41	$28,265.82	$28,188.92
Disbursements	29,340.00	26,451.20	24,269.56
Excess of receipts over disbursements		$ 1,814.62	$ 3,919.36

That the financial operations of the Association follow a decidedly fixed pattern from year to year is clearly demonstrated in the second table, which shows the receipts and expenditures for the last six years, as adjusted to correct certain inconsistencies. First of all, the table discloses a marked uniformity in the revenues; it was only in 1937 that the figures were out of line—due to receipts of more than $7,000 from the initial sales of the new loose-leaf Manual.

This similarity in figures is also indicated for the disbursements, when the expenditures for two large items of "special purposes" are segregated as shown. The figures for "Manual" include only the outlay for the creation of the new loose-leaf volume, expenditures for the annual supplements have been included in the so-called "normal" expenditures.

Incidentally, by extending the analysis still further, it would have been possible to demonstrate that the variation in the normal expenditures may be accounted for very largely by annual differences in the size of the printing bill, as influenced by the amount by which the number of published pages in one year is greater or smaller than in another year.

Comparison of Receipts and Disbursements for a Six-Year Period

	Receipts	Disbursements Normal	Disbursements Special
1935	$29,001	$25,311	$4,799*
1936	28,643	25,050	9,612*
1937	36,523	23,605	8,595*
1938	28,422	22,780	614**
1939	28,189	22,969	878**
1940	28,272	24,000	2,451***

* Outlay for new loose-leaf Manual, except cost of supplements.
** Revision of Trackwork Plans.
*** Manual charge $665, Trackwork Plans $1,786.

Membership

With this issue of the secretary's annual report, a new factor is introduced into the review of membership changes during the year, namely, the Junior grade of membership, which became effective on June 7, 1940, with the adoption of an enabling amendment of the Constitution.

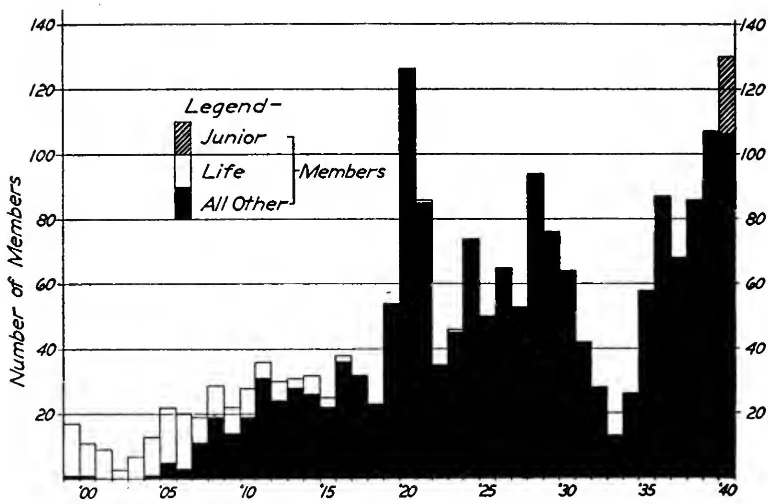
Omitting consideration of Junior members, the record for the year ending March 1, 1941, was as follows:

Members on rolls as of March 1, 1940		1,880
New members		88
Reinstatements		16
		1,984
Lost by death	36	
Resigned	27	
Dropped	39	102
Net gain	2	
Membership as of March 1, 1941		1,882

To this membership total must be added the Junior members of whom 30 were elected during the year. However, as 3 of these were lost because they left railway service, the net number of Junior members is 27. Adding this figure to 1,882 gives a total Association membership of 1,909.

The motive behind the creation of the Junior grade of membership was to stimulate the influx of young men into the Association in order that qualified members will be available to carry on the work as the older men retire or become less active. For the purpose of developing the outlook of the Association as influenced by the "expectancy" of its membership roll, the accompanying graph was prepared in which the members are grouped by the year of affiliation. As is to be expected, the chart discloses a marked correlation between growth of membership in any one year and general economic conditions. It shows also, that only 448, or 23 percent of the present members joined prior to 1919, and that of these, 151 or one-third represent substantially the Association's entire Life membership.

While the chart affords assurance of no marked change in membership status during the next three years, the fact that 265 or nearly 14 percent of the present members joined



Distribution of AREA Membership by Years in Which Members Joined

in the three years, 1919 to 1921, inclusive, points to a marked increase in transfers to Life membership beginning with 1944.

The loss of 36 members by death during the last 12 months was 6 less than the preceding year, but was noteworthy because those 36 members included the president, George S. Fanning, who died on January 2, 1941, and four past-presidents, W. B. Storey, L. A. Downs, J. V. Neubert and J. C. Irwin, the latter having been a member of the Board of Direction at the time of his death on March 20, 1940. The Association also lost a third member of the Board through the death on September 8, 1940, of Robert Faries, director, and the chairman of the Committee on Wood Preservation with the death of C. F. Ford on June 9, 1940.

Publications

General—There was a definite increase in the volume of printed matter published by the Association in the year ending with the 1941 convention. This applies alike to the number of pages in the bulletins, the Proceedings and the Manual supplement.

Bulletins—The number of pages in the seven bulletins ending with the issue of March, 1941, was 1,282 compared with 987 for the preceding seven. However, for a true comparison, it is necessary to deduct 78 pages from the total because the 1,282 pages embrace both the sixth and seventh progress reports on the Investigation of Fissures in Railroad Rails, owing to the fact that the seventh progress report (78 pages) was published prior to the convention (February bulletin) whereas all of the previous reports of this kind have been withheld from publication until after the convention.

Ample material has been available for publication in the so-called summer bulletins as indicated by the following list:

Bulletin 418, June–July, 1940

Sixth Progress Report of the Joint Investigation of Fissures in Railroad Rails
Second Progress Report—Joint Investigation of Continuous Welded Rail

Annual Report on Stresses in Railroad Track
Seventh Progress Report—Committee on Stresses in Railroad Track
Preliminary Report of Committee 5—Track (Installment of 9 trackwork plans)
Tie Renewal Statistics for 1939

Bulletin 419, September–October, 1940

Reports of the Committees of the Electrical Section, Engineering Division, AAR
Mechanization in the Maintenance of Way Department (Special report prepared by Committee 22—Economics of Railway Labor)
Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete
Preliminary Report of Committee 5—Track (Installment of 26 trackwork plans)

Proceedings—The Proceedings for 1940 were larger than in several previous years owing to the publication of several monographs in accordance with a decision of the Board of Direction to resume the reprinting in the Proceedings of all or nearly all of the monographs published in the summer bulletins, as a means of insuring a more permanent record of valuable material. Among the monographs so reprinted was that by E. E. R. Tratman on Car Ferries, which was republished after considerable editing and amplification by the author of the original paper that appeared in Bulletin 387 for July, 1936.

Manual—Progress in the revision of the Manual is shown in the table of annual supplements. The 1940 revision was the most extensive to be issued since the appearance of the loose-leaf Manual.

Supplement	*New Sheets Issued*	*Old Sheets Withdrawn*	*Net Increase*
1937	110	69	41
1938	151	121	30
1939	128	95	33
1940	185	139	46
Total	574	424	150

It is to be expected, of course, that the supplements in the even-numbered years will be larger than in the odd-numbered years owing to the policy of revising and reissuing the alphabetical index of some 24 sheets (48 pages) only in alternate years.

With the approval of the Board of Direction, arrangements have been made to facilitate the sale of the Manual in chapters and parts of chapters, as indicated by the scale of prices appearing on page 491 of Bulletin 422. This was done to meet a growing demand for the smaller units of Manual material.

During the last year 176 copies of the complete Manual were sold, bringing the total distribution to 1,914 copies. Adding to this number of complete Manuals, the number of copies that have been broken up for the sale of chapters and parts thereof, brings the Association to a realization that it has reached another stage in the history of the loose-leaf Manual, namely, to the inception of the first reprinting.

This will not be as formidable a task as it might appear at first thought, for instead of being done all at once, it will be started with the chapters for which there has been the largest demand. This is a rather fortunate situation since it permits the reprinting to be carried out in an orderly manner over a period of about two years.

Track Plans—While progress in the revision of the portfolio of track plans did not equal the rather ambitious program that the Committee on Track had set up, 50 new plans were completed during the year, of which 9 appeared in Bulletin 418, 26 in Bulletin 419, and 15 in Bulletin 423. These, added to the 24 approved last year and 13 others requiring only minor alterations, will provide a total of 87 revised plans that will be ready for distribution shortly after the convention and will leave about 50 more plans to be completed for submission at the convention next year.

Miscellaneous—Only one change of any consequence was made during the year in the make up of the publications, namely, the revision of the introductory statement of the committee reports for the purpose of introducing page-number references to the reports on each assignment. While this is certain to facilitate the study and presentation of the reports, it is believed that the experience with the initial trial of this plan will point the way to the refinement of certain details that will effect further improvements.

Work of the Committees

The total personnel of the Association's 27 standing and special committees includes 858 names. However, because four committees consist of representatives of other committees and because a considerable number of members are identified with more than one committee, the net number of members on committees is 660. While this figure affords an index of the widespread participation in committee work, a more convincing picture is afforded when the analysis is confined to those who actually prepared the reports, namely, the chairmen of the subcommittees that submitted reports this year on subjects assigned to them. A check of the reports appearing in Bulletins 420 to 423, inclusive, shows that 89 individual subcommittee chairmen were responsible for one report each, 8 others wrote two reports each and 3 more prepared three reports each, or a total of 114 reports prepared by exactly 100 men.

From the standpoint of subject matter and content the record is equally interesting. The 1940 outline of work for the 27 committees listed a total of 201 subject assignments. The reports prepared by 26 committees embrace individual subcommittee reports on 128 subjects, and while it is not possible to set up any rigid classification of the material in these reports, the following analysis affords a fair idea of the nature of the contents:

Revisions of the Manual—minor	13
Revisions of the Manual—major	8
New Manual material—minor	5
New Manual material—major	7
New Manual material—tentative	8
Information	50
Reports on research projects	9
Statistical material	5
Mathematical studies	5
Bibliographies	3
Brief reports of progress	15
Total	128

Research Work

Work on a considerable number of committee assignments has been possible only because of the availability of data obtained in the course of research work, most of which has been carried on with funds provided by the Association of American Railroads. Appropriations for investigations in which AREA committees have a particular interest are shown below for both 1940 and 1941. The items in this list are exclusive of the annual appropriations for the work of the research engineer, and do not include the special fund allocated jointly to the Engineering and Mechanical divisions for an investigation of the effect of locomotive counterbalancing on track and equipment.

Project	*1940*	*1941*
Rail Investigations (statistical)	$ 5,400	$ 5,400
Transverse Fissure Investigation	22,500	9,000*
Stresses in Railroad Track	23,000	18,000**
Tests of Joint Bars	3,500	3,500
Tests of Manganese Frogs	1,000	1,000
Tests of Bolt Tension	600	....
Impact Studies	4,000	11,500
Fatigue Tests of Structural Welds	....	5,000
Tests of asphalt and coal tar pitch	....	500

* AAR contribution is matched each year by a like amount of money contributed by the rail manufacturers.

** Part of the expense of the stresses in track staff in 1941 will be charged to the special appropriation for the locomotive counterbalance investigation.

The most important development during 1940 in the field of railway engineering research was the appointment by Vice-President Buford, of the Operations and Maintenance Department, of a Committee on Relation Between Track and Equipment to replace an earlier committee known as the Joint Committee on Relation Between Track and Rolling Stock. The personnel of the new committee as appointed on May 21, 1940 was as follows:

Representing the Engineering Division

Robert Faries (Chairman), Assistant Chief Engineer-Maintenance, Pennsylvania Railroad, Philadelphia, Pa.

W. J. Burton, Assistant to Chief Engineer, Missouri Pacific Railroad, St. Louis, Mo.

G. M. Magee, Research Engineer, Engineering Division, AAR, Chicago.

W. S. Lacher, Secretary, Engineering Division, AAR, Chicago.

Representing the Mechanical Division

Kenneth Cartwright, Mechanical Engineer, New York, New Haven & Hartford Railroad, New Haven, Conn.

A. G. Hoppe, Assistant Mechanical Engineer, Chicago, Milwaukee, St. Paul & Pacific Railroad, Milwaukee, Wis.

W. I. Cantley, Mechanical Engineer, Mechanical Division, AAR, Chicago.

V. R. Hawthorne, Executive Vice-Chairman, Mechanical Division, AAR, Chicago.

Mr. Faries was appointed chairman of the committee, and following his death on September 8, 1940, Mr. Cartwright succeeded him as chairman, and Mr. E. M. Hastings, chief engineer, Richmond, Fredericksburg & Potomac Railroad, Richmond, Va., was appointed to replace him as representative of the Engineering division.

This committee has developed a comprehensive program of investigations in which the study of locomotive counterbalancing will occupy the most important place for the present, and the sum of $115,200 has been appropriated for instruments and work to be done during 1941.

W. S. Lacher,
Secretary.

GEOGRAPHICAL DISTRIBUTION OF MEMBERSHIP

United States and Possessions

Alabama	14	Nebraska	23
Arizona	2	Nevada	2
Arkansas	10	New Hampshire	5
California	57	New Jersey	30
Canal Zone	1	New Mexico	1
Colorado	20	New York	141
Connecticut	26	North Carolina	14
Delaware	2	Ohio	142
District of Columbia	33	Oklahoma	7
Florida	11	Oregon	8
Georgia	25	Pennsylvania	157
Hawaii	1	Puerto Rico	1
Idaho	1	Rhode Island	3
Illinois	321	South Carolina	2
Indiana	37	South Dakota	3
Iowa	18	Tennessee	25
Kansas	29	Texas	73
Kentucky	33	Utah	7
Louisiana	13	Vermont	7
Maine	6	Virginia	91
Maryland	31	Washington	19
Massachusetts	42	West Virginia	23
Michigan	48	Wisconsin	14
Minnesota	59	Wyoming	2
Mississippi	9		
Missouri	94		1748
Montana	5		

Other Countries

Canada	93	Un. Soc. Sov. Rep.	2
Mexico	9	Czechoslovakia	2
Australia	8	Bolivia	1
Brazil	8	Colombia	1
England	5	France	1
Argentine	6	Germany	1
Central America	5	Poland	1
China	3	Switzerland	1
Japan	3	Tanganyika Territory	1
Cuba	4	Uganda	1
India	3		
Manchukuo	2		161

Deceased Members

F. D. Bardwell
Retired Assistant Engineer, New York Central Railroad, New York City

H. A. Bertram
Division Engineer, Chesapeake & Ohio Railway, Peru, Ind.

Lincoln Bush
Retired Consulting Engineer, East Orange, N. J.

J. F. Donovan
Division Engineer, Lehigh Valley Railroad, Wilkes Barre, Pa.

L. A. Downs
Chairman of the Board, Illinois Central System, Chicago

B. T. Elmore
Bureau of Statistics, Interstate Commerce Commission, Washington, D. C.

R. C. Falconer
Assistant Vice-President, Erie Railroad, Cleveland, Ohio

Geo. S. Fanning
Chief Engineer, Erie Railroad, Cleveland, Ohio

Robert Faries
Assistant Chief Engineer Maintenance, Pennsylvania Railroad, Philadelphia, Pa.

C. F. Ford
Supervisor Tie and Timber Department, Chicago, Rock Island & Pacific Railway, Chicago.

C. W. Galloway
Vice-President Operation and Maintenance, Baltimore & Ohio Railroad;
President, Monongahela Railroad, Baltimore, Md.

Geo. Gibbs
Consulting Engineer, Gibbs & Hill, Inc., New York City

H. C. Griswold
President, John P. Morton & Company, Louisville, Ky.

W. W. Gwathmey
Consulting Engineer, Norfolk, Va.

C. S. Gzowski
Chief Engineer, Construction Department, Canadian National Railways, Montreal, Que.

C. S. Heritage
Bridge Engineer, Kansas City Southern Railway, Kansas City, Mo.

E. M. M. Hill
Chief Engineer, Western Region, Canadian National Railways, Winnipeg, Man.

Deceased Members

H. I. Hoag
Division Engineer, New York Central Railroad, Buffalo, N. Y.

J. C. Irwin
Valuation Engineer (Retired), Boston & Albany Railroad (N.Y.C.R.R.), Boston, Mass.

D. J. Kerr
President (Retired), Lehigh Valley Railroad, Spokane, Wash.

G. H. Kimball
Consulting Engineer, Pontiac, Mich.

G. E. Ladd
Consulting Engineer Geologist, Chevy Chase, Md.

H. B. Lincoln
Division Engineer, New York Central Railroad, Cleveland, Ohio

Ralph Modjeski
Consulting Engineer, New York City.

Gilbert Murray
Division Engineer, Canadian National Railways, Prince Albert, Sask.

John V. Neubert
Chief Engineer Maintenance of Way, New York Central Railroad, New York City.

E. H. Pfafflin
Assistant Division Engineer (Retired), Chicago, Milwaukee, St. Paul & Pacific Railroad, Chicago.

J. H. Prior
Chief Architectural Engineer, Chicago Board of Education, Chicago.

L. J. Reiser
Assistant Supervisor, Tie and Timber Department, Chicago, Rock Island & Pacific Railway, Kansas City, Mo.

O. M. Rognan
Architect, Northern Pacific Railway, St. Paul, Minn.

A. B. Scowden
General Bridge Inspector, Baltimore & Ohio Railroad, Cincinnati, Ohio.

H. B. Seaman
Retired Consulting Engineer, Brooklyn, N. Y.

V. I. Smart
Deputy Minister, Department of Transport, Ottawa, Ont.

W. B. Storey
Retired President, Atchison, Topeka & Santa Fe Railway, Chicago

R. H. Washburn
Assistant Division Engineer, Alton Railroad, Bloomington, Ill.

J. W. Williams
Chief Engineer, Western Pacific Railroad, San Francisco, Calif.

FINANCIAL STATEMENT FOR CALENDAR YEAR ENDING DECEMBER 31, 1940

Balance on hand January 1, 1940		$85,323.26

RECEIPTS

Membership Account		
Entrance Fees	$ 920.00	
Dues	17,550.06	
Binding Proceedings	1,467.85	
Sales of Publications		
Proceedings	962.26	
Bulletins	902.66	
Manuals	1,908.17	
Specifications	703.97	
Track Plans	503.75	
Advertising		
Publications	796.68	
Interest Account		
Investments	2,078.26	
Miscellaneous	41.75	
Joint Bar Investigation	430.41	
Total	$28,265.82	

DISBURSEMENTS

Salaries	$ 8,300.00	
Proceedings	4,293.11	
Bulletins	4,009.69	
Stationery and Printing	851.61	
Rents, Light, etc.	780.00	
Supplies	80.49	
Expressage	13.21	
Postage	562.91	
Exchange	97.46	
Office Equipment	168.77	
Annual Convention	669.01	
Refunds, dues, etc.	37.00	
Audit (year 1939)	200.00	
Pensions (E. H. Fritch, A. K. Shurtleff)	2,460.00	
Social Security Act	78.00	
Manual Supplements	1,837.49	
Track Plans	1,785.93	
Miscellaneous	137.96	
Committee and Officer's Expense	88.56	
Total	$26,451.20	
Excess of Receipts over Disbursements		$ 1,814.62
Balance on hand December 31, 1940		$87,137.88

REPORT OF THE TREASURER

To the Members:

Balance on hand January 1, 1940		$85,323.26
Receipts during 1940	$28,265.82	
Paid out on Audited Vouchers	26,451.20	
Excess of Receipts over Disbursements		1,814.62
Balance on hand December 31, 1940		$87,137.88
Consisting of		
*Bonds at cost	$75,945.81	
Cash in Northern Trust Company Bank	10,331.23	
Cash in Royal Bank of Canada	835.84	
Petty Cash	25.00	
	$87,137.88	

* Includes $6,240.00 book value of Rock Island, Arkansas & Louisiana 4¼% bonds due March 1, 1934, not paid, in default.
Also includes St.L.S.W. 5% bonds, book value $1,319.31, interest coupons January 1, 1936 and thereafter in default.

Respectfully submitted,

W. H. Penfield, *Treasurer.*

We have made an audit of the accounts of the American Railway Engineering Association for the year ending December 31, 1940, and find them to be in accordance with the foregoing statements.

C. G. Rivers,
E. Deming,
Auditors.

GENERAL BALANCE SHEET

December 31, 1940

Assets	1940	1939
Due from Members	$ 900.00	$ 765.00
Due from Sales of Publications	33.80	25.95
Due from Advertising	51.00	56.00
Furniture and Fixtures	537.77	410.00
Publications on Hand (estimated)	1,500.00	2,000.00
*Investments (cost)	75,945.81	75,945.81
Interest on Investments (accrued)	609.80	607.29
Cash in Northern Trust Company Bank	10,331.23	9,116.79
Cash in Royal Bank of Canada	835.84	235.66
Petty Cash	25.00	25.00
Manuals (on hand)	1,800.00	2,800.00
Trackwork Plans	800.00	....
Joint Bar Investigation (Due from AAR)	....	430.41
Total	$93,370.25	$92,417.91
Liabilities		
Members' Dues Paid in Advance	$ 5,300.50	$ 5,153.75
Surplus	88,069.75	87,264.16
Total	$93,370.25	$92,417.91

* Includes $6,240.00 book value of Rock Island, Arkansas & Louisiana 4¼% bonds due March 1, 1934, not paid, in default.
Also includes St.L.S.W. 5% bonds, book value $1,319.31, interest coupons January 1, 1936 and thereafter in default.

Discussion on Standardization

(For Report, see pp. 25–27.)

Vice-President Bond: Owing to the enforced absence of Mr. Nicholson, chairman of the committee, the report will be presented by Mr. Wilson who represents us through the Association of American Railroads as a member of the Standards Council of the American Standards Association. We are much obliged to Mr. Wilson for substituting in Mr. Nicholson's absence.

A. R. Wilson (Pennsylvania): At the 1940 convention this committee submitted a tabulation of recommended practices and urged their adoption, insofar as the railroads could do so. The recommended practices which are adopted annually and appear in the Manual are reviewed by this committee and, if found desirable, are sponsored for national standardization through the American Standards Association. The committee has no recommendation at this time looking towards the sponsoring of new standards.

One of the duties of this committee is to maintain contact with other standardization bodies. The interests of your Association are carefully guarded by the appointment to these other bodies of representatives from your respective committees. Last year a complete list was given you as to your representation in these other associations. This year only changes in that list are noted.

The representation on the American Society for Testing Materials is on the second page of the report. I wish to call your attention particularly to the activities of two committees of that society, namely A1 on Steel and C1 on Cement. The activities of both of these committees, on which you are ably represented, are of vital interest to this Association.

This report is presented to you as information.

Vice-President Bond: Thank you, Mr. Wilson. We all appreciate the scope of the activities of the Committee on Standardization and the difficulties with which they have to struggle at times. The committee is excused with the thanks of the convention.

Discussion on Signals and Interlocking

(For Report, see pp. 31–36.)

(Vice-President Bond in the chair)

Chairman H. G. Morgan (Illinois Central): The report of Committee 10 covers two assignments. The first assignment is: Developments in railway signaling. As there have been no developments, there is no report. The second assignment is: The principal current activities of the Signal Section, AAR, of which there have been quite a number. Mr. Post, chairman of the subcommittee, will tell you all about them.

W. M. Post (Pennsylvania): Mr. Morgan has told you that we had no report on the developments in railway signaling. There have been some developments which make it possible to remotely control signals and switches over existing telephone wires, and it is hoped that a report covering them can be presented next year.

Our second assignment is: The principal current activities of the Signal Section, and your attention is again called to the series of pamphlets on American Railway Signaling Principles and Practices, prepared for the education of signalmen and others desiring to study this subject. Members may be asked by young men entering railway service where books describing railway signaling can be obtained. A letter to the secretary of this Association or to Mr. R. H. C. Balliet, secretary of the Signal Section, 30 Vesey street, New York, will produce information on how these pamphlets can be obtained.

I would also like to call attention to some of the subjects reported on and which can be found in the Signal Section Proceedings for 1940.

Referring to No. 1—Costs involved in stopping trains, the Committee on Economics of Railway Signaling presented in its report curves and formulas to obtain the cost of fuel and water wasted in stopping a 4,400-ton (gross weight) train of 45-ton double-truck cars hauled by a 2-8-4 locomotive on grades up to 0.6 percent ascending and 0.6 percent descending in steps of 0.1 percent for speeds up to 60 m.p.h. Examples worked out for this train, stopping from 35 m.p.h., indicate that the cost of coal and water wasted on a 0.1 percent ascending grade was $1.13 and on a 0.1 percent descending grade was $1.27.

Subject 2 covers costs (other than fuel and water) involved in stopping trains. In this report is discussed wear on rail and track; wear on wheels; wear and tear on rolling stock; locomotive maintenance and lubrication; wear on brake shoes; damage to lading; commercial value of delay in delivery; freight train delay hours, and the cost of regaining lost time. Most of these are intangible savings. However, they are discussed in this report, and the report is well worth reading.

No. 4—Economy in signaling construction and maintenance costs by using 78-ft. rails instead of 39-ft. rails: The saving in costs of bonding rails is reported as $37.20 per mile, and the annual saving in maintenance would be $1.11 per mile.

No. 5—Economy of slide detector fences: This report contains the costs and annual savings obtained from several installations of such fences.

No. 7—Economic value of car retarders: The committee has prepared a form to be used in assembling the costs and annual savings. This form will be sent to railroads having car retarder installations with a view to presenting these data at some future meetings. So if you receive a copy of this form, the Signal Section will appreciate it very much if you will take the necessary time to supply the data as requested on that form. We believe some valuable lessons can be learned which will be presented at some future meeting.

No. 10—Protection of traffic against slides and rock falls: This report contains descriptions and drawings showing several types of slide detector fences.

No. 17—This is a report on devices and methods to control automatic signals or special signals for the protection of traffic against high water at vulnerable points and fires at bridges and trestles. If you have any such problems, this report, I think, will be helpful.

No. 24—Illumination of crossings: This report describes how flood lights should be arranged at highway crossings. It calls attention to the fact that flood-lighting does not take the place of crossing signals and should not be used as a warning of the approach of trains.

The rest of the report contains lists of specifications, requisites, drawings and other matter which have been submitted to letter ballot.

Chairman Morgan: This concludes the report.

Vice-President Bond: You have heard the report as presented. Any discussion?

L. J. Hughes (Chicago, Rock Island & Pacific): I should like to inquire of the committee where you get these reports, how do you obtain them and what they cost.

Chairman Morgan: They can be obtained through the secretary of the Signal Section. The prices vary.

Vice-President Bond: If there is no further discussion, Mr. Morgan, your committee is excused with the appreciation of the Association for a very informative report.

Discussion on Economics of Railway Location and Operation

(For Report, see pp. 44–86.)

(Vice-President Clarke presiding)

Chairman H. M. Stout (Northern Pacific): The agenda of this committee the past year has included 14 assigned subjects. Four of these required collaboration with other committees of this Association or other divisions of the Association of American Railroads. In addition, collaboration was required of us in the study of three subjects included in the assignments of other standing committees of this Association. All these assignments have been accepted, and due consideration has been given them during the year.

The report of the committee includes progress reports submitted as information on six of the assigned subjects. Reports were prepared on two additional assignments but publication has been withheld.

First, Revision of Manual: In our constant scrutiny of the sections of the Manual relating to economics of railway location and economics of railway operation, for inaccuracies and opportunities for better statements of principles, the article denoted The Cost of Stopping and Starting Trains (see Chapter 21, pages 2–5 of the Manual) has been undertaken. Last year some preliminary notes on the cost and effect of stopping trains were prepared and submitted for discussion and further study and collaboration with the Signal Section of the Association of American Railroads which has an interest in the subject. The studies and discussions with the Signal Section which have ensued have brought out the fact that the results based on last year's preliminary notes do not agree with those published by the Signal Section. For example, it was found that our proposed method indicated that the fuel and water wasted on account of a stop increased as the weight of the train increased, whereas the Signal Section's method indicated that the fuel and water wasted decreased as the weight of the train increased. Failure of the two methods to agree in this important particular casts doubt upon both methods. Hence, a number of attempts have been made to reconcile the two methods before proceeding with the preparation of a report for presentation to and consideration of the Association.

The AREA method assumes typical locomotives and bases the speed, tractive effort and horsepower curves on the normal capacity, in order to simplify the calculation, because the fuel and water consumptions on this basis are constant. In other words, it is an easy matter to determine the work done if it is expressed in terms of horsepower-hours measured by the boiler output which is constant for all speeds above V_1 and proportional to the fuel and water consumptions. Also, on this basis the same boiler output for a given locomotive can be taken for all weights of trains. Furthermore, the relation between the boiler output and the driver output varies with trains of different weights. Consequently, the driver horsepower-hours on the basis of normal capacity are not a true measure of the boiler output or of the fuel and water consumptions.

It is expected a report on this subject will be developed and made available next year.

Subject No. 2, Methods for obtaining a more intensive use of existing railway facilities: This assignment is a most practical topic. The painful memories of the operating conditions at ports and other railway terminals during the previous World War period suggested the study of the intensification of use of railway facilities resulting from the operation of the port control organization set up, in the autumn of 1939, by the Association of American Railroads, as an addition to the list of projects heretofore reported. As Mr. L. E. Dale, chairman of the subcommittee, is unable to be present today, the report will be presented by Mr. H. F. Schryver.

(H. F. Schryver, New York Central, read the report on Assignment 2.)

Mr. Schryver: I might add that recently Mr. Budd, transportation commissioner, stated that the amount of export traffic handled through the North Atlantic ports has reached the equivalent of the peak movement of 1918. That was as of about the middle of February. It is possible that by this date that amount of traffic has been exceeded.

Chairman Stout: Subject No. 3, Methods or formulas for the solution of special problems relating to more economical and efficient railway operation: The report here offered, under this assignment, is a supplement to the reports to the last two conventions of the Association. The specific topic is, Economic Relation Between Track Structures and Traffic To Be Handled.

The report as published has brought considerable valuable discussion from a number of sources, for which we are grateful. The report will be presented by the subcommittee chairman, Mr. C. H. R. Howe.

C. H. R. Howe (Chesapeake & Ohio): The present discussion illustrates in a general way an analytical method of examining the elements that enter into problems of track and traffic economics. There is no intent whatever of attempting to establish factual data concerning the physical properties or values of track materials; that is the function of committees other than this. When such information becomes available we are very glad to make use of it.

Concerning items of investment, replacements and labor, undoubtedly in any specific case local interest rates and salvage values would be known and given proper consideration, as they would materially affect annual charges. On the individual railway it should be possible to break down labor charges for specific tracks, thus avoiding the necessity of equating. It should also be possible to segregate track laying costs from those of normal upkeep.

In connection with the labor charges shown in this report, a correction should be made in the example given at the bottom of page 48 and in Table G. Beginning with the last sentence of the fourth paragraph on page 48 the text should read:

The increases in labor costs are obtained through the use of the formula evolved on page 134, Vol. 40 of the Proceedings, namely, 1.00 + (3.3865 × percent traffic density increase), and adjustment to terms of the conversion factor of the higher group.

Take for example the 112-lb. rail costs for handling 5,248,898 g.t.m. per mile and determine the costs of handling the 11,309,126 g.t.m. traffic of the 131-lb. group on the lighter rail.

Interest remaining the same \$1,290

Replacement cost increasing in the ratio

$$\frac{11{,}309{,}126}{5{,}248{,}898} = 2.16 \times 0.05 = 0.108$$

Investment \$25,800 × 0.108 = \$2,786

Increased labor cost $\frac{1.56}{1.25} = 1.248 \times \$614$ (from Table F) = \$889

and 1 + (0.386 × 1.16) = 1.448 × \$889 = \$1,109

Total cost for 131-lb. track traffic on 112-lb. track \$5,185

In Table G the increased labor costs and total costs should be corrected to read:

	Increased Labor Cost	*Total Cost*
90 lb.	\$ 630	\$3,427
100 lb.	622	3,392
112 lb.	1,109	5,185

The percent signs should be omitted from Table G as well as in the example shown on page 48.

Vice-President Clarke: Is there any discussion? If not, please proceed, Mr. Stout.

Chairman Stout: The next subject is assignment No. 4—Effect of volume of traffic on railway operating expenses. The report here presented is the fifth progress report offered since the subject was assigned. It is included in the committee report as information and preliminary to a final report with conclusions. The report will be presented by Mr. J. F. Pringle, the chairman of the subcommittee.

J. F. Pringle (Canadian National): Determining the effect of volume of traffic on railway operating expenses is important for two reasons: It enables the results obtained in any previous period to be scrutinized, with a view to taking action for improvement, and it enables us to make estimates for future expenditures.

In previous reports the committee has shown by analysis of mass statistical data the effect of volume of traffic as measured by gross ton-miles, on operating expenses as a whole. The committee has also submitted a method for determining the effect of the volume of traffic on maintenance of way and structures expenses, which method has been adopted by the Association and published in the Manual.

There is also available in a report of the Mechanical Division of the AAR a method of determining the effect on maintenance of equipment expenses.

This year the committee submits a method for determining the effect of volume of traffic on transportation expenses.

It will be noted from the table on page 50 that transportation expenses account for some 49 percent of the total operating expenses. Therefore, the importance of this phase of expenses will be appreciated.

The method as given in detail in the report consists of an analysis of the effect of volume on the primary accounts of General Account No. 4. It is first necessary (and a method is shown by which this can be done) to relate volume of traffic as expressed in earnings to volume of traffic as expressed in operating units, such as net ton-miles, train-miles, and so on.

Then the primary accounts are grouped in accordance with the service, that is, station expenses, yard expenses, train and locomotive operation expenses, and so on, and the effect of fluctuation in volume of traffic on each group is analyzed to arrive at the percent of variations which may be expected under conditions pertaining to any particular property.

It must be understood that the percentages shown here will not apply on any particular property, as the conditions pertaining on that property have to be taken into consideration, but, once having determined the percentages for any particular property, they can be used as long as there are no major changes in the conditions.

The committee is of the opinion that this report is of certain practical value in preparing estimates of operating expenses based on any given volume of traffic. It is submitted as information, with the recommendation that the subject be continued.

Vice-President Clarke: Is there any discussion of this portion of the report? If not, it will be accepted as information.

Chairman Stout: The fifth assignment, Effect of inland waterway transportation on the economics of railway operation: A comprehensive report, the third progress report of information on this assignment, was prepared, but publication has been withheld.

The sixth is: Effect of high speed on railway operating expenses. Although some of the additional costs of operation due to speed are obvious, their measure and a complete determination of all the added costs comprise a complicated problem. The report on this subject, the third progress report, will be given by Mr. M. F. Mannion, chairman of the subcommittee.

M. F. Mannion (Bessemer & Lake Erie): The report outlines the method for making a preliminary study of the effect of any increase in maximum speed on power requirements and fuel and water consumption. Tables 1 and 2 are composite summaries of six different groups of locomotives and types of trains. These tables are based on data contained in Chapter 16 of the Manual and on train resistances which are based on the Davis formula. The tables give the average weight of train for any maximum speed, the average speed, exclusive of time stopped, for various distances between stops, and the horsepower-hours per 1,000 tons, trailing weight.

An example determining the increased power and horsepower-hour requirements for an increase of maximum speed from 45 to 60 miles per hour is shown on page 57. This increase of 15 m.p.h. in maximum speed would require an increase of over 80 percent in the number of locomotives and approximately 40 percent increase in the coal and water consumption. The increase in number of locomotives or number of trains would also result in the same percentage increase in train delays. Wages of engine crews would increase, as well as equipment and track maintenance.

Pages 58 to 67, inclusive, contain Exhibit A which is a more detailed discussion of the factors involved and conditions to be considered if a detailed study of the effects of proposed increased speeds is desired. The same information shown in Tables 1 and 2 is shown in Tables 3 to 13, inclusive, but these tables show separately the information for each of the six different groups of locomotives.

On page 65 is a chart showing train resistances for passenger and freight cars based on the Davis formula. On page 66, Tables 14 and 15 show the maximum speeds for trains of various weights on different grades. The following conclusions are offered:

It will appear from the application of the data contained in these tables that high speed has a widespread influence not only as regards fuel and water consumption, crew wages, and way and equipment maintenance, but also as regards capital expenditures.

Actually, the operating expenses and capital expenditures will very likely be greater than those anticipated, based on the theoretical data presented in this report.

The report is offered as information.

Vice-President Clarke: The effect of high speed on both railway maintenance and operating expenses is one of the important subjects before us today. Is there any discussion of this report in which the committee has presented some very interesting figures and tables? If not, the report will be received as information.

Chairman Stout: We have no report this year to complete Assignment 7, Effect of rail lubrication on train operation.

Eighth assignment, Economics of railway location and operation as affected by railway electrification: The progress reports on this assignment in each of the past two years are supplemented by a report of information. Present conditions on the continents east of the Atlantic Ocean render it impossible to cover now the countries of that hemisphere in our studies of this subject. The present report completes the survey of the countries of the western continents.

Professor E. E. King, chairman of the subcommittee, is unable to present the report on account of an affection of his voice, which we trust is only temporary. Under the circumstances, the report will be presented by Mr. F. N. Nye, a member of the subcommittee.

F. N. Nye (New York Central): Two years ago the subcommittee presented a report on electrification of steam railroads in Canada and the United States. This year the subcommittee has brought together data on electrification of steam lines in the remaining countries of the western hemisphere. These lines include those in Mexico, Cuba, Costa Rica, the Argentine, Bolivia, Brazil, Chile and Venezuela.

In addition, the report includes electrification of steam lines in Australia and New Zealand. Table 1 shows the locations of the electrified sections, the gage of the track, the total number of miles electrified, and gives information concerning tunnels, ruling grades, systems of electrification, kinds of traffic involved, number and capacity of motive-power units, energy requirements, and reasons for electrification. As the last column of the table indicates, some of these lines were electrified on account of tunnel operation, some on account of heavy grades, some on account of scarcity of fuel, some on account of density of traffic, and some to bring about general economy in operation.

As you will note in the table, practically all installations are direct current with overhead distribution systems. The voltages on the d.c. projects vary from 600 to 3,000. The only a.c. installations are on the Pacific Electric Railway in Costa Rica, where the power is single phase with a voltage of 15,000, and on the Guaqui to La Paz Railway in Bolivia, where the power is three phase with a voltage of 575. In suburban service, motor cars are commonly used, but for through freight and passenger service, locomotives are generally employed.

It has not been found feasible to get statistics from the nations involved in the present war. It is the hope of the subcommittee that, when economic conditions in those countries become more stabilized, we can secure data from them that will enable us to bring our report on electrification of steam railroads throughout the world up to date.

The subcommittee is grateful for the assistance of the Railway Section, Transportation Division, Bureau of Foreign and Domestic Commerce of the Department of Commerce of the United States and of the Electrification Committee of the National Electric Light Association.

This report is presented as information.

Vice-President Clarke: Are there any questions? If not, the report will be accepted as information.

Chairman Stout: Assignment 9, Effects of speeds in excess of 75 m.p.h. on the economics of railway location: Three reports treating this subject have been presented heretofore. The fourth report is not ready for presentation at this time.

Assignment 10, Effect of highway transportation on the economics of railway operation: Publication of the progress report prepared on this subject also has been withheld.

Assignment 11, Train resistance of freight trains under various conditions of loading and speed: This is a new assignment. A first report of information, consisting of the survey and résumé of the more important work which has been done in the establishment of general resistance formulas is offered. Mr. L. K. Sillcox, chairman of the subcommittee, will present the report.

L. K. Sillcox (New York Air Brake): Subcommittee 11 of Committee 16 was named and specifically assigned to the investigation of all available data and literature bearing upon the subject of freight train resistance, evaluating their applicability to modern, high-speed operation and, if possible, the derivation of a recommended method of resistance determination, the method to include modifying factors to obtain in specific conditions.

Certain train resistance components were designated for special investigation and study, namely,

1. Effect of rail lubrication upon curve resistance
2. Rail weight and condition
3. Track condition
4. Atmospheric temperature
5. Effect of side winds.

Unfortunately, the literature pertaining to these five important components of the total resistance value is meager due partly to the but recent recognition of the magnitude of their effect upon the total, and partly to their increased significance with modern high operating speeds.

In partial fulfillment of that assignment, an introductory report has been presented on pages 69 to 86, wherein many general train resistance formulas were reported. Each of these has had at least limited or local use during some period of years and on one or more railway systems. The report also includes discussion of the effect of the various train resistance components, both inherent and incidental. The committee has deviated from its specific assignment to the extent that factors, derived through the operation of passenger trains, have been investigated for the reason that much of the most valuable and reliable data, applicable to freight as well as passenger trains, were derived by the operation of test passenger trains.

This introductory report further presents the results of the committee's initial search for data pertinent to items 1, 2 and 3, above, being: First, the data accumulated by the Denver & Salt Lake Railroad in its investigation of reductions in curve resistance obtainable by lubrication of flange and rail; second, those obtained by the Kansas City Southern Railway during its test of resistance encountered on rail of various weights, both with new and old contours; and third, the Association of American Railroad's tests conducted on the tracks of the Pennsylvania, the Chicago & North Western, and the Union Pacific.

The Davis formulas are generally accepted as being basically sound and as being stated in a form consistent with known characteristics of the primary components; journal, flange, vibration and impact, and air resistances. More recent experiments on current design, as exemplified by the lightweight, streamlined trains, have indicated to some authorities the desirability of applying modifying factors when the formulas are employed in the determination of the resistances of such equipment.

Acknowledging the reliability of the Davis formulas, it is now proposed to attempt the derivation of modifying factors which would compensate for:

1. Effect of track modulus and rail weight
2. Temperature effects
3. Effect of side winds

and, in the case of passenger equipment with a possible important influence in some freight services, a fourth element, air conditioning or forced air circulation. Since available test data, bearing upon temperature effects, are limited in scope, and in very few cases have attempts been made to analyze such data by the railways to permit general derivations, the possibility of establishing a reasonable guide for the rating of locomotives under conditions of severe cold, is quite remote. The characteristics of track modulus and rail weight, as they influence train resistance, may be analytically examined. Also, it is hoped that the effect of side winds upon flange friction will lend itself to analytical analysis, using as a base the results of thoughtfully planned and carefully executed test programs completed in wind tunnels. Fortunately, several such programs have been successfully conducted and the results contributed for the common good.

Vice-President Clarke: While this is a new assignment and this is the first report, the committee has presented information of great value. Is there any discussion? If not, the report will be accepted as information.

Chairman Stout: The following three assignments are new: Development of modern power units and the effects on the economics of railway location and operation; The general course of the cost of railway transportation and operation over the past 100 years, the principal determining elements and the economic significance; and, The advantage derived from stiffness of track in improving economics of train operation. During the past year these subjects have been under active consideration and study, but we have no reports ready for presentation to this convention.

That completes the report of Committee 16—Economics of Railway Location and Operation.

Vice-President Clarke: The economics of railway operation is one of the most important subjects which we will have to consider. While our primary responsibility is the maintenance of the railroads, it is also our responsibility to maintain them so they can be most economically operated. Is there any general discussion? If not, the committee is excused with the thanks of the Association. (Applause)

Discussion on Electricity

(For Report, see pp. 28–30.)

(Vice-President Bond presiding)

Chairman H. F. Brown (New York, New Haven & Hartford): The report of the Committee on Electricity might read "from microwatts to kilowatts" because I know of no industry which uses electricity in the breadth of application that the railroads do. We have in mind microwatts in the use of the smallest amount of current that it is possible to detect, in amplifying devices, in radio tubes; and kilowatts where we are moving the heaviest types of freight trains, tonnage trains that are moved on any railroad in the country today, for example as on the Norfolk & Western and on the Virginian. Truly it is "from microwatts to kilowatts."

I am not going to try to give you a complete synopsis of the report, as it is presented in Bulletin 420 which was prepared during my incapacity the past summer by the vice chairman, Mr. D. B. Thompson. It is there for you to read, and it is interesting reading.

One has only to look at the exhibits in the current show at the National Railway Appliances Exhibit this year to see the scope of the application of electricity to the railroads. It is used in all types of track maintenance. It is used in nearly every department of railway activity, from the lighting of office buildings to the operation of shop machinery and the operation of trains.

The year has seen no great, outstanding development of any one phase, but the use and scope have broadened. Possibly the most noted improvement in the application has been in illumination. You are all familiar with new types of illuminants which we now have available in the fluorescent lighting units; great strides are being made. It is safe to prophesy that within the next ten years our illumination will be of an entirely different order than it is today. This is making for economy because all of these devices are operating at higher levels of efficiency, with smaller power consumption and, therefore, lower costs.

The development of power in itself is becoming cheaper. Newer and more efficient power plants are being built. Power is cheaper. Power production in connection with water power, in large concentrated areas, is being continually improved and made. For example, Boulder dam and Bonneville dam are notable examples of concentrated water power developments. Ultimately the power developed there will find its application on railroads in tributary areas.

The standardization of air conditioning equipment is going forward with particular reference to the standby equipment necessary in the large terminals for taking care of parked cars and for cars which are arriving and must lie over for short periods during their further movement.

The air conditioning development itself is so rapid that no time was available for much of the standardization required. This is now going forward at a rapid pace.

An interesting example of how electricity can be used to serve almost any purpose was had this last year at Memphis, Tenn., where Diesel-electric locomotives were parked, and the current from these locomotives was used to operate the cars parked for a large convention. The electrical engineer is a man who has to have a great deal of imagination of how he can best apply all these various tools to new and novel uses.

The report touches on the further development of circuit breakers. The air circuit breaker is being rapidly developed to supplant oil circuit breakers where the use of oil presents a fire hazard.

Mr. Post, in his report a few moments ago, told you how supervisory control is being applied to signaling. It is also being applied to outlying facilities. The operation of pumps, the operation of various types of facilities can be controlled very simply and very economically and easily today over telephone lines by this new development of supervisory control.

The second assignment of the Committee on Electricity is to review the current activities of the Electrical Section. The committee reports were published in full in Bulletin 419 and I will not attempt to go into detail concerning them except to call your attention to the broad scope covered by the section. It has standing committees dealing with power supply, electrolysis, electric heating and welding, the application of motors, clearances for third rail and overhead working conductors, track and third-rail bonds, illumination, high tension cables, and the application of corrosion-resisting materials to railroad electrical construction.

In mentioning these, I would like to call your attention to the research work that has been done by the Committee on the Application of Corrosion-Resisting Materials. This has been referred to each year for the last five years, and the work this year practically completes the studies which were started some ten years ago to determine which of a great number of commercial alloys are best adaptable for use not only on electrified railroads but on any railroad where smoke and the atmospheric pollution of neighboring industries causes so much damage and loss through the corrosion of ferrous materials.

That this particular subject has been of great interest is evidenced by the fact that your secretary has had a great many calls for copies of this report from the suppliers and manufacturers who are dealing with railroad hardware. This is, I feel, a real contribution to railway engineering.

I would be entirely lacking in appreciation if I did not add my own personal word of appreciation to the great help that the Electrical Section has had each year from the American Railway Engineering Association. It has been my good fortune to have been in contact with the various presidents of your Association in connection with my work in the Electrical Section for the past four years, and each year I have found that the directors and officers of the Engineering Association have been most helpful to the Electrical Section. I want to add my own tribute to what has been said of Mr. Fanning this morning. Mr. Fanning, last October, came to our annual meeting and addressed us, and he gave me personally a great deal of good, sound advice and help. I sincerely regret as much as anyone in this room his untimely passing. I want to bespeak for my successor in the Electrical Section the same cooperation that I have had the past four years from your officers. Thank you.

Vice-President Bond: Any discussion on the report as presented? If there is no further discussion, Mr. Brown, I want to thank you very much for presenting a difficult report in a very interesting way, also for the résumé of the work of the Electrical Section. We are very much indebted to you. (Applause)

Discussion on Waterways and Harbors

(For Report, see pp. 87–93.)

(Vice-President Bond presiding)

Chairman G. P. Palmer (Baltimore & Ohio Chicago Terminal): We have nothing to report on Revision of Manual.

On subject 2, we completed the report last year with the exception of some definitions which were withheld for certain changes and are now presented for approval and inclusion in the Manual. The three definitions of words used in the report that was presented last year you will find at the top of page 88, and I will read them as they are now submitted.

(Chairman Palmer then read the three definitions at top of page 88.)

Chairman Palmer: I move that these three definitions be adopted for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Palmer: The report on Assignment 4 will be submitted by the subcommittee chairman, Mr. Hyde.

N. D. Hyde (New York Central): The study of metal and other protective casings for pier structures under water was first assigned last year. Several types of such casings are manufactured and on the market. There are experimental installations in several places on the Atlantic seaboard. None of them has been in use a sufficient length of time so that conclusions can be reached as to their effectiveness. We therefore suggest that the subject be kept open for further report.

Vice-President Bond: Accepted as a progress report.

Chairman Palmer: Assignment 6. Seawalls and ocean shore protection, including wave action and ice: Mr. Smith, the subcommittee chairman, is not present. Therefore, I will attempt to give the report.

The information contained herein has been obtained from various publications as shown on page 90, and is really a summary of conclusions reached by various authorities, including the office of the chief of engineers, U. S. Army, and other associations.

The conclusions of this report are as follows: Seawalls of various design and groins may be properly used in protecting shores and beaches after careful studies of all conditions have been concluded to enable the selection of an adequate design of seawall or groin or a combination of both.

No recommendations are made with reference to any effective type of structure by reason of the great variance in conditions.

This report is submitted as information. However, included in this report we have a definition for the word "groin" which we recommend for inclusion in the Manual. It reads as follows:

Groin.—A barrier extending into the water from a beach to arrest traveling sand and shingle and to give protection against wave-wash or current. A small jetty.

I move that this definition for groin be included in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Palmer: Report on assignment 7. Reasonable life of steel casings immersed in sea water: This report will be given by Mr. Faucette, the subcommittee chairman.

W. D. Faucette (Seaboard Air Line): Those who are close to the coast, who have to deal with brackish water and sea water may find this report rather educational. The subject was assigned to this committee some two or three years ago, and after your subcommittee chairman had considered the question of approach to the subject, he learned that the War Department, through the office of the chief of engineers and more particularly through the Beach Erosion Board at Washington, was investigating at some length a report on steel sheet piling in various parts of the country and was carrying this work on in considerable detail and thoroughness. In view of the time and care that was being devoted to this investigation by the War Department, it was the opinion of the subcommittee that its study could be pursued to greater advantage, if it were deferred until the War Department's report was more nearly complete.

I had several conferences with the Beach Erosion Board and with some of the investigators who are going into this subject in a rather thorough way. It is natural that a study of this kind must be progressive. But if you are really interested from an engineering point of view, it will pay you to read, when you get home, pages 90, 91, 92 and 93. The information that is set forth in the pamphlet issued by the Department of Scientific and Industrial Research under the title "Deterioration of Structures in Sea Water" which is designated as the Seventeenth Interim Report of the Committee of the Institute of Civil Engineers, London, England, printed in 1938, is very interesting. On page 91 are the conclusions, which I will not read, but they are worth your time.

Of course, a good many of you are familiar with Dr. William F. Clapp's work at Duxbury, to which I allude on page 92.

If you have any problems that touch upon this subject, and think it is worth while to go to Washington, you will get a very cordial reception on the part of the War Department at the Beach Erosion Board headquarters. We have recently had some problems, and we found the board very helpful in discussing the matters with us.

The information on page 93 is given as a progress report with respect to the annual loss of metal thickness in inches at certain elevations. This is rather illuminating but is not to be taken as a definite conclusion in any way whatsoever.

Your subcommittee offers these data and this progress report as information to those who are particularly interested in the subject of the reasonable life of steel casings immersed in sea water. The committee feels that the subject should be continued into the next year or two, at least.

Chairman Palmer: This completes the report of Committee 25.

Vice-President Bond: If there is no discussion, the committee will be excused with the thanks of the Association for its very valuable work. (Applause)

Discussion on Highways

(For Report, see pp. 149–153.)

(Vice-President Bond presiding)

Chairman J. G. Brennan (Association of American Railroads): Assignment 1. Revision of Manual: This is a progress report and it is hardly necessary to read it. The committee will continue the work during the coming year and hopes to have a report for the convention next year.

The report on assignment No. 2—Design and specifications for highway crossings at grade over railway tracks, both steam and electric, is likewise a progress report, and it is not necessary to read that.

Assignment No. 3—Comparative merits of various types of grade crossing protection: Mr. H. M. Shepard, the chairman of the subcommittee, is not here, so I am going to ask Mr. G. P. Palmer, who has been very active in this particular work, to make the report for the committee.

G. P. Palmer (Baltimore & Ohio Chicago Terminal): This is a new subject on which we are just starting to gather information, collaborating with Committee 10—Singals and Interlocking, of the Signal Section, AAR, and the Highway Research Board.

During the year just passed, we endeavored to assemble data on various types of reflectorized crossbuck signs now on the market or proposed to be placed on the market. This report, as information, covers several different types of material being used. Since this report was written, one of the signs of the Reflecting Metal Corporation has been installed at 104th street in Chicago, for test. On the Scotchlite sign, two more signs have been placed at Central avenue near 103rd street, just outside of Chicago, and two of the signs of the Cuneo Press, which were put up last August and blown down in the windstorm on November 11, have been replaced and are again located at 105th and Rockwell streets.

The purpose of these signs is to test them under all weather conditions which any sign has to stand while it is in service. We of course do not expect to get any definite conclusion from these tests for some little time, but the committee has in mind testing other signs at other points in the immediate future.

This report is submitted as information with the recommendation that the subject be continued.

Vice-President Bond: Any discussion? If not, the report will be accepted as information.

Chairman Brennan: Assignment No. 4—Prepare drawings of typical location for grade crossing signals, for various degrees of crossing angles: Mr. A. P. Button, chairman of the subcommittee, will present the report.

(A. P. Button, New York Central, read the report on assignment 4.)

Vice-President Bond: The committee's recommendation as stated in the report will be duly submitted to the Committee on Outline of Work.

Chairman Brennan: Assignment 7—Recommend methods of protecting highway crossings and flangeways against obstructions and damage caused by use or passage of highway work equipment: Mr. Bernard Blum, chairman of the subcommittee, will make the report.

Bernard Blum (Northern Pacific): The report was prepared to meet a condition that has arisen several times in the past few years by serious accidents at highway-railroad grade crossings where equipment of the highway departments has been struck by trains and, in some cases, derailment of trains at highway grade crossings have occurred because the flangeways became filled up with dirt or gravel or ice in the course of work of the highway department.

It hardly seems necessary to read the report which is given in the form of instructions to be issued by the several highway departments to their employees. Several states have issued instructions in line with these recommendations. One state, I am advised, has adopted it as submitted and several states in the Northwest have adopted it substantially in the form it was originally prepared, but with a few corrections.

It is believed it will be of considerable advantage in the work of safety on the highways and on the railroads.

The other recommendation about submitting it to the American Association of State Highway Officials will be taken care of in due course.

I move that it be adopted and printed in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Brennan: It may be of interest to you gentlemen to know that these requisites have already been adopted by the State Highway Department of Arkansas. I was so informed this morning by Mr. R. E. Warden from that state.

This completes the report of Committee 9.

Vice-President Bond: Any further discussion on the report as submitted? If not, I wish to say that the work of your committee is very much appreciated, and you are excused with the thanks of the Association. (Applause)

Discussion on Cooperative Relations with Universities

(For Report, see pp. 155–171.)

(Vice-President Bond presiding)

Chairman E. T. Howson (Railway Age): Your Committee on Cooperative Relations with Universities presents its first report, having been re-created shortly prior to the last convention. It has devoted its attention up to the present largely to work of an exploratory character, looking to the development of the scope of the assignments given.

The work of this committee differs from that of other committees of the Association in that it is not dealing primarily with materials or detailed practices of working; neither is it concerned with the immediate present. Rather it is dealing with a problem of management, the full impact of which will not be felt for some years. Its work is, however, of fundamental importance to the permanent well being of the railway industry of which we are all a part.

The railways comprise one of our largest industries. They are an industry whose maximum efficiency is essential to the industrial life of this country. The railways are meeting new and increasingly intensive competition from other agencies of transportation. All of these conditions place a great responsibility on railway managements, and they demand that the railways bring into their organizations men of the highest ability in order that they may be able to cope with and solve these problems as they arise from year to year in the future.

A far larger proportion of the more promising young men are now enjoying the privileges of a college education than in any previous generation. It is pertinent, therefore, to inquire whether the railways are attracting their due proportion of these young men of promise. It is pertinent, also, to inquire whether the colleges and universities are training these young men in matters of education and in point of view to prepare them best for service in the railway industry.

Railroading has changed greatly in recent years. It is no longer an industry, from an engineering standpoint, of extensions. It is an industry now of intensive development. That requires a different type of engineering, and yet it is a type of engineering that is of just as high grade, yes, even higher grade than that of the pioneers of a generation ago. Engineering today requires a more thorough appreciation and knowledge of economics as applied to transportation, a greater willingness to develop plans and practices to effect economies in costs and to increase effectiveness in service. In fact, it requires a far greater degree of exactness.

(At this point Mr. Howson presented the substance of the last three paragraphs of the Statement of Scope and Purpose appearing on page 157.)

Mr. Howson: Your committee has been instructed by the Board to study, among other subjects, that of stimulating greater cooperation between railway officials and officers of universities and colleges in preparing the best courses of instruction to meet changing railway problems. The committee has this subject under study but has no report to present at this convention.

The committee was also instructed to call the attention of universities and colleges to such information and conclusions developed by the Association as would be thought to be of special interest or value to them. That subject is also in process of development, but the committee is not yet prepared to report.

The committee was instructed to develop means of bringing to the attention of railway managements the value of a technical education as a qualifying factor for young men desiring to enter railway service with a view to advancement. The committee has a report of progress to present. Mr. Schwinn, chairman of the subcommittee, will present the report.

F. S. Schwinn (Missouri Pacific Lines): Because of the broad scope and importance of the subject, your committee has undertaken to develop its study progressively. This year's report deals with the possible opportunities offered by railways to technically educated and other college men, coupled with the views of several railway executives. Much of the report is in the form of quotations from men whose opinions are valuable, although these opinions are not unanimous in every respect.

Without undertaking to read extensively from this report, we wish to direct attention to the fact that these railway executives were practically unanimous in that they favored employing college men, that they believed that college men would meet the requirements of advanced positions more satisfactorily than those without a college education, all other factors being equal, and that the technical or college man might be expected to advance more rapidly than a man without such advantages.

A very excellent composite picture of the attitude of railway executives is expressed in a letter written by Mr. F. E. Williamson, president of the New York Central System. From this I quote:

(He read the paragraph at the bottom of page 167 and the top of page 168.)

Mr. Schwinn: Those of you who are responsible for the efficient organization of a department, technical or otherwise, and who are considering not only today but also tomorrow will find this report interesting and helpful to your managements as well as to yourselves. I cannot urge too strongly that you bring it to the attention of your managements.

The brief review of this report given on page 168 includes your committee's preliminary observations which are introduced for the purpose of stimulating the attention and concern of railway managements in the young college men, and to indicate to those men the attributes required for success in the railway industry.

During the coming year it is intended to carefully analyze and report on the practices followed by other industries in the selection and training of college men, by which the committee will show the growing importance given to technical education by these industries.

Chairman Howson: The committee was also asked to stimulate a greater interest in the science of transportation among university and college students, and create thereby a greater appreciation of the place of transportation in our national economic structure. Professor W. C. Sadler, chairman of that subcommittee, will present this report.

W. C. Sadler (University of Michigan): I think in reading this report I should call your attention to the fact that the committee thought it was to the interest of the railroads to concern themselves with university students, not only from the point of view of potential material for employment but also from the point of view of potential shippers; particularly in the field of engineering, the railroads had a very vital interest in university circles.

(Mr. Sadler then read the report on Assignment 4.)

Chairman Howson: The committee has been instructed, also, to develop means whereby facilities of the universities may be made more directly available for research work of the Association and the railway industry by cooperative effort between the staffs of the universities and the committees of the Association. That subcommittee has a report to present to you. Its chairman is Professor Russell. In his absence, the report will be presented by Mr. Lem Adams.

Lem Adams (Oxweld Railroad Service): Your committee's first activity has been to develop, by means of a questionnaire, as complete information as possible regarding the present facilities, personnel, activities, and interests of the various schools bearing on railroad problems, as well as a compilation of the subjects already investigated and the reports that are available for distribution.

Information of this character can be collected most readily from the colleges giving engineering degrees, of which there are about 145 in the United States. A questionnaire was sent to 125 of these schools. This questionnaire included the following questions:

(He then read the questions listed on page 170, and gave the substance of the concluding paragraph of the report.)

Chairman Howson: The committee was instructed to stimulate a greater appreciation among university and college authorities of the fundamental importance of instruction in transportation and economics, and of the necessity for assigning men of adequate ability, experience and fitness for such teaching. The committee has that subject under way. It has no report to present at this time.

The committee was instructed to cooperate with organizations of university and college students engaged in study or discussion of engineering or transportation matters and contribute to their activities in such manner as may be mutually arranged. The chairman of that subcommittee is Mr. Gault who is unable to be with us because of illness. Mr. Faucette, a member of the subcommittee, will present the report.

W. D. Faucette (Seaboard Air Line): It is with much regret that we record Mr. Gault's sickness and absence from this work and, in his behalf I can no better paraphrase the assignment than to re-read what it is: "Cooperate with organizations of university and college students engaged in study or discussion of engineering or transportation matters and contribute to their activities in such manner as may be mutually arranged."

The deans of 17 colleges were communicated with, and, as you will note in the progress report, 14 of them replied. We digested and give you briefly on page 171 the five general headings under which this matter falls in the replies.

This is a progress report. It must be realized by the membership that this committee, reconstituted only a year ago, must necessarily make its progress with some deliberation and some care in approaching this very large assignment.

In behalf of the subcommittee and for the committee as a whole, I would like to say that this cooperation with these universities and colleges may sometimes have to come solely through railroads with colleges and universities local to those systems. If those colleges and universities which are local to certain railroad systems do not receive the cooperation from them, the chance that they will receive it from anybody else in the railroad field is very remote.

Therefore, although you are not members of this special committee, we urge you to investigate yourselves what colleges and universities or institutions are local to your railroad system, and ask you to make a contact with them in such a way as to indicate that you are cooperatively interested in them, and in the subject of this assignment.

You must remember that in the progress of this American Railway Engineering Association, in probably a generation or at least a half generation, the active membership and the active direction and administration of this Association and the railroads too, will come, not entirely from these men with whom you are going to cooperate in these colleges and universities, in railroad service, but they will have a very large representation. So you may be sowing seeds not only for the benefits of the properties which you represent, and the problems which you may solve in transportation, but you also may be sowing seeds of interest in which you may raise up the administrators and workers of this Association who will perpetuate not only the railroad as an instrumentality of this nation but will perpetuate the work of this Association (this year being its forty-second annual meeting). If you were to take the poll now, you would probably find in this room a very large percentage of men who have had the opportunity to go to colleges and universities, and, therefore, one generation hence you will find as much a proportion of those men coming from the institutions, who will carry along for us.

With that idea from our committee, we therefore impress upon you and ask you please to review this report with as broad a viewpoint as possible and remember that you may be the only contact railroad to some institution in this country, because there may not be any other railroad close to those universities and colleges.

Chairman Howson: That concludes the report of this committee.

Vice-President Bond: Mr. Howson, you and your very able committee are to be warmly congratulated on the broad lines with which you have begun the study of continuing and continuous interest, and we are all very much indebted.

It has been brought to my attention that there are about 25 senior engineering students who are here largely through the instrumentality of the committee now on the platform. I think I saw most of the engineering students at lunch today, and they are such a good-looking crowd, I am going to ask them to stand up so that the convention can also see them. Will the junior members stand up? (Applause)

The committee is excused with the thanks of the Association. (Applause)

Discussion on Uniform General Contract Forms

(For Report, see pp. 37-43.)

(Vice-President Bond presiding)

Chairman W. G. Nusz (Illinois Central): The committee cannot present its report to the Association this year without reference to the loss of our fellow committee member, Past-President James C. Irwin. Mr. Irwin served as vice chairman and chairman of this committee, as well as a member from its formation in 1909 to the time of his death, March 20, 1940. The committee feels deeply the passing of a wise counsel, always interested in its work and one who endeared himself to all of its members. Both the committee and the Association have lost a valiant friend whom we will miss keenly.

The first subject assigned to the committee is Revision of Manual. At the request of the Electrical Section of the Engineering Division, a subcommittee of Committee 20 has been collaborating with Committee 1—Power Supply of the Electrical Section in a comparison of the form of our present agreement for the purchase of electrical energy, now in the Manual, with a tentative form drawn up by the Committee on Power Supply. Progress has been made but it is not now deemed desirable to present it to the convention. The report will probably be made on this subject next year.

The second assignment is: Form of agreement for commercial signs on railway property. Mr. O. K. Morgan, chairman of the subcommittee, is absent, and Mr. E. H. Barnhart will present the report.

E. H. Barnhart (Baltimore and Ohio): The tentative form of this agreement was submitted at the last convention of the Association. All suggestions received have been considered, and the committee now presents for adoption the Form of Agreement for Commercial Signs on Railway Property. If there is no objection, I will read the subheadings.

Mr. Barnhart: I move the adoption of the Form of Agreement for Commercial Signs on Railway Property for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Nusz: The third assignment, Form of lease for air-right development, has been before the committee a couple of years. No report is made at this time. The committee has given the subject a great deal of study and has accumulated a number of documents but it does not seem advisable at this time to present a detailed form for adoption by the Association.

The fourth assignment, Form of agreement for wire or cable line crossings, collaborating with Committee 3—Overhead Transmission Line and Catenary Construction, Electrical Section, was made a year ago. A form of agreement was adopted at the last convention. It is reassigned for the purpose of considering revisions which may be necessary in this form. The committee has nothing to report at this time on this assignment. Since the last annual convention we have continued negotiations with the Rural Electrification Authority. Written criticisms have been received, and a redraft has been made and is being considered.

The form now under consideration, seems to be fairly satisfactory, and it is the hope that it will be completed in a short time and can be submitted to the convention next year.

The fifth assignment, Form of agreement for unloading liquefied petroleum and other gases, will be presented by the sub-chairman, Mr. W. R. Swatosh.

W. R. Swatosh (Erie): Form of agreement for unloading liquefied petroleum and other gases was prepared about a year ago by a special committee collaborating with the AAR Bureau of Explosives, and the agreement as prepared has the approval of the Law Department of the AAR and the endorsement of the General Committee of the Engineering Division.

The agreement is being presented for adoption in the Manual. If there is no objection, I will read the various subheadings.

(Mr. Swatosh then read paragraph headings one to nine.)

Mr. Swatosh: I move the adoption by the Association for printing in the Manual.

(The motion was seconded.)

W. L. Roller (Chesapeake & Ohio): Under the second heading, Ownership of Facilities, should there not be some provision in the form to cover the ownership of facilities by the unloading concern?

Mr. Swatosh: That was not included in the assignment. The assignment was restricted to the preparation of an agreement to cover ownership of facilities by rail companies.

(Mr. Swatosh's motion was then put to a vote and carried.)

Chairman Nusz: This concludes the report of Committee 20.

Vice-President Bond: The forms which this committee painstakingly composes from year to year and presents for inclusion in the Manual are valuable contributions in the records of our work. I want to thank you, Mr. Nusz. Your committee is now excused with the thanks of the Association. (Applause)

Discussion on Water Service, Fire Protection and Sanitation

(For Report, see pp. 95–106.)

(Vice-President Bond presiding)

Chairman B. W. DeGeer (Great Northern): The progress report on Subject 1, Revision of Manual, will be presented by the chairman of the subcomm'ttee, Mr. E. M. Grime.

E. M. Grime (Northern Pacific): The committee has but one small change to submit.

(Mr. Grime then read the report on Assignment 1.)

Mr. Grime: I move the adoption of this change for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman DeGeer: The progress report on Subject 2, Cause of and remedy for pitting and corrosion of locomotive boiler tubes and sheets, with special reference to status of embrittlement investigations, will be presented by the chairman of the subcommittee, Mr. R. E. Coughlan.

(R. E. Coughlan, Chicago & North Western, read the first paragraph on assignment 2, on page 96.)

Mr. Coughlan: This report of Dr. Schroeder is directly in line with the information obtained by your committee in working with the Bureau of Mines. A brief abstract of his paper shows that it has now been definitely proven that embrittlement or, as it is now called, intercrystalline corrosion, is not produced in a boiler by direct action of the water but by a concentrated solution formed from it in capillary spaces in rivet seams in a stressed area.

There is no doubt, from the results of the studies up to the present time, that a boiler constructed to resist embrittlement will need no other protection throughout the life of such a boiler. Welding of seams, the use of alloy steels and chemical treatment, control of water supplies, are the three important items under consideration in this study. Organic inhibitors to prevent intercrystalline corrosion in locomotive boilers already built have proven of valuable assistance.

The evidence obtained to date from actual railroad operation indicates that a combination of good construction and shop practice greatly reduces the possibility of costly failures from intercrystalline corrosion or cracking.

This report is offered in the line of information.

Chairman DeGeer: Your committee has no report on Subject 3, Value of water treatment, and 4, Progress being made by federal or state authorities on regulations pertaining to railway sanitation.

The final report on 5, Cathodic protection for prevention of corrosion of steel tanks, collaborating with the Electrical Section, Engineering Division, AAR, will be presented by the subcommittee chairman, Mr. H. E. Silcox.

H. E. Silcox (Chesapeake & Ohio): In the past few years the subject of corrosion has been widely discussed and various methods have been tried to reduce the deterioration of steel water tanks. Many methods of preventing corrosion have been found efficient in their application to the exterior surfaces, but are not proving entirely satisfactory when applied to the interior surface of the tank shell which is subjected to corrosive action of water.

Cathodic protection is a recent development in the control of corrosion on the interior of steel water tanks. The process is based on the principle of an electric cell in which a continuous current flows in one direction to the steel tank shell which is protected by a hydrogen film plated on its surface.

In the application, direct electric current is required to provide continuous current flow. The supply is usually secured from a regular 105-120-volt electric lighting circuit which is connected to a transformer and rectifier changing the power to direct current at 8 to 27 volts. One or more electrodes of carbon, graphite, stainless steel or other metals are suspended inside the tank from which the current flows through the water to the tank shell, depositing an insulating film below the water line, thus excluding oxygen which is a requisite of corrosion. The electric circuit is completed by a wire connected to the outside of the tank shell returning to the rectifier.

The cost of installed units ranges from $250 up, depending on area of tank, with power for operating from 50 cents per month up.

With such installations, it is still necessary to paint the tank shell above the water line, as protection does not extend to the surface area above the water level. This type of installation has an advantage, in that it is not necessary to remove the tank from service for application of the protective coating, as is required in a cleaning and painting operation.

This report is presented as information.

Chairman DeGeer: The final report on Assignment 6, Effect of lubricating oil in boilers and methods for correction, will be presented by Mr. R. M. Stimmel in the absence of the subcommittee chairman, G. E. Durham.

R. M. Stimmel (New York, Chicago & St. Louis): Condensed steam exhausted from steam cylinders usually contains lubricating oil. Oil in the feedwater from this source or from industrial wastes, and so forth, may be detrimental to boilers, depending on the alkalinity, dissolved solids and floc in the boiler water. Even slightly oily deposits on boiler heating surfaces have an insulating effect which reduces boiler efficiency. A discontinuous coating may cause pitting.

Usually the entrance of oil into boiler water can be prevented. In any case, treatment of water with suitable alkalis and coagulants may be considered an effective means of correcting boiler troubles due to oil.

The report is submitted as information.

Chairman DeGeer: The final report on Assignment 7, Removal of silica from boiler feedwater, will be presented by Mr. Ray McBrian, chairman of the subcommittee.

Ray McBrian (Denver & Rio Grande Western): Silica in boiler feed water, we learn, is very undesirable since it may form a hard, dense scale which possesses the lowest of thermal conductivities. Since the trend is towards locomotives with higher pressures and to Diesel operations, it is necessary to keep the heating surfaces free from this type of scale formation, or else there is great danger of overheating. It is found that there are two fundamental methods which have been used to prevent its formation.

1. The internal treatment, through suitable physical chemical treatment.
2. The external treatment, which removes the silica before it enters the boiler.

The internal treatments have been found to limit certain types of silica scale deposits. The typical chemicals which are used are sodium phosphate, iron compounds, sodium aluminate, and organic compounds such as starches, tannins, lignins, tannic acid, and the glucosides. The external treatment is more needed, especially with increasing trends to higher boiler pressures, so as to prevent danger of loss of heat conductivity by silica scale formation, and it is therefore necessary to remove the silica before it enters the boiler.

The methods discussed cover the use of ferric sulphate, magnesium compounds, and aluminum compounds. A description is given of a plant in operation on the Atlantic Coast Line at Savannah, Ga., where by using sodium aluminate and lime in an especially designed plant, silica is satisfactorily removed. It is noted that the silica content of the raw water was 3.8 grains per gallon, and it was reduced to 0.60 grains per gallon at a cost of $0.0734 per 1,000 gal. of water.

I want to call attention to an error on page 102, paragraph on Internal Treatment. Line 5 should read . . . . to precipitate it as a non-adherent *sludge* . . . . instead of . . . . as a non-adherent *scale*.

This report is presented as information.

Chairman DeGeer: The report on Assignment 8, The principal current activities of the Fire Proteciton and Insurance Section, AAR, will be presented by subcommittee chairman, Mr. G. F. Metzdorf.

(G. F. Metzdorf, New York, Chicago & St. Louis, read the first three paragraphs on page 106.)

Mr. Metzdorf: There has been a recent change in the names and duties of Committees 2 and 3 from those shown in the table on page 106. I will read the correct names of these two committees.

Committee 2—Protection

Committee 3—Buildings, Bridges, Piers and Other Structures

(a) Maintenance

(b) Operation

(Mr. Metzdorf then read the balance of the report.)

Chairman DeGeer: Your committee has no report on Subject 9, Use of anti-foam compounds to reduce road blowing, and no report on Subject 10, Specifications for welded steel tanks for water service, collaborating with Committee 15—Iron and Steel Structures.

This completes the report of Committee 13.

Vice-President Bond: May I congratulate you and your committee for a very interesting report in all its details. You are now excused with the thanks of the Association. (Applause)

Discussion on Economics of Railway Labor

(See Report, see pp. 213–224.)

(Vice-President Bond presiding)

Chairman G. M. O'Rourke (Illinois Central): Committee 22—Economics of Railway Labor reports on four of the ten assigned subjects. The committee reports progress in study for: 5. Review and revise factors previously established for equating track values for labor distribution; 6. Labor economies possible though the use of highway motor vehicles for maintenance forces; 8. Labor economies resulting from periodic spot welding of rail ends as compared with less frequent out-of-face welding, and 9. Labor economies to be derived from keeping vegetation out of ballast.

Subject 2. Analysis of operation of railways that have made marked progress in the reduction of labor required in maintenance of way work, is one of long standing, having been reassigned yearly. The report, to be presented by Mr. H. A. Cassil, describes the methods and effect on the Central of Georgia.

H. A. Cassil (Pere Marquette): The report of the subcommittee relates to the so-called "flat work" track maintenance, particularly as practiced on the Central of Georgia Railway. It was made as a result of a trip by a portion of the committee over that line last year. The advantages and disadvantages of the method and the conditions to which it is adapted are discussed. The conclusions stated in the report are as follows:

(He read the three conclusions on pages 216 and 217.)

Chairman O'Rourke: Subject 3. The relative economy of combined vs. separate bridge and building gangs, was to be presented by Mr. Chumley who was detained in the South by the beginning of the construction of one of the large defense projects. The subject will be presented by Mr. Vance. The report he will place before the convention has been prepared after several years of investigation and study on most of the railroads of the country and does, we believe, represent the best practice. Careful consideration of the conclusions offered for inclusion in the Manual will be appreciated.

W. H. Vance (Missouri Pacific): As Mr. O'Rourke stated, this subject has been under consideration for quite some time. In order to determine the prevailing practice, the committee sent a questionnaire to representative railroads throughout the United States and Canada. Thirty-eight of the railroads replied, furnishing valuable information on this subject. These 38 roads of a combined mileage of approximately 232,202, with 3,303 miles of steel and masonry bridges, 1,500 miles of timber bridges, with approximately 80 percent of the buildings and miscellaneous structures of wood. Twenty-seven of these roads, with 85 percent of the total mileage, 95 percent of the steel and masonry bridges, and 80 percent of the timber bridges, use combined gangs. Eleven roads, with 15 percent of the total mileage, 5 percent of the steel and masonry bridges, and 20 percent of the timber bridges, use so-called separate gangs.

The various railroad maintenance officers set forth the advantages and disadvantages of the so-called separate gangs. The committee considered all those replies and came to the following conclusion:

The relative economy of combined or separate gangs for bridge and building work depends upon the conditions prevailing on individual railroads and, in many cases, on grand divisions or districts of a single railroad. For railroads in general, with half or more of their bridges of timber construction and with a large proportion of their buildings of frame construction, combined gangs are preferable to separate gangs.

We have undertaken to define combined gangs and separate gangs.

(He read the definitions on page 218.)

Mr. Vance: I neglected to say a moment ago that nearly all of the railroads of any size do have special gangs for their steel bridge work, and this report has to do with the ordinary maintenance work rather than the heavy steel work.

The committee recommends that the conclusions be adopted and published in Chapter 22 of the Manual, following the matter on programming of bridge and building work, and that the definitions be adopted and published in the Glossary.

I move the adoption of this material.

(The motion was seconded, put to a vote and carried.)

Chairman O'Rourke: Subject 7. Added labor economies resulting from use of off-track maintenance equipment: The report to be presented by Mr. Armstrong Chinn is the result of two years' study and contains the most complete information on the subject available today. It is of growing importance and warrants the serious consideration of every maintenance of way officer.

Armstrong Chinn (Alton): The gist of the report will be found in the list of factors at the top of page 222 which, in the opinion of the committee, have brought about the development and use of off-track equipment, and the list of economies found at the bottom of page 223 which the committee believes will result from the use of off-track equipment. I will read these two portions of the report.

(Mr. Chinn read the first paragraph, including subhead paragraphs, on page 222, and the possible labor economies listed at the bottom of page 223 and concluding on page 224.)

Mr. Chinn: The report is submitted as information.

Chairman O'Rourke: I unintentionally skipped over the report of a very important subject, Assignment 4. Labor economies resulting from improvements in drainage practices. This assignment, recently given to the Committee on Economics of Railway Labor, has been handled from a different point of study by the Roadway committee in the past, and perhaps by others. We have given consideration to the labor economies resulting from sub-surface drainage. The report will be submitted by Mr. E. H. McIlheran.

E. H. McIlheran (St. Louis Southwestern): The first part of this report of the subcommittee on this subject states that many reports have previously been made indicating the necessity for good drainage and the benefits to be derived therefrom, and shows in what volumes of the Association Proceedings some of this information may be found.

Questionnaires were sent to 52 railroads to ascertain if possible the monetary savings in labor resulting from improvements in drainage practices. The figures received from the 20 railroads that furnished any costs were consolidated and are tabulated on the bottom of page 219. They show that a very substantial saving in labor has been secured by installations of the several types of drainage.

At the top of page 220 there is a description of tile drain installed in 1920, according to AREA recommended practice, on the St. Louis Southwestern Railway a short distance south of Pine Bluff, Ark., where 8,349 ft. of track was drained at a cost of $15,162, which resulted in an estimated annual saving in track labor of about $2,620 and improved the track, on which permanent slow orders of 10 or 15 miles per hour had been maintained, so that trains could be safely operated at a speed of 60 miles per hour.

On the lower part of page 220 there is described a perforated corrugated metal pipe drain installation on the Illinois Central Railroad on the Bluford district near Fulton, Ky., where 4,000 ft. of 8-in. perforated corrugated asphalt-coated iron pipe was installed at a cost of about $13,000 in a sliding fill to drain water pockets, and which work has apparently stabilized the fill, resulting in an estimated annual saving of about $2,250, and the removal of a 466-ft. temporary trestle which had been maintained for years because of the unstable fill.

(Mr. McIlheran then read the conclusion on page 221.)

Chairman O'Rourke: Your committee desires to offer as information a special report on the studies of the subcommittee headed up by the late Robert Faries. The carriers' Special Committee on Mechanization in the Maintenance of Way Department presented testimony before the Railroad Carrier Industry Committee in Washington a year ago. The report shows in detail how advances in hourly rates accelerate the mechanization of labor operations in maintenance of way. Mr. F. S. Schwinn was a member of that subcommittee and will present the report.

F. S. Schwinn (Missouri Pacific Lines): This report appears on pages 1 to 25 inclusive of Bulletin 419 (pages 1 to 25 of the monograph section of the Proceedings). Your attention is directed to an error in the sub-title as the basis of the report was testimony presented *before* the Railroad Carrier Industry Committee and not by that committee. The testimony was presented by the late Robert Faries of Pennsylvania and was the result of exhaustive studies of the effects of mechanization in maintenance of way departments of railroads. I was privileged to have the opportunity of being associated with Mr. Faries when he made these studies, and I therefore greatly appreciate this opportunity of placing this information before the convention.

Your committee feels that the report contains a large amount of valuable data in a concise form, and that such data should be of material assistance in meeting present day conditions and traffic demands. It reflects one of the many outstanding efforts of Mr. Faries in behalf of the railroad industry.

Chairman O'Rourke: A revision of the Manual was given due consideration, and no revision was recommended. That concludes the report of Committee 22.

A. A. Miller (Missouri Pacific): I would like to say before the committee is excused that, in my opinion, the work that this committee is doing is of such importance, particularly at this time and possibly in the future, that any assistance that we can give the members in the way of suggestions or information during the year, I am sure the chairman and members of the committee would welcome.

To those who have not as yet read the information and suggestions and recommendations made in the bulletins covering this committee's work, I suggest that it would be well to do so. There is one part of the committee's work that we on the Missouri Pacific have come in contact with strongly. That feature is the so-called "flat work" which has been referred to here and covered in a brief report. Several years ago that thought came out of the South, from the Central of Georgia. It didn't appeal to me at all at the time, but we took it on. This kind of work is surely effectively applicable to the so-called light traffic lines, light rail lines, or branch lines of doubtful future.

We undertook some of this work in a test sort of way five or six years ago on the Missouri Pacific Railroad, and it has grown and grown so that now we have set it up as program work. I should say that our light traffic lines or lines of doubtful future (light rail lines), are now 50 percent covered by the flat work process. It is what might be called line and surface work without the use of very much, if any, ballast, and is done primarily by section forces and not by extra gangs. It gives some measure of the work being done in application of man-hours out on these light traffic lines where, as supervisory officers, we well know we don't get very often. We have been more or less dependent upon asking questions and getting answers, accepting them but sometimes doubting them with respect to conditions on such lines. But now we can really have a measure of the application of those man-hours. It would be well in my opinion for those who have that kind of branch lines to look after, to read the report of this committee with reference to the so-called "flat work".

Vice-President Bond: This committee is to be congratulated on its very fine work, and is now excused with the thanks of the Association.

Discussion on Maintenance of Way Work Equipment

(For Report, see pp. 173–212.)

(Vice-President Bond presiding)

Chairman G. R. Westcott (Missouri Pacific): Counting one subject that is divided and the assignment of Revision of the Manual, Committee 27 had 14 assigned subjects. We are reporting on seven of them. Of the subjects on which there is no report, I mention Revision of the Manual, but we are reporting on one small item of Manual revision in connection with one of the other subjects.

Assignment No. 3 is Lubrication. The report is under way but not ready for this year. No. 4 is: Self-contained direct-blow gasoline tampers. Owing to lack of developments in that line we have not found anything warranting a report, but anticipate developments worthy of report next year.

The other four are as follows:

No. 9 (a) Oxy-acetylene welding: Some progress was made on this but no definite results were obtained this year. No. 10 is: Automotive equipment used on the railroads. That is a subject that is developing very rapidly, and I think next year we shall have a report. No. 12 is: Weed burners and extinguisher cars, and No. 13 is: Safety devices for work equipment. That disposes of one-half of our assignments.

On the other seven subjects we are presenting reports, beginning with subject No. 2, Standardization of parts and accessories for railway maintenance motor cars. I will ask Mr. R. K. Johnson to present the report.

(R. K. Johnson, Chesapeake & Ohio, read the report on Assignment 2, page 174.)

Mr. Johnson: I move that Fig. 5.—Safety Rails for Light Inspection Motor Car, shown on page 176, be adopted and published in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Westcott: The next assignment on which we have a report is No. 5, Devices for applying metal preservatives to rail and fastenings. I will ask Mr. Fero to present the report in the absence of Mr. R. R. Smith, who is chairman of the subcommittee.

C. L. Fero (Boston & Maine): This is a rather long report, and I will just skim over it. You all know the general causes of corrosion to rail and track fastenings, so I will skip that.

The prevention or control of corrosion is achieved by the simple expedient of placing a protective coating on the surface of the metal. The most commonly employed material is an asphalt base oil usually containing 45 to 55 percent asphalt.

Hand application consists of brushing or painting, the use of hand operated one-man sprayers, and the application of joint packing.

(Mr. Fero then read, beginning with the second paragraph under Hand Operated Appliances on page 177 and ending with the tenth line on page 180.)

Mr. Fero: There is available through a manufacturer a self-propelled track oiler of rather large capacity designed to accomplish all of the oiling on track or roadway. The machine, consisting of two units, the track oiler and the trailer tank car, is powered with a 72-hp. gasoline motor for propulsion and the operation of all the mechanical equipment, such as the air pump, oil pumps, etc.

(Mr. Fero then read the six paragraphs beginning at the top of page 183.)

H. Austill (Terminal Railroad Association of St. Louis): I would regret very much to see this subject dropped by the committee. The damage to track by brine drippings is enormous in this country. This subject is very closely related to that question. I believe it should be continued, and the committee should keep up with progress in the hope of developing some methods of combating the damage caused by brine to rail bases, spikeheads, tie plates and ground switches.

It may interest the committee that I built a little outfit for spraying the outside of the track rail, spikeheads and tie plates with regular paint spray equipment, using a 45 percent asphalt oil. I think you get much better diffusion, much better protection, than you do by simply applying the oil under pressure. It is hauled by standard motor cars, covering about 12 miles of track a day. The spray guns are detachable, so that with sufficient hose one can stop at switches and turnouts in yards to spray them with the gun, hook it up again and go on down the track.

I will be glad to furnish the committee a plan of that outfit.

Vice-President Bond: The suggestion that this subject be discontinued will be duly dealt with by the Committee on Outline of Work.

Chairman Westcott: May I make a remark about that particular thing. This committee is unique in this respect: Our function is to discuss those things that are available for a given purpose. We are not permitted to discuss their economic features, particularly. We can tell what they are and what they do and what we hope to get from them, but we do not design them. We did not know about Mr. Austill's paint sprayer; we are glad to know about it. But it seemed to the committee in this particular instance that we had covered the ground, as the situation now stands, pretty thoroughly, and that it would perhaps be better to discontinue the subject for a year or two until someone had devised something better than what we now have. That is not in the way of argument at all but just an explanation as to the view of the committee.

Subject No. 6 on this assignment is Methods of keeping data on work equipment. This subject has been before the committee quite a number of years. In the last two or three years we have tried to clear it up, and we hope this year we have cleared it up. Mr. N. W. Hutchison will present the report.

N. W. Hutchison (Chesapeake & Ohio): Although there are probably as many methods of keeping data on work equipment as there are railroads, it is generally agreed that data of some description should be secured for the following purposes, regardless of the methods followed:

(He read items 1 to 8 on pages 183 and 184.)

Mr. Hutchison: Study of the assigned subject thoroughly indicates that standardization of methods for keeping data on work equipment is difficult, if not impossible. Standardization of forms for the purpose, however, is not only practical but desirable. With this in mind, your committee has submitted a series of illustrative forms which we believe, while not specifically adaptable in each case, will provide for better control of work equipment.

These forms, the use of which is briefly described and on which illustrative but fictitious data are inserted, are shown on pages 185 to 194, inclusive. This report is presented as information, with the recommendation that the subject be discontinued.

Chairman Westcott: Assignment 7 is: Pneumatic tired tractor equipment. Mr. R. M. Leeds will present the report.

R. M. Leeds (Louisville & Nashville): The report of your subcommittee outlines the uses of pneumatic tired equipment as applied to the railroads, the reasons therefor and the needs for further development. Concerted action by the railroads and manufacturers is suggested in order to develop more units suitable for railroad service.

The committee did not confine itself entirely to tractors, as will be shown by some of the illustrations in the report, as it was thought that it would be well to show some more of the diversified uses to which pneumatic tired equipment could be put. Continuation of the subject is recommended by the committee.

Chairman Westcott: Assignment 8 is: Impact wrenches, something that we all have heard of and, I guess as a general rule, do not know very much about. Mr. R. A. Morrison will present the report.

Mr. R. A. Morrison (Pere Marquette): This report is a simple description of two types of wrenches that are now on the market and in use by the maintenance of way department. One is the spring and cam type and the other is a power vane wrench. One type is shown on page 199, and the other on page 200. I might add that this impact wrench is used more extensively by the mechanical department in the repairs of locomotives and cars than possibly in the maintenance of way department. Any one who has not seen them in operation or who is not familiar with them can get good information on their operation and use if he will investigate the repair shops of his road. The mechanical departments use a much larger wrench than we do. It was possibly because of the use and development of this larger wrench that enough progress was made to bring forth a much lighter tool for the maintenance department. The big improvement in the modern wrench is the small recoil action that permits its use in overhead work, with less scaffolding.

This report is submitted as information, and it is recommended that the subject be discontinued.

Chairman Westcott: For several years we have had assigned to us the subject of equipment for track welding, both oxy-acetylene and arc welding. This year, on the second half of that assignment, which is No. 9 (b), Mr. Morgan, chairman of the subcommittee, will present a discussion of mountings for arc welding machines.

C. E. Morgan (Chicago, Milwaukee, St. Paul & Pacific): The report this year on arc welding equipment is confined strictly to the mounting of machines for maintenance work. We have not tried to cover in any way a description of the process or how the arc welding work is done. Because of interest in the manner in which arc welding machines may be adapted to suit the users' purpose, illustrations of each of many types in use today are presented in the hope that they may help someone to solve his particular problem. Believing we can learn a little faster through using pictures than by reading detailed information, we have included practically every kind of a mounting in which an arc welding machine is used either in smaller or in more extensive numbers. There are a few of these which are quite rare but which are so effective in their application that we feel our responsibility in calling them to your attention.

On page 201, Fig. 1 shows the standard skid-mounted machine which has been placed on track wheels, so that it may be moved readily from one place to another.

Fig. 2 shows a truck-mounted welding generator, in which the welding machine gets the power from the truck engine through a power take-off.

At the bottom of page 201, Fig. 3, is the pneumatic-tired wheel-mounted machine, the one that we would ordinarily speak of as almost universal among the various contractors in building work, and in a great many cases in bridge repair and work that requires it to be towed around by trucks.

On page 202, Figs. 4 and 5 show two views of a machine, Fig. 4 showing it on the track, and Fig. 5, the same machine, after it has been moved to the position over the shoulder where it clears the track.

On page 203, Fig. 6, illustrates an ingenious arrangement whereby a machine, which can be towed around on pneumatic wheels, may also be placed on an underslung push car for movement on tracks. Fig. 7 shows the push car with the apron down, to illustrate how this machine is quickly loaded for moving.

Fig. 8 illustrates a means for meeting the problem of traffic density that does not permit machines to occupy the track at any time, in which case the welding machine must remain in the ditch or along the bank. Here we have a crawler mounted machine that is made narrow for this purpose. The end view is illustrated in Fig. 9.

Turning to page 204, we recognize the front end of a crawler tractor. Crawler tractors have been used quite extensively in handling arc welding work where either a small tractor with one arc mounted on it, or the larger machine with two arcs on it, is employed. These units, of course, are self-propelling off the track, and the only place where it is necessary for them to occupy the track is where they cross bridges or trestles.

Fig. 11 shows another mounting with which a machine can be operated on the track and which also embodies a series of telescoping pipes to connect to a stand with adjustable legs which are set up as shown in Fig. 12 for moving the machine horizontally into the clear. Fig. 13 shows the same machine in its place out on the ballast shoulder.

It is contended by many that the use to which welding is put in the maintenance work depends on the mobility of the equipment associated with it. To this end, the mountings described have been designed for a broad field of application.

This report is submitted as information, and it is recommended that the subject be discontinued.

Vice-President Bond: I agree with Mr. Morgan that these photographs are very helpful in explaining the subject of his paper. A great deal depends upon the clarity of the photographs, and on some of them the subcommittee is to be commended—I am afraid I can only say on *some*—but they are very helpful. It is a very complete report. I don't think the subject can be considered as concluded.

Chairman Westcott: One other assignment, No. 11, on our docket is: Off-track grading equipment. Mr. A. J. Neff will present the report.

A. J. Neff (Denver & Rio Grande Western): The present tendency of railroads to replace expensive on-track equipment with the latest off-track machines indicates that greater advantages are being found in the use of crawler machines.

In this report are illustrated crawler tractors with various types of blade, front-end loaders, carryalls, scrapers, shovels and draglines. Mention is made of the different types of work they can perform. Three examples of typical application of this type of equipment are also given.

Members engaged on this assignment have concluded that the use of off-track grading equipment will expedite work, minimize traffic delays, perform work impossible to perform with on-track equipment, and effect gratifying returns on investment costs.

This report has been presented as information, and it is recommended that the subject be discontinued.

Chairman Westcott: I was a bit surprised that our president did not call attention to the fact that we also requested this assignment be discontinued. I would like to make one other comment on this feature. Committee 27 is made up of men who are good soldiers. If the Committee on Outline of Work says we shall continue a subject, we will do the best we can with what material is available. If they see eye to eye with us that, for the present at least, there is not available material on which to work and for a year or so discontinue the subject, we will be gratified. In either case, we will do the best that we can.

This concludes the report of Committee 27.

Vice-President Bond: We are very much obliged to you for the very able and extensive series of reports which you submitted, and your committee is relieved with the thanks of the Association for your very valuable work and contribution. (Applause)

Discussion on Wood Preservation

(For Report, see pp. 489–514.)

(Vice-President Bond presiding)

Chairman H. R. Duncan (Chicago, Burlington & Quincy): The subcommittees assigned to Subjects 1, 4, 6, 7, 8 and 9 have made considerable progress and study of their subjects during the past year but have no reports completed to present at this time.

Subject 2, Service test records for treated ties, is the usual progress report of tests on various railroads, revised to include the latest available figures on five roads. The report also includes special reports on test tracks on a number of railroads. Each year this particular committee report becomes of more and more value. It gives definite records on what life is being secured throughout the country where traffic and climatic conditions are different and where various species and methods of wood preservation or wood preservatives have been used. The report is submitted as information.

Subject 3, Piling used for marine construction, covers the inspection of long-time test pieces of piling in the Canal Zone and other localities under observation. For a number of years Colonel Atwood has served as chairman of this subcommittee and, due to his intimate contact with work of this character and close association with various army and navy officers carrying on research work of this kind, he has been able to bring to this Association a considerable amount of data that, in our opinion, are most valuable.

Colonel Atwood has recently advised us that he has resigned from the Association, and a new chairman will be assigned to this subcommittee, but he has also assured us that, although he will no longer be a member of our Association, he will continue to work with the committee, and we will be able to maintain a contract with the army and navy as we have heretofore. This will insure that we will secure further reports of the same character.

The report is submitted as information.

Subject 5, Destruction by termites and possible ways of prevention: This report will be submitted by the subcommittee chairman, Dr. von Schrenk.

Hermann von Schrenk (St. Louis, Mo.): This committee has little to report. The information in the report is all we have this year. The main thing about the termite situation is that it is worse instead of getting better. While I am not an alarmist, it seems to me they are rapidly getting the best of the human race.

I was in Texas for a little while and had a very interesting visit to several of the new army posts that are being constructed there, involving hundreds and hundreds of new buildings. I was very much interested to note with what great efficiency the U. S. Engineer Corps and the Architectural Department of the army are following the specifications which have been drawn up and which our Association has in the Manual for the prevention of termites, particularly the shield construction.

If there is one thing we are emphasizing this year it is that, wherever buildings are put up, shield construction be used, and that you not be scared off by all sorts of reports, which are increasing in number from time to time that the shields are no good. Several cases have been reported in which it was claimed the shields did not work. The reasons were obvious because the joints were not soldered; they weren't gripped, so the termites could readily get in behind the adjoining ends.

Chairman Duncan: One of the interesting characteristics of the Doctor is that he doesn't have any report but he continues to bring us new and valuable information each time he is on the floor.

That concludes our report.

Vice-President Bond: We thank Mr. Duncan for his very good report and for the able assistance which he has had from his committee. You are now excused with the thanks of the Association. (Applause)

Discussion on Roadway and Ballast

(For Report, see pp. 539–574.)

(Vice-President Bond presiding)

Chairman A. E. Botts (Chesapeake & Ohio): We have 11 subjects subdivided into 23 assignments, of which we are reporting on 14. Our first assignment, Physical properties of earth materials will be held for presentation between four and five o'clock, at which time Mr. Herbert Ensz, in the absence of Mr. Legro, the chairman, will present the subject, and he has a few slides he will use in connection therewith.*

Our second assignment, Size of waterway openings, formulas, will be presented by Mr. Rose, chairman of the subcommittee.

L. S. Rose (Erie): With the exception of two corrections in the formulas found on page 544, which were called to your attention at the last convention and a few minor changes made since, this report is the same as that submitted a year ago as information. It is now submitted for publication in the Manual. As the report is not subdivided under headings, unless there are objections, I shall read only the conclusion found on page 546.

(He read the five lines under the heading Conclusions.)

Mr. Rose: This report is now offered for publication in the Manual, and I so move.

(The motion was seconded, put to a vote and carried.)

Chairman Botts: Our third and fourth assignments, Specifications for vitrified clay culverts and Specifications for pipe line crossings carrying non-inflammable substances under pressure, will be presented by Mr. Swartout, chairman of the subcommittee.

W. C. Swartout (Missouri Pacific): As you recall, last year we presented as information a complete specification for triple strength clay culvert pipe as distinguished

* At the close of the afternoon session, Mr. Ensz gave a 30-min. talk on various phases of soil mechanics which he illustrated with lantern slides. His remarks were received without comment.

from sewer pipe. It was with the firm expectation that this year we would offer that specification for publication and inclusion in the Manual, but we regret very much that we find it undesirable to do this, for the following reasons:

1. The strength of any rigid culvert pipe is usually expressed as a factor of the horizontal diameter in feet per lineal foot of pipe. In Table 1 of the specification, this factor is 2,000. During the last month, we have learned that the Federal Specifications Executive Committee has been working on a proposed federal specification for clay sewer pipe including culvert pipe and proposes to use for acceptable crushing strength for extra strong vitrified clay culvert pipe a factor of 2,200. That is a 10 percent increase. This federal committee specification, when approved, will govern and no doubt will be used on all federal purchases by departments, agencies and individuals buying for the government and for government aid projects.

This change affects the most important single requirement in a rigid culvert pipe specification, that is, strength. Inasmuch as the Public Roads Administration will undoubtedly use the federal specification, we can see that, as the choice of what is probably the largest single consumer, that specification will undoubtedly govern the industry.

The strength requirement for railroad use is unquestionably higher than for street or highway use, due to loading and impact. Therefore, the strength factor in the AREA specification should be at least as high as any other.

The industry, speaking through the Clay Products Association, I understand is not averse to this higher crushing strength, and the question of putting the smaller producers out of business does not enter into the matter, especially in view of the fact that this so-called extra strong or triple strength clay pipe is a new product and not as yet widely produced.

2. The federal specification now being discussed also tightens up a little on some of the tolerances.

3. We also find that, by rearrangement, Tables 1, 2 and 3 as presented and now before you can be combined in one table, which will be far simpler and easier of understanding by the inspector for any purchaser, which will in itself be highly desirable. If you doubt that statement, just take the dimensions in Table 2 and try to apply the tolerances as set out in Table 3. Unless you have better luck than Mr. Botts and I had with some of them, you will be quite confused.

This new table eliminates all the arithmetic which the inspector has to apply. It simply sets before him the dimensions for each diameter of pipe that are acceptable and those which are outside of the specification.

For the above reasons and the further fact that we feel that any specification issued by our Association should be as nearly perfect and complete as we can make it, the committee desires to retain jurisdiction over this subject for another year for the purpose of making these essential revisions. In making this request, we feel that we are pursuing the proper course and are not putting something in the Manual that in a year or two will have to be revised at considerable expense to the Association.

In 1933 the Association adopted specifications for pipe line crossings under railway tracks. These were inclusive specifications for pipe lines carrying all substances and were worked out in collaboration with Committee 20 of this Association and the American Petroleum Institute after a protracted series of conferences.

These specifications have been found to be very satisfactory except that they are too rigid for pipe lines carrying non-inflammable substances. The Committee on Outline of Work therefore gave us the job of preparing a new specification for that class of crossing.

We found, however, that the scope of the specification now in the Manual will have to be revised before we can present a specification for non-inflammable substances.

Therefore, calling attention to page 556, we desire to move for adoption in the Manual the change indicated at the middle of the page. The present form for the specification for pipe lines carrying inflammable substances reads as follows:

"Pipe lines included under these specifications are those installed to carry oil, gas, gasoline or other inflammable or highly volatile substance, under pressure, [now I want to call your particular attention to this clause] *or any substance which from its nature or pressure might cause damage if escaping on or in vicinity of railway property.* Gas transmission and distribution lines in city streets, carrying less than 45 pounds pressure, are not to be considered as coming under these specifications."

That clause to which I called your attention must be deleted from the specification now in the Manual so that it will read:

"Pipe lines included under these specifications are those installed to carry oil, gas, gasoline or other inflammable or highly volatile substance, under pressure. Gas transmission and distribution lines in city streets, carrying less than 45 pounds pressure, are not to be considered as coming under these specifications."

The specification for oil pipe line crossings does not have the paragraphs numbered nor is the subject matter in any way outlined. Therefore, it is further recommended that to save time in the use of this specification that each paragraph be given headings as shown in the skeleton form as printed. There has been not the slightest change in the specification itself for the obvious reason that, if we did that, it would again be necessary to go to the American Petroleum Institute for approval. This addition of headings is simply to make the specification easier to use.

I move that the changes in the present specification for pipe line crossings carrying inflammable substances be revised as I have read.

(The motion was seconded, put to a vote and carried.)

Mr. Swartout: The specification for non-inflammable substances beginning on page 557 is offered this year as information so that the members will have the specification before them for a year and during that time can give the committee any suggestions or criticisms or additions which they may think desirable. It is our intention to submit it next year for inclusion in the Manual.

Chairman Botts: The fifth and sixth assignments of this committee are Roadway: Settlement, shrinkage, subsidence, and Placing material in embankments, which will be presented by Mr. Chipman, chairman of the subcommittee.

Paul Chipman (Pere Marquette): This report covers two assignments. Assignment 4 (a) involves a revision of material in the Manual relating to shrinkage and subsidence.

(Mr. Chipman read the first paragraph on page 559.)

Mr. Chipman: The present form in the Manual is shown in italics on page 559. The proposed form is shown on page 560. The subjects of shrinkage and subsidence are considered separately.

(He then read the paragraph headings on page 560.)

Mr. Chipman: Under Subsidence the conclusions are those presented last year as information. I would like to call attention to an error in printing. Under 5 (a) the first word should be "settling" instead of "setting."

I move that this revision of the Manual be made.

(The motion was put to a vote and carried.)

Mr. Chipman: Assignment 4 (b) deals with artificial compaction of embankments. Until recent years we have depended upon Nature to complete the solidification of fills, but highway engineers concluded that Nature is too slow and have very generally adopted methods of compaction by rolling and sprinkling that were primarily developed for earth dams and reservoir walls. This report discusses the applicability of such methods to railroad work.

Their justification on railroads depends largely on the nature and extent of the traffic. Under heavy or fast traffic, surfacing to take up settlement must be done more frequently and at greater cost than if traffic is light or slow. Where the new fill is to carry fast or heavy traffic from the start, as in the case of a change of line, special compaction may well be justified. It is useful for detour tracks around grade separation projects, where a part of the track is on an old fill and part on the new one, especially if reduction of speed must be minimized.

That portion of the report ending with and including the bibliography at the top of page 564 is submitted as information.

Provision for sprinkling or rolling or both, in cases where such treatment is desirable, calls for the revision of Sections 33 and 34 of the Specifications for the Formation of the Roadway. The committee recommends that present Sections 33 and 34 be withdrawn and that they be replaced by new Sections 33 and 34. The present form of Section 33 is shown in italics on page 564 and the proposed form just below it.

Present Section 34 in regard to Rolling is shown at the bottom of page 564. Proposed form of Section 34 is headed Moisture Content, Rolling. It provides for compacting fills by methods which are in very general use in building highways. Our specifications have not heretofore provided for such treatment.

I move that the Manual be revised as recommended.

(The motion was seconded, put to a vote and carried.)

(Vice-President Clarke assumed the chair.)

Chairman Botts: The seventh assignment of this committee is tunnel lighting. In the absence of the subcommittee chairman, Mr. Moore, I will attempt to present the subject.

(Chairman Botts read the first four paragraphs found at the bottom of page 565.)

Chairman Botts: I recommend and move that the material under 704. Lighting, at the top of page 566 be adopted for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Botts: Our eighth, ninth and tenth assignments are: Corrosion-resisting fence wire, Wood fence posts, and Electrified fences, and will be presented by Mr. Hillman in the absence of Mr. Jones, the chairman.

F. W. Hillman (Chicago & North Western): Your committee is collaborating with and receiving reports of the exposure tests of farm field fence, unfabricated wire, wire strand, barbed wire and chain link fencing of ASTM Committee A-5 on Corrosion of Iron and Steel. The first report of this committee is published in the ASTM Proceedings for 1939, Vol. 42, page 156. It indicates the trends as shown in the subcommittee's report which is offered as information.

Wood Fence Posts, Specifications: This committee has collected a number of specifications for wood fence posts now in use, and after a thorough study of these, offers the following specifications as information and invites comments and criticisms prior to offering them for inclusion in the Manual at the 1942 convention.

Electrified Fences: This committee has collaborated with Committee 3—Overhead Transmission Line and Catenary Construction of the Electrical Section, Engineering Division, AAR. The report of the subcommittee includes method of construction, securing power, and reference to certain codes that it has been able to find. It quotes from the General Orders of the Industrial Commission of Wisconsin which seem to be the most complete that we have found so far.

Electric fences are increasing in use for farm fencing. Their application to right-of-way would require determination in each state as to meet the requirements for legal right-of-way fence. Policing is necessary to keep vegetation cleared as a possible cause of short circuits. This type of fencing along the right-of-way would lend itself to claims for injury to persons and to stock.

The committee is of the opinion that the electric fence is not suitable for general use as a right-of-way fence.

The report is submitted as information.

Chairman Botts: The eleventh assignment of this committee is: Design of signs. It will be presented by Mr. Drumeller, chairman of the subcommittee.

L. J. Drumeller (Chesapeake & Ohio): As may be noted from the report, the committee has prepared a tabulation of answers received from the questionnaire mailed to a number of roads showing the various types of signs appearing in Manual pages 1–87 and 1–88 under the heading "901. Roadway Signs Required."

Due to the great diversity of signs now in use on the various roads, your committee is of the opinion it would be impractical to develop a recommended design for roadway signs. We believe, however, that individual roads could effect some economies by the reduction in the number of shapes of signs, as suggested in the third paragraph of this report. This report is offered as information.

Chairman Botts: The twelfth and thirteenth assignments of this committee are Ballast section design and Adherence to stone specifications, particularly as pertaining to size. The reports thereon will be presented by Mr. Kennedy, the chairman of the subcommittee.

A. D. Kennedy (Atchison, Topeka & Sante Fe): The ballast sections that this committee is offering for adoption this year are along similar lines to the sections now in the Manual. They are for materials under 20 percent crushed and for pit run gravel. They are designed for curves of over three-inch elevation. I move that these sections be adopted for printing in the Manual.

(The motion was seconded, put to a vote and carried.)

Mr. Kennedy: This committee also reports on the subject, Adherence to stone ballast specifications, particularly size. In the first place I want to call your attention to an error at the top of page 574, second line. The dimension "½-in." should be "¾-in." to agree with that in the table.

From the replies to the questionnaire that is printed on pages 572 and 573, the committee learned that 53 percent of the roads using stone ballast adhere to the AREA specifications as to size. In the replies, 60 percent of them indicated that they wanted a gradation of smaller size than is now shown in the Manual or in those specifications. For that reason, and primarily to conform with the Bureau of Standards Simplified Practice Recommendation R 163–39. the committee recommends that Table 1 showing the gradation now shown in the specification be withdrawn and replaced with Table 2 shown right below it on page 573. The only difference between the two tables is merely in the matter of designation and arrangement. and you will note that we add size No. 57 as indicated in the replies to the questionnaire. I move that this change be made.

(The motion was seconded, put to a vote and carried.)

Chairman Botts: The next assignment is Investigate the use of asphalt in ballast. Mr. Podmore has a brief progress report.

(J. M. Podmore, New York Central, read the report on assignment 10 (c) found on pages 571 and 572.)

Mr. Podmore: I might say that the test section has gone through two winters, and there has been no heaving of track either winter, and the track at either end of this test section has heaved. The track is fully tie-plated. In order to bring the track down at the end of the test section, it was necessary to take off the tie plates. It has stood up better, I think, this winter than it did last. This is due to the fact, I believe, that we did a little work on it last summer. It is showing very good results.

Chairman Botts: For our final assignment, Revision of Manual, we have nothing to offer other than what has already been presented. This concludes the report of this committee.

Vice-President Clarke: If there is no further discussion, the committee will be excused with the thanks of the Association. (Applause)

Discussion on Track

(For Report, see pp. 575–638.)

(Vice-President H. R. Clarke presiding.)

Chairman W. G. Arn (Illinois Central): The first assignment is Revision of Manual. Several of the reports which will be submitted by the respective subcommittee chairman contain revisions of the Manual incident to the work of those subcommittees this year. In addition, there are several items of revision of the Manual handled by the subcommittee assigned to that subject. Mr. Zeeman, chairman of that subcommittee, will submit the report.

M. J. T. Zeeman (Atchison, Topeka & Sante Fe): The first revision is a little change in the language in one of the notes in the tie plate specification which pertains to the question of how much overweight will be paid for. We recommend that the present paragraph shown as 401 (e) be deleted and in lieu thereof the following paragraph be inserted:

(e) Tie plates shall be paid for on the basis of actual weight as applied to the entire order, except that payment shall not be made for any weight in excess of three percent over the weight calculated from the specified dimensions.

There is no change in the intent. The object is to clarify the meaning. I move the adoption of this change.

(The motion was seconded, put to a vote and carried.)

Mr. Zeeman: The change just approved was in the specifications for soft and medium grade of steel tie plates. It is suggested the same paragraph be inserted in the hot worked high carbon specification on page 5-14.2, paragraph 401 (f) in the Manual, in lieu of the one that is there now. I so move.

(The motion was seconded, put to a vote and carried.)

Mr. Zeeman: The next revision your committee submits is in the design of the track spike on page 5-16.2. The only change recommended is a slight decrease in the size of the head which is now shown as 1⅜ in. square, which it is suggested be reduced to 1$\frac{5}{16}$ in., conforming to the other ⅝-in spike in the Manual, which we are not now considering. The reason for the suggested change is that the manufacturers have found difficulty in correctly forming the head of the spike as it is now shown in the Manual. Another reason is that certain railroads object if the specified tolerance now allowed all falls at the toe end of the spike.

Your committee recommends the adoption of the design submitted in lieu of the design now in the Manual. I so move.

(The motion was seconded, put to a vote and carried.)

Mr. Zeeman: The next revision submitted is on page 5-34 of the Manual where a tabulation is shown giving the permissible speed through turnouts. This table is based on the use of straight switch points. In view of the fact that the AREA now has recommended practices for curved switch points as well as straight switch points, and in view of the fact that some of the lengths now shown in the Manual do not conform to standard recommended switch point lengths in the Manual, your committee recommends the deletion of the present text in the Manual and, in lieu thereof, the adoption of two paragraphs and the two tables giving the permissible speed through turnouts, one, turnouts with straight switch points of standard AREA lengths, and another table showing the permissible speed in miles per hour for turnouts with curved switch points. The committee also recommends the deletion of Fig. 511.—Speed of Trains Through Level Turnouts now in the Manual on page 5-35. I move these adoptions be approved.

(The motion was seconded, put to a vote and carried.)

Mr. Zeeman: The next revision submitted to this convention is on the subject of tamping. The matter on tamping appearing on page 5-45 was adopted in 1905, and is quite inadequate for the present day, in view of the changes in practice since that time. The present Manual specifies a certain distance for tamping inside and outside of the tie. Since this rule was adopted in 1905, it is quite evident that it was based on the use of eight-foot ties. As there is practically 15 in. from the outside edge of the base of a 112-lb. rail to the end of an 8-ft. tie, it follows that in order to secure uniform bearing it would be necessary to specify tamping for a distance of 15 in. inside the tie.

However, Dr. Talbot, in reports of the Special Committee on Stresses in Railroad Track, has stated that some distance, possibly three, four or maybe five inches from the end of the tie is ineffective for bearing purposes. We feel that some consideration should be given to this. If 15 in. is correct for an 8-ft. tie, when a road goes to 9-ft. ties, to get the increased bearing area, an equal amount should be added for tamping on the inside of the rail in order to get uniform bearing.

There seems to be quite a difference of opinion on this subject. However, your committee recommends the deletion of the present text on tamping which is now shown on page 5-45 and in lieu thereof adopt the text shown on page 579 as a substitute for the present text. I so move.

(The motion was seconded, put to a vote and carried.)

Mr. Zeeman: The last recommended revision is a little insertion on the page containing the Table of Contents, in order to show clearly where the data for gages and flangeways can be found. It comprises a reference to the Portfolio of Trackwork Plans. I so move.

(The motion was seconded, put to a vote and carried.)

Chairman Arn: The next assignment of this committee is Fastenings for continuous welded rail. Mr. Magee is chairman of this subcommittee and will submit a progress report.

G. M. Magee (Association of American Railroads): The most important phase of the work on this assignment has been to inspect and report on the service performance of installations of continuous welded rail with various types of fastenings. Four different test installations with four different types of fastenings are included in this year's report. I am sure you will be interested in knowing there has been nothing in the service performance to date to indicate the continuous welded rail is not a practical development, if properly secured to the ties. Broken rails have been reported in this and previous reports, and the method by which these have been corrected is of general interest.

The committee was also instructed to present a recommended design of screw spike to secure the tie plate to the tie independently of the rail fastening. There does not seem to be at this time a trend toward increasing the use of screw spikes for this purpose.

A description and discussion of the relative advantages and disadvantages of two kinds of screw spikes which have been used for this purpose are presented as a matter of information. If you are interested in the use of screw spikes for this purpose, this information will be of value to you.

Chairman Arn: The next assignment is a subject on which we have been working for several years and have submitted plans from time to time. We now have further plans to submit. The subject is: Plans and specifications for track tools and recommended limits of wear. Mr. Roller, chairman of this subcommittee, will submit the report.

W. L. Roller (Chesapeake & Ohio): Plan No. 7—Tie Tongs, which appears in the Manual on page 5-57, Fig. 519: These tongs were found to be too light and we are offering a substitute in a heavier design to overcome the fault in this tool and to present a design that will hold the rivet better. I move the adoption of Plan No. 7-41.

(The motion was seconded, put to a vote and carried.)

Mr. Roller: Plan 27-40 in the Manual, has been revised as Plan No. 27-41—Track Level, as to a few dimensions which were overlooked in the original publication. I move the adoption of this revision.

(The motion was seconded, put to a vote and carried.)

Mr. Roller: Last year the committee offered as information Plan No. 20A-40 as an alternate to the pipe-connected gage in the form of a wood connected gage. We are offering this same plan for adoption this year, with slight revisions.

I so move.

(The motion was seconded, put to a vote and carried.)

Mr. Roller: As Chairman Arn has said, this committee has been assigned a new subject: Recommended limits of wear of track tools. Considerable discussion arose as to just who was to be the judge of the amount of wear on the track tools before they were scrapped. The conclusion was reached that, since this subject was offered by the Purchases and Stores Division for the matter of reclamation, the plan should be so devised as to set limits of wear to which a tool could be worn before it was scrapped. Certain requisites were set up, and I will read the part of our report found on page 587:

It was assumed in pursuing the study of limits of wear for track tools, that a definite recommendation is desired for each particular tool which would indicate the minimum limit of reclaimed tools. Only tools which are otherwise sound and serviceable without flaw or physical defect should be considered for reclamation and the minimum recommended sizes of reclaimed tools are indicated in dashed lines on original plans.

You will find these plans on pages 588 to 594, showing in dashed lines the committee's recommendation as to limits of wear.

(Mr. Roller then read the fourth, fifth and sixth paragraphs under Recommended Limits of Wear of Track Tools on page 587.)

Mr. Roller: Then follows a description of the manner of reclaiming. There is one phase of this report to which we want to pay particular emphasis. The committee has construed the subject to mean that no additional material will be applied to bring the tool to a desired contour or to restore it to its original shape.

This report is one of information, and the committee recommends its continued study. We also wish to recommend, in closing, that the assignment in general be continued as we wish to continue the study of specifications of hickory handles and ash handles for tools.

Chairman Arn: As you are aware, this committee has been endeavoring to do a complete overhauling of the Manual of Trackwork Plans. This has been quite an extensive job and has been under way now for two years. We are submitting the second group of plans for your approval. Mr. Caruthers, chairman of the subcommittee, will submit this report.

E. W. Caruthers (Pennsylvania): At the last convention the Association adopted a number of plans that were presented by the committee as key plans. We reviewed and selected certain plans that were considered more or less of a key nature, based on the adoption by the Association, of these plans. Work has been continued on the balance of the plans, and we now wish to present for adoption a series of plans covering the various items of trackwork.

(Mr. Caruthers then offered a series of motions submitting for adoption and publication in the Manual of all of the plans with a suffix "—41" that are listed on pages 596 to 600, inclusive. All of the motions were seconded, put to a vote and carried.)

Mr. Caruthers: A number of plans are listed that will be revised and reissued. but the revisions are not material, and it was not thought that it would be necessary to offer these plans for any action by the Association.

In view of the adoption of the plans that have been presented, there is a group of plans starting about the middle of page 600 which may now be withdrawn, and I move the withdrawal of the plans as listed, starting on page 600 and continuing through to page 605.

(The motion was seconded, put to a vote and carried.)

Chairman Arn: The next subject assigned to the committee is Corrosion of rail and fastenings in tunnels. Mr. Perlman, the chairman of this subcommittee, will submit the report.

A. E. Perlman (Denver & Rio Grande Western): In 1938 a study was begun on this subject using the Moffat tunnel for a testing ground and using the D. & R. G. W. laboratory facilities to help in these tests.

Heavy Mallet steam power is used through the Moffat tunnel, which is 6.21 miles long, and there are as many as 34 train movements a day through the tunnel. The problem came about through the formation of sulfurous acid gases which attack the metal, especially where metal touches metal. The shanks of spikes were eaten out to within 50 percent of the cross-section, and where angle bars touched bolts or where angle bars touched rail, the problem was greatly aggravated.

As a result, several methods were tried in an attempt to overcome this difficulty. About 1,000 test pieces with protective coatings of a non-metallic nature were used. A number of corrosion-resistant alloys were used, and sprayed metal plates and cathodic protection were attempted, and also the neutralization of the stack gases through the use of lime in the locomotives.

As pointed out, starting on page 605, the committee found no practical, or economical means of employing a corrosion-resistant alloy, because the materials tested depend upon a protecting film of corrosion products for their resistance and this protecting film naturally cannot be maintained on the running surface of the rail.

Then there are a number of other conclusions, namely, that while you can protect the metal with a metal spray, there is no way of protecting the running surface of the rail, so a special section would have to be used in which the running surface would be of greater thickness than would normally be used, and the rest of the metal could be protected by a metal spray. The only other way of overcoming the difficulty would be through the use of Diesel or electric power. Electric power would entirely overcome the difficulties. There is some sulfur in Diesel oil and while certain oil companies put out a special Diesel oil with a low sulfur content, even with this there would still be some sulfurous acid formed.

This report is submitted as information with the recommendation that the subject be discontinued.

C. H. Blackman (Louisvile & Nashville): May I ask if the committee has tried ventilation to reduce the corrosion.

Mr. Perlman: A different type of fan was recently installed in the tunnel, which moves the air through the tunnel twice as quickly as the old fan. We have found it dries out the rail and ballast section much more rapidly than the old fan, but for 20 min. after a train has gone through the tunnel moisture is formed. This is because the inside of the tunnel stays at a uniform temperature throughout the year, while it may be 30 deg. below zero or 80 deg. above outside. We are bound to get condensate in the tunnel when we have as much water present as is evaporated by a locomotive. We feel the ventilating system will help a great deal but it will not overcome the difficulty.

Chairman Arn: On the next assignment, Design of tie plates for RE rail sections, there is no report this year.

The next subject is: Practicability of using "reflex" units for switch lamps and targets. Mr. Adams, chairman of the subcommittee, will submit this report.

L. L. Adams (Louisville & Nashville): Your committee did not think it necessary to send out a questionnaire this year to determine the number of reflex lamps being used on the various roads. This information was secured in 1939 and reported in the Proceedings for that year. However, from information that we secured in an informal way, there is no doubt that the use of reflex light units is being extended and, due to the saving that can be effected by these units, that use has been substantial and is well worth considering by any railroad.

We have learned that some states had laws pertaining to the use of switch lamps on main line turnouts, so we arranged for a check of these laws. We find that nine states have such laws. Any road operating in those states should give them consideration before doing away with the oil lamps. However, there are as many as 39 states that have no law pertaining to this matter. The report is submitted as information.

Chairman Arn: The next assignment is: Welding of manganese castings in special trackwork. The manganese castings which were submitted for test and are undergoing test have held up so well that there is nothing as yet to report on them.

The next subject is: Bolt tension necessary for proper supporting of rail joints. Mr. Breed, the chairman of the subcommittee, will submit this report.

C. W. Breed (Chicago, Burlington & Quincy): There is a small correction on page 610. Under Loss of Bolt Tension the date should be October 5, 1938 instead of 1939. Previous reports of this subcommittee on bolt tension appear in the 1939 and 1940 Proceedings.

This report contains considerable data on the out-to-out measurement of joint bars. A study of these data for test joints maintained with high, medium and low bolt tension indicates that there is little difference in the rate of wear of the fishing surface due to the amount of bolt tension. Fishing wear appears to have some relation to traffic density, but further data are required to definitely establish this relation.

You will recall that last year's report included a statement of monthly loss of bolt tension throughout the year which varied from 800 to 1,500 lb. Loss of bolt tension per month in the second year appears to be about the same as in the first year. In the first and second months, after retightening, bolt tension falls away rather rapidly, and then settles down to a more moderate rate of loss. This loss averages 500 to 1,000 lb. per month, depending upon the type of spring washer used, the amount of bolt tension applied at tightening and the traffic density.

For determining the amount of tension to be applied in tightening, it is suggested that the upper value of 1,000 lb. loss per month be used. For example, if it is desired that bolt tension should not be less than 5,000 lb., and if tightening is to be done once a year, then 17,000 lb. per bolt should be applied. If tightening is to be done at six-month intervals, 11,000 lb. per bolt should be applied.

The committee has given much attention to the problem of securing uniformity of bolt tension in bolt tightening. The test data indicated that power wrenches, when properly used, will give somewhat better uniformity than hand tightening, but the improvement is not great. A difficulty with machine tightening is that the machine has greater tightening capacity than hand tightening and, if improperly handled, is likely to result in very high bolt tensions. With either hand or machine tightening, values of bolt tension may be expected to be 5,000 to 10,000 lb. greater or less than the average obtained. Variation in friction between nut and bolt is principally responsible for this variation.

To improve this condition, some railroads are getting bolts manufactured to a specification requiring minimum and maximum values of 5 and 25 lb. at the end of a 24-in. wrench to turn the nut throughout the threaded length.

Reliable means are needed for adjusting the bolt tension release on power wrenches to give desired tension. Closer supervision of operators of power wrenches is necessary to obtain the best performance out of present adjustment.

With hand tightening, a track wrench at least 42 in. long, is desirable to enable the track man to tighten bolts while standing upright. Tests have shown that with a wrench of this length, a track man can quite easily tighten bolts to tensions as high as 35,000 to 40,000 lb. if he is permitted to jerk on the wrench. If the track man is trained to tighten bolts with a steady pull on the wrench, bolt tensions of 15,000 to 20,000 lb. will be obtained with reasonable uniformity if the nut and bolt friction is reduced as previously suggested.

The committee acknowledges the invaluable assistance given by Mr. G. M. Magee who carried out the greater part of the field tests.

This report is submitted as information.

G. R. Westcott (Missouri Pacific): I am wondering if any survey has been made by this committee to determine to what extent track bolts with "finger free" threads are used over the country and to what extent the railroads are still using the wrench-tight nut. I am thinking particularly of the use of power machines. If you use a power machine on a wrench-tight nut, an unknown part of the power exerted, of course, is applied to overcoming the friction in forcing the threads of the nut on the bolt, whereas, with "finger free" threads on the bolt, there is a closer relation between the torque applied by the machine and the tension applied in the bolt.

Mr. Breed: We haven't had a test with a "finger free" nut. We think such a test is a possibility for obtaining more uniform tension, and we hope to include it in this year's work.

Mr. Westcott: I think, perhaps, this is something that ought to be considered because there are a number of railroads in the country that have been using "finger free" nuts for a number of years, very successfully. I mention my own road as one of them.

We changed some five or six years ago, and have never had any thought of going back to wrench-tight nuts. I recommend that the committee go into that, as suggested by the subcommittee chairman.

Mr. Breed: Mr. Magee has a few remarks to make about "finger free" nuts on the Pennsylvania test.

Mr. Magee: I didn't intend to make any remarks on it except to call attention to the fact that the tests on the Pennsylvania installation were made on "finger free" nuts, and a somewhat better uniformity was secured in tightening the bolts during that test, compared to other tests where wrench-tight nuts were used.

Vice-President Clarke: Isn't it the intention of the committee to consider this matter that has been raised?

Mr. Breed: Yes.

Chairman Arn: The next subject assigned to the Track committee is: Lubrication of rail on curves. Mr. Hales, chairman of that committee, is unfortunately not able to be here. The chairman for next year, Mr. Strattman, will submit the report.

C. R. Strattman (Michigan Central): There have been two previous reports on this subject, in the Proceedings, Vol. 39, pages 419 to 421, and Vol. 40, pages 575 to 581. I will just read the conclusions of our current report.

(Mr. Strattman read the conclusions on page 628.)

Mr. Strattman: Your committee recommends that these conclusions be adopted and published in the Manual. I so move.

(The motion was put to a vote and carried.)

Chairman Arn: The next subject is: Prevention of damage due to brine drippings on tracks and structures. This subject is being considered jointly by this subcommittee and a committee of the Mechanical Division. Mr. Magee, the chairman of the subcommittee, will submit the report.

Mr. Magee: If you will recall, past reports of the committee have advised you of progress made in the laboratory in determining a corrosion inhibitor which could be added to the salt used in refrigerator cars for the purpose of neutralizing the corrosive action of the brine drippings in the track, from these cars. You were also informed that sodium-dichromate and soda ash, when added to the salt, had shown very promising results in laboratory tests.

An interesting test was conducted this year to determine whether this inhibitor, sodium-dichromate and soda ash, if used in refrigerator cars, would dissolve at the same rate as the salt and be contained in uniform concentration in the brine drip throughout the car trip.

With the assistance of the Santa Fe Refrigerator Dispatch, a car was iced and salted with salt containing this inhibitor at Los Angeles. A car with a revenue load destined for the east was selected for this test. Samples were taken of brine drippings at intervals over a period of eight days. This included the period for pre-icing the car and also the period during which the car was on the road in making the trip from Los Angeles to Kansas City. The samples were then analyzed for inhibitor content by the Denver & Rio Grande Western laboratory. The results of the test were, in general, satisfactory. A reasonably uniform concentration of inhibitor was found in the samples of the brine drippings throughout the test period.

Additional tests are now under way to determine the benefit to the tanks and trucks of the refrigerator cars from use of the inhibitor.

The committee at this time is pleased to report that the progress to date appears quite encouraging. It should also be noted that the work reported is the result of joint investigational work by both the Engineering and Mechanical divisions. This report is offered as information.

Chairman Arn: The next subject assigned to the Track committee is: Specifications for laying rails designed to set up the requirements for good workmanship. This is a subject on which the subcommittee has been working for about three years and on which it is now ready to submit specifications. Mr. Schram, the chairman, will submit the report.

I. H. Schram (Erie): The report is substantially the same as last year when it was submitted as information. Comments and criticisms were requested, a number were received and some small changes were made. Unfortunately, a few of these criticisms came after the report was printed in the Bulletin and these late criticisms were considered at a meeting of the Track committee, at which some of them were thought worthy of adoption. We therefore wish to make the following changes:

On page 634, the first paragraph under the heading "Unloading" has been changed by adding a period after the word "base" in the second line, and deleting the rest of the sentence. The committee took this action after having its attention called to the fact that practice in the facing of the brand is about equally divided.

On page 635, the second paragraph is changed by substituting the word "multiple" for "double" in the first line. The committee considers that multiple-track lines require the same treatment as double-track lines.

On page 636, under the heading "Completion of Work," the first line of the sixth paragraph "All ties on which the new rail does not have a full bearing," etc., has been changed by eliminating the word "new" before rail and substituting "newly laid" so that the sentence reads "All ties on which the newly laid rail does not have a full bearing shall be tamped and the spikes re-driven; proper slow orders shall be maintained until this is done." This change was made by the committee merely to clarify the meaning.

The changes that were made during the year were rather small. On page 634, under "Unloading" the last paragraph was revised to add "that small material shall be left in the containers until the rail is laid". Under the heading "Laying", the word "immediately" was introduced in the first line of the first paragraph.

On page 635, under the heading "Laying", the paragraph covering application of rail anchors has been revised to provide for the immediate application of the full quota of rail anchors.

This covers the changes that were made in the report of this committee following the consideration of a number of suggestions received by the committee. I move that this specification be adopted and published in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Arn: The final subject for the past year's work is: Spirals for high speed operation. Mr. Baldridge, the chairman, will submit this report.

C. W. Baldridge (Atchison, Topeka & Santa Fe): The subcommittee on Spirals for high speed operation endeavored this year to complete the work that was not finished last year, and we have the following to report:

From the time, more than one hundred years ago, when the first railroad was built in America, to the present time, the methods of construction and the kinds of material used both in roadway and equipment have been undergoing improvement to increase effectiveness and safety.

One of the incidents of the opening of the first American railway, was a race between the famous locomotive Tom Thumb and a horse-drawn vehicle, in which the horse was the winner. At that time and for several years thereafter, curves in railway tracks called for but little more attention than was required by tangent track. As weights and speeds of railway trains increased, more and more improvements in track construction and maintenance have become necessary. The first improvement in the alinement of curves and the nature of easements at the ends of the curves was accomplished by beginning with a short length of low degree curve, usually a two-degree curve, and continuing by two-degree increments until the degree of the main curve was reached, the leaving end of the curve being made in the same manner in reverse. It has not been very long since the curve records of some railways still showed curves of this nature to be in use. It was but natural that this early form of easement should be displaced by spiral curves beginning with very small variation from the tangent and continuing an increasing degree of curvature up to the degree of the central part of the curve.

When the high speed trains of the present era came into operation it soon become evident that longer and more accurately located spirals are necessary for safety and comfortable riding trains. The revision of the matter in the Manual as submitted last year was intended to be an outline of the method for calculating and staking a ten-chord spiral by deflections, given step-by-step so that it could be more readily understood by the man in the field who is the one who must use it.

This year's report is intended to outline the staking of the same kind of spiral by offsets, followed by a method of staking a spiral of somewhat different ratio of curvature wherein the offsets are calculated for such points along the curve as are desired. In the second method the values of X for each of the desired points are assumed and the offsets calculated for each point assumed.

Beginning on page 636 you will find under the subheading Staking Spirals by Offsets:

(Mr. Baldridge then read the material under Staking Spirals by Offsets on pages 636 and 637, calling attention to an error in the next to the last line on page 636, that "chord and point" should be changed to "chord end point".)

Mr. Baldridge: The formulas are given on page 637, and I will not read them. The table given on page 637 is, in fact, a two-column table, the word Elevation having been omitted above the word Inches in the first column. The third and fourth column and fifth and sixth columns are actually a continuation of the first but are put in the present position to save space in printing.

The use of this method does not give identically the same curve as the curve that was given last year, and the two methods are not interchangeable in the same piece of work, but each one will give very nearly the same result finally.

The committee recommends that the matter now in the Manual, page 5-26 beginning with "Staking Spirals by Offsets" and ending on page 5-27 with "Staking Spirals by Deflections" be withdrawn and that the matter which I have just read to you, be adopted for inclusion in the Manual and inserted following the matter which is now on page 5-28.

I move that this deletion and substitution be made.

(The motion was seconded, put to a vote and carried.)

Chairman Arn: That concludes the report.

Vice-President Clarke: I know personally this is one of the hard working committees of the Association. It has presented a comprehensive and excellent report. If there is no discussion, the committee is excused with the thanks of the Association.

Discussion on Ties

(For Report, see pp. 485–487.)

(Vice-President Clarke in the chair.)

Chairman John Foley (Pennsylvania): Committee 3 presents no statements in reference to Assignments 1, 3 and 6. For your information only there are presented statements on the other assignments.

In connection with Assignment 2, your attention is called to statements in a recent address by a railroad executive, who, after citing "features of maintenance which contribute to a maximum life for crossties and to substantial economies in tie renewals and other maintenance costs", said "all of these efforts would have only limited value unless we can use the best obtainable material", and "here we meet the question of inspection. I am sorry to say that this question does not always receive the preferred consideration which it merits." He continued that on his railroad "inspection is inspection and in the full meaning of that word."

The general adoption of that attitude toward the acceptance of ties has been the hope of the Committee on Ties during 16 years of commenting on adherence to AREA specifications. We realize that absolute accuracy is impossible in the inspection of ties. We expect only that all railroads adhere to the standard as successfully as so many have proved they can. We are glad to acclaim those of you who have brought about the betterment in the quality and size of ties generally by your accepting as constructive the critical comments of the Committee on Ties and bringing your specifications and inspection into conformance with AREA recommended practice.

Our observations have made clear that adherence to the specifications on paper does not assure suitable ties. Mere adoption of the standard is not enough. The results of the application of the specification for crossties in actual practice were sought by your committee in order to point out possible improvements.

A summary of the committee observations to date will be presented by Mr. W. D. Simpson, chairman of the subcommittee on Assignment 2, who will also comment on the 1940 statement.

W. D. Simpson (Seaboard Air Line): Observations to determine the extent of adherence to the specifications for crossties began in 1925. They have been made annually since, except in 1927, 1931, 1932 and 1933. During the 13 years of field work, 20 trips have been made to 37 points where 42 seasoning yards are located. Return trips have been made to 14 of these yards. The ties observed have belonged to 43 railroads, 15 of which were visited more than once. The number of ties observed total 33,500,000. The producing territories represented by the ties looked at extend from Maine to Minnesota, inclusive, south to the Gulf of Mexico, plus Oklahoma and Texas.

On its first inspection trip (1925), which covered 3,000,000 ties of 15 railroads, the committee found and informed you that ties conforming fully to the Association's specifications were being produced in quantity, and that on some railroads all ties fully, or satisfactorily, met the requirements of the AREA standards, but that on some railroads such was not the case.

That report also said that "interest in the character of the ties delivered on the part of those responsible for their use would correct much of the fault in the procurement of ties." Evidence of increased interest in ties is found in the subsequent reports, which generally record improvement in conditions as a whole. The committee gets considerable satisfaction from the evidence of the better inspection noted on return visits to some yards, and derives real pleasure from seeing a lot of excellent ties in a yard where housekeeping approximates what it should be.

Where there is laxity in inspection it is usually characterized by:

1. Oversizing: In that case we pay for a size we do not get.

2. Accepting decay and excessive split: In that case, the deterioration of the tie has started before we buy it at the price for a solid, sound tie; and

3. Improper storage: In that case we prevent satisfactory seasoning, promote decay, increase splitting, and induce conditions which result in the loss of many years of tie life.

The committee repeats its suggestion of 15 years ago, that you inquire into the quality of the inspection of the ties on your property. If you find it good, commend those responsible for it; if not, do something toward securing full adherence to AREA standards.

The record of our 1940 observations is marred only by the fact that one railroad accepted substandard ties and another permitted substandard stacking, as you will see by reference to the report on page 485, which also points out that the wider spacing of seasoning ties which is practiced in some yards does not cause more splitting than the closer spacing commonly used.

This report is offered as information.

Chairman Foley: The report on Assignment 4, Tie averages and costs per maintained mile, was published in the June-July Bulletin and is not repeated in full. You will find the detailed figures in that bulletin.

The last statement we wish to make is on Assignment 5, Investigate and report on the dimensions of ties, and bring up to date the information in the 1924 and 1932 Proceedings. The committee is launching a recommendation that warrants very full consideration and discussion. The facts in connection with it will be presented by the chairman of the subcommittee, Mr. W. J. Burton.

W. J. Burton (Missouri Pacific): For several years the subject of tie dimensions has been assigned to your committee and special attention has been given to tie length. Previous reports have shown the desirability of longer ties and have presented information as to what was involved in making a change.

Realizing the importance of the change in a standard so long in effect, your committee is presenting proposed recommendations for further discussion during the ensuing year, with the idea that, unless this discussion brings up some unexpected objections, the recommendations will be offered for adoption next year.

The committee expects to recommend the following for adoption and publication in the Manual:

(a) The adoption of nine-foot ties and the discontinuance of the purchase of eight-foot ties as rapidly as practicable and economical.

(b) The use of nine-foot ties at least for lines of heavy traffic.

(c) The adoption of the nine-foot length whenever change is made from the eight-foot length.

These recommendations are based on the studies of the committee as reported in recent years. I will briefly review the considerations justifying them.

It is a fact that the economically best dimensions for a crosstie cannot be determined solely by a consideration of stresses; in other words, a tie cannot be designed in the sense that a bridge beam may be designed to carry a given load. But it is necessary to have standard dimensions for ties even though there is wide variation from tie to tie in the strength of the wood and in the character and amount of support.

The observed results in track, therefore, become of great importance in selecting the most suitable dimensions.

It is well known that if ties are tamped for their full length, the track tends to become center-bound, and, in order to avoid center-bound track it is the universal practice not to tamp a portion of the ties at the center of the track.

This tendency of track to become center-bound is an indication that with ties of usual length, there is more support inside than outside of the rails or, in other words, that the ties are too short. The untamped portions of the ties, and the ballast under these portions, are therefore wasted as far as furnishing support is concerned.

If each part of the length of a tie were equally effective in transmitting load to the ballast, the proper action might be secured by making the tie length twice the center-to-center of rail distance, so as to have as much support outside of the rails as between them. However, it was shown by Dr. Talbot, early in the work of the Stresses in Track committee, that under the vibratory conditions of actual service in track, it is not possible to maintain effective ballast tamping at the ends of the ties or for several inches in from the ends. If the ineffective length is taken at four inches at each end, the required tie length for standard gage and 131-lb. rail figures out 10 ft. 7 in. Assuming that a tie of this length had sufficient beam stiffness, it might be tamped for its entire length without danger of center-bound track.

At this point the questions of cost and practicability must be considered. An increase in length of 2½ ft. over present practice is out of the question for reasons not necessary to develop here. Your committee, however, has considered the practicability of increasing tie length to nine feet and it should be pointed out again that a given increase in tie length allows double that increase in the permissible tamped length of the tie. Thus, increasing the length of the tie 6 in. adds 12 in. to the effective support.

Observations over a considerable period of years, supplemented by opinions secured from tie producers and from national forest supervisors support the conclusion that relatively few trees as now cut for crossties, would not make as many ties six inches or a foot longer as they now make of the shorter lengths. Also, many of the elements going to make up complete tie costs are either unaffected, or only slightly affected by the proposed changes in length.

These conclusions are supported, at least partly, by a study of the present regional practices as to length as reported in our 1940 report. There it was shown that the choice as between 8-ft. and 8½-ft. ties was apparently a matter of precedent in the particular region. It is a fact that in a region where the standard length is 8 ft. 6 in. a premium will be asked for 8-ft. ties. The most important elements of cost, affected by length increase, are freight, due to increased weight, preservative and cost of treatment. The increase in amount of preservative is somewhat less than that proportional to increased length due to a greater absorption and retention near the ends of the ties. The increased cost of treating is largely due to fewer trams, usually one, which can be placed in a cylinder for treatment.

In comparing costs of different lengths of ties it is, of course, proper to compare total cost in track rather than merely first cost of the tie. We have previously reported that the increased cost of 8½-ft. ties over 8-ft. ties may be as much as 5 percent of the total cost in track and a similar figure would apply to the change from 8½-ft. to 9-ft. ties. However, such percentages would apply only where most or all of the tie buyers in a given region made the change at the same time.

It is because of the great desirability of concerted action on the part of all railroads that we are proposing adoption of these recommendations. As we have previously pointed out, more additional track support can be purchased through increased tie length than through other means.

It is expected that during the ensuing year this subject of tie length and the proposed Manual recommendation will be subjected to full discussion and criticism. The change is not only very important to the railroads but one in which concerted action is most desirable. It is for this reason that we are inviting a full year of discussion and criticism before Manual action.

The committee invites discussion orally at this time and in writing during the year.

Vice-President Clarke: The report at the present time will be accepted as information.

Chairman Foley: That completes the report.

Vice-President Clarke: This committee is doing very constructive work and is to be complimented. If there is no discussion, the committee will be excused with the thanks of the Association. (Applause)

Discussion on Stresses in Railroad Track

(For Report, see pp. 753-757 and 759)

Vice-President Clarke (in the chair): Dr. Talbot, we wish to convey to you our appreciation for the many years of invaluable service which you have rendered this Association, the railroads of the continent and, in fact, of the world in advancing our knowledge in regard to the behavior of railroad tracks under load.

Past President Yager has had the privilege of serving with Dr. Talbot for a number of years on this important committee, as vice-chairman, and I will ask him to express, better than I can, our appreciation of Dr. Talbot's work.

Louis Yager (Northern Pacific): We believe it is fitting that we pause in the convention deliberations to recognize the passing of another milepost in the progress of our Association affairs.

It is with regret that it is necessary to announce that this has been the last formal appearance of Dr. Talbot before this body as chairman of the Committee on Stresses in Track which he created and directed with such great distinction for a period of more than a quarter of a century. That fact has given the officers of your Association considerable concern. It is with some degree of assurance that we proceed, because of the fact that Dr. Talbot will be available to the committee and offer his advice in deliberations of that group of men who will continue the work from here on.

The fact that Dr. Talbot is retiring from the carrying of his weighty duties in the manner in which he has, is an illustration of the true, democratic character of our Association. We assume these duties voluntarily, and we relinquish them, likewise, voluntarily when we believe we have served our purpose.

The unselfish devotion of such men as Dr. Talbot, serving without monetary compensation, is one of the outstanding examples of professional service in the public interest, which represents the voluntary contributions of time and talent by gifted men and women trained in the physical and social sciences to create and sustain our cherished ideals of American democracy.

The intellectual attainments and the quality of service rendered in the engineering profession have been an inspiration to those of our members who are fortunate enough to have been, during the more impressionable periods of life, students under Dr. Talbot at the University of Illinois. We, who have been privileged to have contact with Dr. Talbot in his great contribution to the research aspects of railway engineering, are proud to acknowledge our student relationship to him in what we have perhaps boastfully regarded as the post-graduate phase of our professional development. Men of the type of Dr. Talbot, in collaboration with the engineers engaged in the railroad industry early in the career of our Association, set up those standards of accomplishment which have given professional standing to our Association.

The work of the Stresses in Track Committee afforded the first, unqualified recognition of the fact that the Association, by reason of talent and professional outlook was qualified to undertake and prosecute research work of the highest order.

If we are mindful of the fact that there is no immediate or distinct line of demarcation between the periods which I shall mention, then it may be correctly said that in the 42 years of existence of our Association, Dr. Talbot has served three generations. The first generation, comprising the founders and the pioneers who have passed beyond or have retired from active duty, were those men of our profession who recognized early that there were many problems facing our group which were beyond the possibility of solution through the usual analytical approach and, therefore, required the application of scientific laboratory methods. The leaders and officers of our Association at that time, in looking about for someone to undertake the work of finding a rational solution for many of our track problems, selected Dr. Talbot because of the fact that by that time he had already made a name for himself through original work in the application of laboratory methods and the development of those lines of investigation approach which have become, in more recent years, commonly accepted as research work.

Now, then the second generation, to which we belong, perhaps have been the greatest beneficiaries of the work of Dr. Talbot, and it is to us that he has opened up and expanded the horizon of what is still possible of accomplishment in this field in which he has done such great pioneering work.

Then we come to that third generation of younger men who, some of them I know, with awe and respect, have stood on the sidelines and have attempted to appraise the work that is represented by the contributions made by Dr. Talbot. That group of men have, to some extent, and are still serving an apprenticeship and will soon take our places and carry on.

The several engineering professions, including our own, the scientific associations and the teaching profession have already given acknowledgment to Dr. Talbot through the election to high office and through formal public recognition of his high standing and accomplishments as a scientist, an engineer and a research director and, last but not least, as an outstanding educator wherein the high order of personal character has been an inspiring influence to students and co-workers alike.

It has been particularly gratifying to us that it has been possible to make these public acknowledgments throughout the long and useful career and to add an expression of our affectionate regard while the recipient was still engaged in productive effort, and in the possession of full mental vigor.

Dr. Talbot has created for himself in this outstanding research work an enduring memorial to be found in the records of all scientific libraries, to serve as a guide to the succeeding generations of research workers in this field.

So, we are not proposing to duplicate the former public recognition of those accomplishments but, rather, to make this particular occasion the starting point of another type of appreciation.

It therefore seems highly appropriate to acknowledge in a formal manner the closing of the unique period of the first and only Chairman of the Stresses in Track Committee extending over a period of 27 years, through providing an appropriate, permanent tribute at Dr. Talbot's Alma Mater where he labored for so many years to bring about those professional achievements, which we are pleased to proclaim.

It therefore gives us a great sense of satisfaction to be able to announce to you at this time that, in view of the fact that Dr. Talbot has resigned his commission, arrangements are being made for a suitable permanent tribute expressing the appreciation of the Association, and that we are the donors and the University of Illinois will be the custodian of that perpetual tribute. This tribute is to be located in the Arthur Newell Talbot Laboratory at the University of Illinois. At a later time we will announce to you the date and the character of the ceremonial arrangements which will complete the dedication of that permanent tribute. (Applause)

Vice-President Clarke: Dr. Talbot and members of the Committee on Stresses in Railroad Track: In excusing the committee for the last time I again wish to express to you our depth of gratitude for the great piece of work which you have done. The committee is excused with the thanks of the Association.

Discussion on Rail

(For Report, see pp. 639-679.)

(Vice-President Clarke presiding)

Chairman W. H. Penfield (Chicago, Milwaukee, St. Paul & Pacific): During 1940 the committee lost three of its members, Chairman John V. Neubert who died June 4, 1940; Vice-Chairman Robert Faries who died on September 8, 1940, and former Vice-Chairman August F. Blaess on February 19, 1940. The loss of these members is keenly felt by the committee, and resolutions showing the respect in which these members were held by their associates appear on page 640.

Eight subjects were assigned to the committee for 1940. Under the Revision of Manual we are offering two recommended changes. Reports of all other subjects are presented as information only.

Late in the season a ninth subject was assigned: Corrugated rail, causes and remedy. Effect upon riding qualities of tracks and upon the costs of track and equipment maintenance. We are perfecting an organization for this study but have no report to make at this time.

I will now ask Mr. C. B. Bronson, our vice-chairman, to present our recommendations for revision in the Manual.

C. B. Bronson (New York Central): Revisions are requested this year in the forms for reporting rail failures and transverse fissure rail failures. It is recognized there is certain non-essential information in those two forms. To bring them up to date, they and also the instructions that go with them have been revised.

We recommend the adoption of these revised forms and their substitution for those now in the Manual. I so move.

(The motion was seconded, put to a vote and carried.)

Chairman Penfield: Our second assignment covers: Further research, including details of mill practice and manufacture as they affect rail quality and rail failures, giving special attention to transverse fissure failures and other defects in the head, web and base, collaborating with Rail Manufacturers' Technical Committee. Mr. H. F. Moore, research professor of engineering materials at the University of Illinois, who hase been in charge of the investigations, has compiled a seventh progress report of the Joint Investigation of Fissures in Railroad Rails, giving a résumé of the work and accomplishments to date. This is published in full beginning with page 681.

This investigation was started January 1, 1931 and has established the following facts:

Shatter cracks in rails developed during manufacture are the major cause of interior transverse fissures.

Heavy wheel impacts are an important factor in causing shatter cracks to develop into fissures. Laboratory studies show that fissures can be developed in shatter-cracked rails under repeated wheel loads of 40,000 lb. or more.

Field checks indicate that at equivalent wheel loads of this magnitude fissures are developed by one wheel in 500 to 600.

Shatter cracks can be prevented by thermal treatment of rails after rolling, and as a result of this investigation thermal treated rails are now commercially produced. A few fissures have been found in thermal treated rail, but in all cases these have been shown to have developed from inclusions and not from shatter cracks.

At the close of Committee 4 report, Professor Moore will give an oral presentation of the work of the Rails Investigation party.

Assignment 3, Compilation of statistics: Mr. W. C. Barnes, engineer of tests, is chairman of the subcommittee, and I will ask him to present the report.

W. C. Barnes (American Railway Engineering Association): The rail failure statistics, page 645, were prepared in the same manner as those presented last year. The rail tonnages reported exceed those of last year by over 213,000 tons. Your attention is called to Table 1 which shows that the 1934 rollings, which five-year period of observations is now concluded, had a failure rate of 100 track miles of 35.8, which is the lowest on record, the nearest approach to that being a rate of 60 for the 1930 rollings.

The returns so far recorded for the 1935 to 1938 rollings, which have not yet, of course, completed the five-year period, indicate that they will also give a good performance record.

Fig. 2 on page 647 shows that each mill contributed in establishing this record. The remainder of the report requires no special comment, and the statistics are presented as information.

Transverse Fissure Failures: Transverse fissure statistics for the year ended December 31, 1939 are shown on page 650. The increase in fissure failures in 1939 over 1938 is an unwelcome though not unexpected development. Despite the removal of 1,398 more detected fissured rails in track in 1939 than in 1938, there were 1,575 more service failures. As will be seen from Fig. 1 on page 652, the 1939 service failures were exceeded only in 1936 and 1937. These statistics are presented as information.

Controlled-cooled and Brunorized rail: Data are being accumulated to assist in determining the performance in service of controlled-cooled and Brunorized rail rolled under contract. The total tonnages now under consideration are 3,022,206 of controlled-cooled rail and 123,873 of Brunorized. The failures, classified as to type, appear on Table 2.

As Mr. Penfield said a few moments ago, no transverse fissure failures originating from shatter cracks, which these special processes are intended to prevent, have occurred in controlled-cooled rail nor in Brunorized rail rolled by the revised process.

This report is presented as information.

Chairman Penfield: Our assignment No. 4 is: Study the cause and prevention of rail battering and methods of reconditioning rail ends. Mr. F. M. Graham, assistant engineer of standards, Pennsylvania Railroad, the subcommittee chairman will present the report.

(F. M. Graham, Pennsylvania, read the report on Assignment 4 on page 658, calling attention to the fact that the first line should read "Subcommittee 4" in place of "Subcommittee 6".)

Mr. Graham: I might add that since this was prepared, the committee has selected a site on the R. F. & P. Railroad. Of course, anyone caring to visit the installation of this test can do so. It will start on May 5, 1941 and continue through that week.

This is submitted as a progress report, and it is recommended that the subject be continued.

Chairman Penfield: Assignment 5 is: Economic value of different sizes of rail. Mr. J. M. Farrin, special engineer, Illinois Central Railroad, is the subcommittee chairman and will present the report.

J. M. Farrin (Illinois Central): The work of this subcommittee during the past year has been directed towards the confirmation of the accuracy of the expense ratios of the different sizes of rail that were established in preceding years by means of their mathematical properties that affect track performance.

The theory of the expense ratio method is predicated on the assumption that the minimum size of rail is to be determined from viewpoint of safety. With the minimum size known and expense ratios of the different sizes of rails established and costs known for any particular size of rail in a given location, then the cost of any other weight of rail can be quickly determined for the same location and the traffic density by means of the simple proportion of their ratios. This result can then be used as a guide in forming a conclusion as to what size of rail best suits the location being considered.

As one of the means of checking the accuracy of the ratios tentatively established, the subcommittee each year checks the maintenance ratio with the actual performance of the test sections totaling about 40 miles in length established by the Kansas City Southern Railway, the result for the years 1938 and 1939 being shown on page 659. The apparent discrepancy for the 127-lb. rail in 1939 is probably due to the fact that the amount of money spent has not been used up, and, consequently, has not been averaged over a long enough time. Otherwise the ratios give comparable results.

Also opportunity was had to make a comparison between 100-lb. and 131-lb. rail by means of testimony presented before a congressional committee by the late Robert Faries of the Pennsylvania Railroad. The occasion of this testimony was to show what the railroads could do in event section labor wages were increased, the material presented being the result of the consolidated judgment of the maintenance officers of about 100 railroads. It is to be noted that the tentative ratios are in fair agreement with the testimony.

A questionnaire was sent out to all members of the rail committee requesting their experience in tonnage life in the first location of the various sizes of rail, together with man-hours of section labor expended in track laying and surfacing. These replies were plotted and found on the average to produce curves approximately parallel to those developed in the tentative report, thus indicating the approximate correctness of the ratios tentatively established.

This report is presented as information with the recommendation that the subject be continued.

Chairman Penfield: Assignment 6 is: Continuous welding of rail, collaborating with Committee 5—Track and Special Committee on Stresses in Railroad Track. Mr. J. C. Patterson, chief engineer, maintenance of way of the Erie Railroad is the subcommittee chairman and will present the report.

(J. C. Patterson, Erie, read the first three paragraphs under Assignment 6 on page 660.)

Mr. Patterson: The report is submitted as information with the recommendation that the subject be continued.

I think Professor Moore has a few remarks he would like to make.

H. F. Moore (University of Illinois): Laboratory experiments reported in certain progress reports have been carried on, and we have a more complete report of the strength of various welded joints.

At present we may say, in a general way, the electric flash weld, the oxy-acetylene heat pressure weld, based upon resistance to wheel load, show results equal and, in some cases, superior to the original rail. Based upon bending moment, they show values coming around 90 percent of the original rail. The thermit welds show values about equal to those of carefully applied joint bars in our laboratory tests. Great care was given that the bolt tension was not too high, and that it was kept constant. The two fusion weld processes show results far below joint bars.

Chairman Penfield: Our next assignment, No. 7, is: Service tests of various types of joint bars. Mr. Ray McBrian, engineer of tests, Denver & Rio Grande Western Railroad is the subcommittee chairman and will present the report.

Ray McBrian (Denver & Rio Grande Western): The report is a record of the observations made during the past year of the service tests of the various types of joint bars in the test track on the Santa Fe and Pennsylvania railroads. It is to be noted that details as to rail surface profile, joint camber, bolt tension, rail gap and out-to-out measurements are given. On the question of comparison of types of bars installed in the test tracks, it may be said, except for one design of bar, the bars have not been in track long enough to determine their relative values.

The report is presented as information with the recommendation that the subject be continued.

Chairman Penfield: Our next assignment, No. 8, is: Investigate joint bar failures and give consideration to the revision of design and specifications. Mr. Ray McBrian is also the subcommittee chairman of that subject and will present the report. I would like to announce, however, that at the close of Mr. McBrian's report, Mr. Walter B. Leaf, research technician of the Denver & Rio Grande Western Railroad, will present an ilustrated monograph on photoelastic investigations of the design of joint bars, which I am sure you will all find interesting.*

Mr. McBrian: The report of the subcommittee continues the study from last year and interprets the assignment to include the study of cracks which may not lead to ultimate breakage. Through observation of tests in progress and the study of failures, data were obtained bearing on some of the theories as to cause of failure. It is noted that the data were obtained from actual service tests, full size fatigue tests and laboratory studies as possible means to eliminate cracking. Possible means studied were:

(1) Improving physical properties;
(2) Photoelastic studies as to effect of design and bolt tension;
(3) Fatigue tests, using full size bars in assembled joints;
(4) Observation as to effect of saw swelling of the rail end.

Details were given as to manner in which these tests are being conducted. The report is offered as information, with the recommendation that the subject be continued.

Chairman Penfield: Mr. Leaf, are you ready to proceed?

(W. B. Leaf, Denver & Rio Grande Western, gave an illustrated talk. See page 672.)

Chairman Penfield: Mr. Leaf, the committee is very much indebted to you, and we would like to thank you for this demonstration.

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* See monograph by Mr. Leaf on page 672 of the committee's report.

Professor Moore will now close the committee work with his summary of the more recent activities in connection with the rails investigation.

(For Professor Moore's formal report for the year, see the Seventh Progress Report of the Investigation of Fissures in Railroad Rails, page 681.)

Vice-President Clarke: The work being done by the Rail committee is of great importance, and none of it is more important than the work being done by Professor Moore's committee. We appreciate very much the report which he has just presented. If there is no discussion, the committee is discharged with the thanks of the Association.

Discussion on Yards and Terminals

(For Report, see pp. 107-148.)

(Vice-President Bond presiding)

Chairman C. H. Mottier (Illinois Central): The report of the Yards and Terminals committee embraces reports on all nine assignments. The first assignment is Revision of Manual and will be presented by the subcommittee chairman, Mr. Lyford.

L. L. Lyford (Illinois Central): This year's report on Revision of Manual is in three parts: First, definitions; second, change in Manual material covering freight terminals, and, third, change in specifications for weighbeams and accessories for the four-section, knife-edge railway track scales, the two-section, knife-edge railway track scales, and the motor truck, built-in, self-contained and portable scales for railway service.

(Mr. Lyford read the paragraphs under Glossary found on page 108.)

Mr. Lyford: The reason for this change is because the Manual did not have a definition for a siding, and that word is used in the Standard Code of Operating Rules. I move that this material be approved for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Mr. Lyford: Under the second portion, Freight Terminals, it is proposed to delete paragraph 322 (e), page 14–21 and insert in its place the following paragraph.

(Mr. Lyford then read the proposed new paragraph (e), ending with the text under Departure Tracks.)

Mr. Lyford: The purpose of these changes is to emphasize the desirability of operating trains, wherever possible, direct from the classification yard tracks. There is a saving in the handling of cars and a consequent saving in the cost of operation.

I move that this new material be approved for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Mr. Lyford: The remaining material has to do with the design of notches and pawls or latches on the different types of scales covered by the specifications. It is proposed in each case, that is, for the three types of scales, to delete the present paragraphs on Notches or Pawl and insert in their place the following paragraphs:

(Mr. Lyford then read the new material on Notches and Pawl or Latch on page 109.)

Mr. Lyford: The purpose of this change is not to specify with a great degree of exactness just how these notches shall be made but, rather, to state in general terms that they shall be made so that accurate positioning of the poise will automatically result at any graduation.

I move that these changes in the Manual, which are the same for the three types of scales, be adopted for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Mottier: Report on Assignment 2, General requirements in terminal facilities for various later types of equipment, will be presented by the subcommittee chairman, Mr. Giles.

W. H. Giles (Missouri Pacific): For the purpose of this report later types of equipment are considered to be the so-called streamline passenger cars. Some highlights of the study are set forth, with the conclusions of your committee as outlined on page 111. The report is submitted as information.

Chairman Mottier: Report on Assignment 3, Terminal facilities required for servicing electrical and air conditioning equipment in passenger cars, is to be presented by the subcommittee chairman, Mr. Hedley.

W. J. Hedley (Wabash): This report deals with facilities for passenger stations and coach yards for electrical and air conditioning equipment. It involves two closely related subjects. In fact, they are so closely related, they can't very well be separated because there is a great deal of air conditioning equipment that requires electric current for standby use while it is idle at the passenger station and also while it is in the coach yard.

This report shows a tabulation on page 113 of Bulletin 421 of the number of passenger cars equipped with the various types of air conditioning systems during the past few years. The tabulation ends with the year 1938 because a tabulation of the cars equipped with these systems for the years 1939 and 1940 has not been compiled. However, the AAR compilation of air conditioned passenger cars in operation as of January 1, 1941 shows that Class I railroads had 6,961 cars, which was an increase of 365 over the previous January 1, 1940, report. The Pullman Company had 5,239 air conditioned cars in operation, which was an increase of 120, making a total for Class I railroads and the Pullman Company of 12,200 cars, an increase of 485.

You will note that most of the air conditioning of passenger cars was done during the years 1935, '36 and '37, although some was done prior to that, and there has been some since.

The first consideration for one who is to decide what facilities should be provided for servicing air conditioning equipment, particularly, is to determine what type of air conditioning is in use in the cars that are to use the terminal.

Then the next consideration is, what is the trend in the use of the air conditioning systems. Some railroads are gradually changing from one type or system to another, so it is important to know what types of air conditioning equipment are coming into the passenger terminals and also what types may be expected during the next few years.

For servicing electrical equipment, the primary need is for a method of charging storage batteries. That is necessary usually in the passenger station as well as in the coach yard. For charging batteries, it is necessary to use direct current. The matter resolves itself into a question of whether to provide direct-current outlets at all the places that you will need them, or whether to use portable charging units which are commonly known as buggies, which will operate from 220-volt three-phase a.c. circuits, converting that into the necessary voltage of direct current.

The committee proposes to continue its study of this matter, and next year to determine the most desirable and economical spacing of electrical outlets to be used for both air conditioning and electrical equipment. This will be done in conjunction with the committee of the Electrical Section, as the report for this year was worked out.

This report is submitted as information.

Chairman Mottier: The report on Assignment No. 4, Scales used in railway service, appearing on page 114, will be presented by the subcommittee chairman, Mr. Harrison.

M. J. J. Harrison (Pennsylvania): In presenting this year's report under this particular subject, your committee has been informally asked how it happened that it apparently departed from the type of scale which was ordinarily thought of as being used in railway service. By way of explanation, I might point out that this particular report is prepared in response to an assignment which came to your committee from the AAR. The reason for the interest of the AAR in this particular matter is that, as a matter of fact, in terminal grain markets, not only the buying and selling of the grain is determined on scales of the type contemplated by the material presented here, but also the charges made for its transportation from point of origin to the terminal market and sometimes from one terminal market to another.

The material submitted at this time is set forth purely as a tentative proposal. It has, since the bulletin was printed, been submitted to other organizations and groups that have a very vital interest in the subject. It has been discussed with representatives of those groups. Unless there be objection, your committee proposes to continue that discussion and, when possible, to report further with regard to any alterations or amendments which may be indicated as being desirable in the light of all of the discussions which may eventuate with the other parties concerned in this matter.

Your committee would be particularly happy to have written discussions on any of the detail covered by this report from anybody who is interested in it, and particularly solicits criticisms of its material.

At this time the report is submitted as information, with the request that it be so received.

Chairman Mottier: Report on Assignment 5, Terminal facilities required for the care of Diesel locomotive equipment, will be presented by the subcommittee chairman, Mr. Lorenz.

H. C. Lorenz (Cleveland, Cincinnati, Chicago & St. Louis): In this report the committee has assembled information regarding the manner in which the railroads are meeting the problem of providing facilities for servicing and repairing Diesel-electric locomotives. More definitely, the following subjects are treated: General requirements for ordinary servicing; facilities for light or running repairs; shops for heavy repairs; truck and wheel removing equipment, with a résumé of what the railroads are doing in particular, in the way of adapting and supplementing existing facilities and the construction of new facilities and an outline of requirements in Diesel-electric locomotive details to facilitate repairs under given circumstances.

This report is offered as information.

Chairman Mottier: Report on Assignment 6, Classification yards, will be reported by the subcommittee chairman, Mr. George Hand.

G. F. Hand (New York, New Haven & Hartford): This year the subcommittee has studied the departure end of the classification yard. The principal purpose was to consider the design of classification tracks and of the departure tracks in relation to the method of operation, with the object of expediting freight and, at the same time, reducing the cost as far as possible.

The point of principal interest in the findings in this study is contained in paragraph 3 on page 134. This has been covered by the subcommittee on change in Manual, and the essence of that will be included in the Manual.

The main thing to emphasize is that, with the necessity for quick dispatch of trains at a minimum cost, it has become more and more the practice to make up and dispatch trains from the classification tracks themselves. The need for departure tracks is set out in a later paragraph on that same page.

We believe, after the very careful canvass we have made of all the principal yards in the country through direct contact with operating men as well as with our own engineers, that under existing conditions the seven points listed on the bottom of pages 133 and 134 represent good practice. The report is submitted as information.

Chairman Mottier: Report on Assignment 7, Terminal facilities required for the washing of passenger cars mechanically: Unfortunately, Mr. Metcalf is not with us to present the report. In recent years bus, street car and interurban companies have been using mechanical equipment to wash their cars. Buses have been doing it very successfully and economically, which fact suggested this assignment. So far as we have been able to learn, there are only two railroads in this country that have adopted mechanical washing of cars, though others in foreign countries are doing so. One American road has two installations; the other has one. They appear to be very well pleased with their performance and the resulting economies.

The equipment used in washing cars consists primarily of revolving cylindrical brushes which bear against the side of the cars and are subject to tipping, so they will conform to the profile of the car. Water is sprayed onto the car while it is being moved rather slowly through the washer. In the modern installations equipment is moved through at the rate of about one car per minute. If the cars can be moved through these washers without extra switch-engine expense they have considerable promise in the reduction of labor costs.

Quite a number of studies have been made by railroads to install this equipment, but it is rather difficult to do so in an old layout. It is almost necessary to design a yard with this equipment in mind to get the full advantage of it. The washer should be placed on a tangent track where cars can be washed as they are moved in a normal movement between the station and the yard. The new equipment can wash cars moving in either direction.

At the bottom of page 135 the committee cites certain advantages claimed for mechanical car washers. These washers are made principally by two American companies. They have many installations for buses and street cars. Several desirable features to be incorporated in installations for mechanical washing of passenger equipment are also presented.

This report is presented as information and, incidentally, is a final report on the assignment.

The report on Assignment 8, Terminal facilities required for the handling of highway trucks and trailers on and off railroad cars will be presented by the subcommittee chairman, Mr. Ripley.

H. L. Ripley (New York, New Haven & Hartford): Looking at me now, it would be hard for you to believe that I was once a student, but I remember being taught, in connection with the study of philosophy, that man is a selfish animal. Of course, there are exceptions to that but, speaking of mankind in general, it was true then and it is true now. So, if you want to find a way to get back onto the rails some of the business that has been lost to rubber, the surest way to do it is to find something that is of benefit to both.

That is what a few railroads have attempted in connection with this subject. There is nothing in it for the Manual, and perhaps, after you read it, you will think I should have said there is nothing in it, but the committee is hopeful that it may offer some help to some railroad and be of interest and perhaps of advantage to it and to the railroads in general in making a study of the subject from the angle suggested.

Chairman Mottier: The report on Assignment 9, Bibliography on subjects pertaining to yards and terminals, appearing in current periodicals, will be presented by the subcommittee chairman, Mr. Tratman, who, incidentally, is the patriarch of our committee and, outside of the chairman, is the most modest and hardest working man on the committee. . . . . . . He does not think it necessary for him to present the report, which demonstrates that he is modest. The report is presented as information and covers eight pages of references and required a great deal of work. We appreciate Mr. Tratman's effort.

Mr. Chairman, that concludes the report of the Yards and Terminals Committee.

Vice-President Bond: Is there any discussion? If not, the committee is excused with the thanks of the Association. (Applause)

Discussion on Records and Accounts

(For Report, see pp. 369-392.)

(Vice-President Bond presiding)

Chairman C. A. Knowles (Chesapeake & Ohio): Records and Accounts: This is not the dry subject those words would seem to denote. Records used in the conduct of a business undertaking, telling the story of success or failure, are vibrant with life. This is especially true of the railroad industry, with properties extending over hundreds and thousands of miles, with daily transactions, multitudinous daily transactions with the public and with each other. It does not seem too much to say that the present stage of efficiency of our industry has been reached, to a great extent, through the preparation and study of records that indicate to proceed with caution or stop.

It was called to my attention a short time ago that a man had said, "I am a forward-looking man. I am not concerned with things of the past." I don't think he really meant that because no man could successfully chart his future course without consideration of the past, no more than a vessel could steam towards the port without the rudder trailing in the wind or without the benefit of the logs of navigators long since gone.

A striking example of this is the magnificent accomplishment of Matthew Fontaine Maury, he who, through the study of the logs of the captains of sailing vessels, discovered to the lasting benefit of future navigators that the currents of the sea follow fixed paths. Now, in its practical consideration, are the railroads today about to save over half a million dollars through the recent discovery of records, some of which were made seventy-five years ago. It is safe to say that the makers of those records had no idea of the beneficial use to which they would be put today, and neither do we know what use our successors may make of the records we are now preparing. It is our duty and our privilege to so prepare the records that they clearly and fully state the facts.

No doubt many of you have a question in your mind as to why I am making these remarks. The purpose is an attempt to engage your interest and to invite discussion on the subcommittee's reports which are to follow.

The report on Assignment No. 1, Revision of Manual, will be given by Mr. Field, chairman of the subcommittee.

D. E. Field (Columbus & Greenville): It has just been said that records and accounts are far removed from the grave, but I still suggest that this particular subject might be called the desert surrounding the oases formed by our other subcommittee reports. But it is the purpose of our subcommittee that the Manual shall not be a burial ground for conclusions of the Association which have become obsolete through changed conditions.

The brief paragraphs printed on page 370 only partially indicate the amount of time and thought given by the committee during the past year to a review of the material in the Manual, contained on 125 of its pages.

The necessity for a somewhat extensive revision of much of the material in Chapter 11 has become increasingly evident. During the coming year the committee expects to offer for your approval a rearrangement of the subject matter, consisting, among other things, of a revision of forms, specifications and definitions to conform to modern practice.

In preparing any proposed revisions, the committee will not neglect to consider whether the expense to the Association is justified.

Chairman Knowles: The report on Assignment 2 will be given by Mr. Braden, chairman of the subcommittee.

E. V. Braden (Pittsburgh, Chartiers & Youghiogheny): What could be drier than a bibliography on a dry subject? Fortunately for the work of this committee, our chairman, Mr. Knowles, has made clear that, instead of being a dry subject, records and accounts is a very live subject, vibrant, in fact, with that something, that experience, shall we say, orderly recorded, a knowledge of which is essential to the intelligent steering of the good ship Transportation through the turbulent waters of today.

Subcommittee 2 has compiled from many sources the bibliography on pages 371 and 372. We believe the list to be useful to one seeking such information, not only as a casual interest but particularly to one who from duty must keep informed on the trend of thought and practice in railroad valuation, taxation, financing and accounting.

Because of the number of American railroads in bankruptcy and the number of railroads now undergoing reorganization in the hope of avoiding bankruptcy, your attention is called to an item on the list of subjects, of widest general interest and importance at this time. I refer to the publication of Duke University Law School, of a symposium of thirteen articles on railroad reorganization. Here the intricacies of the law, finance and economic problems are brought together with the interests of organized labor and ownership, and they are discussed by men particularly competent in their respective fields of railroad administration, large financing operations, corporation law, organized labor and organized ownership.

The potential consequences of the policies that are being developed through the solution of these problems will certainly be vital to the future of American railroads. The bibliography is, as usual, submitted as information.

Chairman Knowles: The report on Assignment 3, Office and drafting room practices, will be given by Mr. Teal, the chairman of the subcommittee.

D. C. Teal (Chesapeake & Ohio): This report presents discussion on five subjects. The reports on three topics are submitted as information while the other two offer material recommended for inclusion in the Manual.

Under the heading Drafting Equipment and Tools it is noted that the subject was reported last year as information. This year, after reviewing for possible Manual material, your committee recommends that the subject be discontinued.

The report on Specifications of material to be used for drawings and drafting, discusses the various factors that influence the selection of drawing materials and describes present common practices of ordering them. The conclusions are that the present methods of selecting and ordering are quite satisfactory and that specifications would be unnecessary. The report is presented as information, with the recommendation that the subject be discontinued.

The report on Standard system for filing drawings, describes the various methods and equipment used by railroad offices. The conclusions are that standardization of methods would be impractical because of the differences in individual requirements. The report is presented as information.

The subject Welding symbols is brought before the Association at this time because of certain late developments. The American Welding Society has recently adopted a new code of symbols. Recognizing their authority in such matters, it is believed desirable to have their symbols available for railway drafting room use. However, in order to avoid having material in the Manual that would be subjected to revisions by another organization and, so, might soon be out of date, it is proposed to publish only the reference to them as indicated in the second paragraph on page 379. This reads: "It is recommended that the symbols of the American Welding Society be used. These symbols, together with instructions for their use, are published in bulletin form and may be obtained from the American Welding Society."

I move that this information on Welding Symbols be published in the Manual.

(The motion was seconded.)

H. M. Stout (Northern Pacific): I would like to inquire of the chairman of the subcommittee how extensive a bulletin that document is to which he refers.

Mr. Teal: The bulletin in its present form is 32 pages of standard letterhead, 8½ by 11, and, besides the symbols themselves, it embodies quite a bit of detailed instructions for their use. The symbols would be useless without the instructions. It would require the entire publication.

Mr. Stout: The idea of the subcommittee is that the symbols, as they are presented now, are not fixed, that is, they vary from time to time?

Mr. Teal: They have been revised two or three times in the last two years, to my knowledge, and they will be subject to further revision without any knowledge on our part.

Mr. Stout: Under the circumstances, Mr. Chairman, I think the subcommittee's recommendation is a wise one, not to try to publish it themselves because they couldn't keep up with the procession, probably.

Mr. Teal: That was the thought. The bulletins cost, I think, 15 cents, if you apply to the proper authority, the secretary of the American Welding Society.

(Mr. Teal's motion was then put to a vote and carried.)

Mr. Teal: Your committee has also reviewed the report entitled "Style To Be Used in the Preparation of Reports and Specifications" which was originally submitted in 1938 as information, but with the understanding that it would later be considered for inclusion in the Manual. Believing it worthy, your committee recommends its publication.

I move that the report on "Style To Be Used in the Preparation of Reports and Specifications" now appearing in Vol. 39, pages 661 to 669 of the Proceedings, be published in the Manual.

(The motion was seconded.)

Secretary Lacher: I would like to call attention to the fact that many of the abbreviations recommended are not the same as those used in the present Manual. For example, in the first part, on abbreviations, it specifies the same standard that we use in our other publications, namely, to abbreviate units of measure such as inches, feet, pounds, and so forth, when used with numerals and to spell them out when used with numbers spelled out.

I agree with the committee that that is the best system but the fact remains that the editor of the Manual, presumably with the support of the Manual committee, decided that feet, inches, pounds and other units of measure were to be spelled out in all cases. Consequently, if what the committee now submits is to be adopted, either we must rewrite a large part of the Manual or we must have the Manual carry out a style which is not in conformity with what is now submitted.

Vice-President Bond: That is an important point that the secretary has brought to our notice, to the effect that, while the substance of the matter may be in order, its set-up is subject to further revision insofar as abbreviations, to make it consistent with what is already in the Manual.

Mr. Teal: Perhaps in view of the non-conformity we had better withdraw our motion and attempt to get together, before presenting it for inclusion.

Secretary Lacher: I would like to suggest that this be brought to the attention of the Manual Committee of the Board with a view to arriving at some agreement as to the best policy to pursue.

(The motion was withdrawn with the consent of the seconder.)

Mr. Teal: This concludes the report of the subcommittee.

Chairman Knowles: The report on Assignment 4 will be given by Mr. Restall, chairman of the subcommittee.

H. L. Restall (Boston & Maine): The report of Subcommittee 4 is one of progress. It has recently been demonstrated by floods, hurricanes and operating emergencies arising from other occasions that many carriers do not have readily available sufficient information to facilitate the immediate replacement of certain electrical equipment.

The demand for this kind of information being obvious, this subcommittee has undertaken the study of the conditions for the purpose of calling attention to such deficiencies of records and recommending a system whereby the information may be collected and perpetuated.

Under this specific assignment the committee found itself confined to property coming under the jurisdiction of the maintenance of way department. Realizing that some railroad organizations place the responsibility for electrical equipment in other departments, it has requested that the scope of the assignment be enlarged to include all such electrical equipment, regardless of what department may be responsible therefor.

The study further indicated the probable desirability of including, in addition to electrical equipment, such items as motor cars, machinery and roadway tools. Permission has now been granted, with the proper collaboration, to include these features in the committee's study and it proposes to proceed along these lines for the ensuing year.

The report of this subcommittee is offered as a progress report.

Chairman Knowles: Assignment No. 5 is: Construction reports and records. The committee has no report to offer at this time. A study has been in progress during the year, and the committee expects to offer some recommendations at the convention next year. The report on Assignment 6, Valuation, will be given by Mr. Barnhart, chairman of the subcommittee.

S. H. Barnhart (Norfolk & Western): The first assigned subject is: Résumé of developments of the current year in connection with regulatory bodies and the courts. We have recorded the developments, under this assignment, and I shall not take your time to attempt to reiterate the items of the report, other than to say that there is nothing of major importance that should be called to the attention of the convention.

The second assigned subject, ICC valuation orders, reports and records: First under this assignment we present a form for a record of ballast changes, with the recommendation that it be included in the Manual.

The second is a study of Valuation Order No. 3 reports and records to determine if further simplifications are possible. While the committee recognizes that there are many things that we would like to do in connection with these reports and records of property changes or valuation work, we have nothing of major importance to report this year.

There have been a number of items that have come to the attention of the committee. They have been handled, and some results have been obtained.

The last subject assigned is: Form of Order No. 3 reports in connection with joint projects, federal-railroad. Our report shows we have been unable to reach a conclusion in connection with this matter, largely because we find difficulty between several departments of the Bureau of Valuation as to how these matters are to be handled. We are hopeful that in another year this subject may be concluded.

The report is offered as information except Exhibit I, which I move be adopted for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Knowles: The report on Assignment 7 will be given by Mr. Barnes, chairman of the subcommittee.

H. D. Barnes (Chicago & North Western): As in previous years, the committee has reviewed a number of proposed accounting case rulings or orders submitted to Mr. Bunnell, vice-president, Association of American Railroads, by the Bureau of Accounts of the Interstate Commerce Commission. These subjects are described in the first part of the report.

Lists of the orders modifying the accounting classifications and accounting rulings and interpretations issued by the Interstate Commerce Commission are shown in the latter part of the report.

It is obvious that the accounting classifications are undergoing a gradual revision and this procedure is of great importance to the railways. As stated in presenting this committee's report for 1939, informal arrangements are effective with Mr. Bunnell whereby proposed accounting orders or rulings pertaining to the accounting for property changes or maintenance of roadway and structures are referred to this committee for consideration. Representatives of the Bureau of Accounts have indicated an appreciation of our comments. We would like to have every member of this Association who is interested in the changes that are being made in the accounting classification feel that he is afforded an opportunity for expressing his opinions in regard to these important questions through any member of this committee.

This report is submitted as information with the recommendation that the subject be continued.

Chairman Knowles: The report on Subject 8 will be given by Mr. Baldwin, chairman of the subcommittee.

F. B. Baldwin (Atchison, Topeka & Santa Fe): The assignment is: Methods of avoiding duplication of reports and for simplifying and coordinating work under the requirements of the ICC and other public authorities. Duplication of reports is something that grows like many things in nature. Reports are like thistles or dandelions. The first one is no problem but in a few years it is found that where one plant is allowed to grow, hundreds have come into existence and have sapped the vigor of the more useful plant life. Once the growth has started, the seed gets into the soil, and a constant war must be waged to enable the useful plant life to exist.

When a business organization is small, no reports are necessary because the boss sees all and knows all that is going on. As the organization grows larger, departments are created. One man can no longer oversee the entire workings, and department heads are required to make periodic reports. Thus the thing starts. As the organization continues to grow, departments create branches. The branch heads make reports to department heads, and department heads condense these reports into reports to the superintendent.

Eventually the organization becomes quite complex. Cost studies have to be made, and numerous other factors have to be given consideration, all of which require reports and more reports. It becomes necessary to create a department for making reports. This department, in order to justify its existence, must be fed with reports upon which to base its own reports. There seems to be no end.

Public interest in the growth of an industry demands regulation by a public authority. A governmental bureau gets started, and there is created a further demand for reports by this higher authority. This demand goes to the officials of the industry. Additional reports are required of the record department, and this extends on down into the very roots of the plant.

Until public regulation came into the picture, the industry had some chance to curtail this growth of reports within its own organization. Where reports no longer served any useful purpose, or duplicates were found, they could be discontinued. The management could simply say "Stop" and the employees could turn to more useful work. Even at that the weeding out of unnecessary reports was usually incomplete. Experience shows that many reports once started continue automatically, long after there is any real demand for them. Demand by governmental authorities cannot be easily decreased. One bureau finds needs for certain information; other bureaus need reports from other points of view. Duplication is a natural result. One bureau does not always inquire what information the other bureaus have.

In recent years the growth of bureaus has followed the same expanding pattern. As indicated in the first paragraph of the subcommittee's report, the Association of American Railroads has an organization helping to fight this growth of reports. Recently that organization has, to some extent, been able to curtail this growth of demands for additional reports and, to a small degree, has been able to lessen the burden of existing demands.

In the second paragraph of the report, the subcommittee calls attention to two instances where expanding bureaucratic activities have increased the burden on railroads. The subcommittee finds a certain amount of hesitancy on the part of railroad representatives to join in concerted action in this matter. The interests of various departments are involved, and the benefits to be derived from the existence of a particular report and its effect upon the good relations with public officials must be weighed against its cost.

Each railroad has its experiences not only with the requirements of the bureaus of the federal government but also with the requirements of the commissions of the various states. The subcommittee calls attention in the fourth and fifth paragraphs of the report to two instances where the requirements of the commissions of individual states were substantial duplications of reports furnished to a federal bureau. In these instances considerable saving in expense appears to have been accomplished by prevailing upon the state commissions to accept a copy of the report to the federal bureau in lieu of its own requirements.

The subcommittee has not been able to get many definite suggestions for improvement of the situation. Is it possible that this condition is like the weather problem, where everybody complains and nobody can do anything about it? Complaining is not effective unless you have some solution to offer.

As stated, the Association of American Railroads is working on this problem and I am sure will gladly give consideration to any suggestions an individual railroad may have.

The subcommittee calls attention to another feature in this year's report. This should be of special interest to many railroad engineers. The inside workings of the Interstate Commerce Commission may be familiar to lawyers and, to some extent, to the accountants but to many engineers this great regulatory body is pretty much of a mystery.

Attached to our report on pages 386 and 392 in Exhibit 2 we have included in the Proceedings, where it would be readily available to all members of the Association, the latest organization schedule and assignment of work and functions of the commission. This should give anyone interested a general idea of how the commission operates. While this information does not directly relate to the subcommittee assignment, it is considered useful and, in some respects, is not entirely foreign to the assignment.

The subcommittee's report is offered as information.

Chairman Knowles: The subject of Assignment 9 is: Records of property leased and available for lease. This is a somewhat new subject. The committee is studying it but has no report to offer you at this time.

This concludes the report of Committee 11.

E. M. Hastings (Richmond, Fredericksburg & Potomac): I don't think we ought to pass this report without some comment on the splendid presentation that has been made by Mr. Knowles and his committee. They have departed somewhat, in fact considerably, from the usual stereotyped form of presenting subcommittee reports and have made a most splendid presentation. The report contains information which is of great value to all of us. I personally want to say this word of commendation of the committee.

Vice-President Bond: The presentation has certainly been done in a very interesting way, and I am very glad to hear the remarks from the floor to that effect.

The committee is excused with the thanks of the Association.

Discussion on Rules and Organization

(For Report, see pp. 515–538.)

(Vice-President Bond presiding)

Chairman W. T. Dorrance (New York, New Haven & Hartford): The first subject assigned to this committee, as to all committees, is Revision of Manual. The committee finds the situation somewhat peculiar in this respect as the present Manual contains no subject matter for this committee, but the 1929 Manual and supplements thereto contain matter that has been approved by the Association at various times.

In order to carry out the intent of the assignment for revision of the Manual, the committee felt that it was necessary to go back to the old material. In order to present new, revised material, the committee recommends the elimination of all material hitherto adopted by the Association on the recommendation of Committee 12 and published in the 1929 Manual and supplements thereto but withheld from publication in the present Manual by order of the Board of Direction.

I move the adoption of this recommendation.

(The motion was seconded.)

H. L. Browne (Chicago): I was a member of this committee, previous to 1938, for 20 years. I have been a member of the Association 30 years. During that period I said two sentences from the platform but never spoke from the floor. You are a Canadian. I am a great nephew of George Browne whose statue is on the left hand as you go into the parliament of your home town. I am no public speaker, very poorly equipped. I don't want to offend anybody. I don't want to use personalities, but I have probably attended more committee meetings than any other member of the Rules and Organization committee.

There has been a great variance of opinion. We have gone before the Board of Direction and the Committee on Outline of Work time and time again. We never held an opinion opposite to any other committee, where we could get them together. We were a conciliation committee. I think in a five-year period I read every word of 107 rule books. I don't claim to be any authority, either. I haven't had time to think over all the rules in this book, but one of the striking things of this book was that the superior officer was relieved of his responsibility. In one place it says the employee shall provide himself with a rule book. About page 90 it rules that the superior should provide that. Sears, Roebuck won't sell a rule book.

Vice-President Bond: Mr. Browne, may I ask if you are speaking to the motion that is now before the house?

Mr. Browne: Am I out of order?

Vice-President Bond: I think some of the remarks are somewhat foreign to the motion.

Mr. Browne: Here is what I want to say: I don't think that this committee has existed long enough to go into one-tenth of the responsibilities and realities connected with this thing. I don't believe anyone has had time enough to consider these rules, and I don't believe the various committees that are concerned have had time to consider these rules.

Vice-President Bond: Will you kindly repeat the motion?

Chairman Dorrance: The motion is that the committee recommends the elimination of all material heretofore adopted by the Association on the recommendation of Committee 12, and published in the 1929 Manual and supplements thereto but withheld from publication in the present Manual by order of the Board of Direction.

Vice-President Bond: The motion is to withdraw what has already been published—

Chairman Dorrance: What has been published in the 1929 Manual, pages 789 to 871; Bulletin 337, pages 82 to 85; Bulletin 347, pages 26 to 30; Bulletin 356, page 52; Bulletin 367, pages 106 and 107; and Bulletin 378, pages 57 to 62.

Mr. Browne: I want to say one thing more. Mr. A. R. Wilson came before our committee in 1938 and said he was authorized by the Board of Direction to publish everything that had been passed by the convention up to that time and had previously passed. I want the Board of Direction to do that—either do it or don't do it. I don't see Mr. Wilson around here but he can verify that. He asked permission, and I said I would ask the committee if they would permit him to speak, and he appeared there and, after quite a long discussion, I think he was 100 percent for the committee. He came back and said they would publish it. Therefore, I think the Board of Direction should be responsible to the membership. I want that promise kept. That is what I am after, Mr. Bond.

I have worked a great many years, and I don't think that this committee in two years even scratched the surface.

(Chairman Dorrance's motion was then put to a vote and carried.)

Chairman Dorrance: Subject No. 2 instructed the committee to prepare rules and regulations for the guidance of employees of the maintenance of way department, collaborating with appropriate standing committees.

The committee offers at this time as a substitute for the matter which has now been deleted the new matter, which appears in the committee's report. This represents the work of two years of rather intensive study, with careful review of books of rules of various railroads. The proposed rules are intended to be general rules and we attempted to eliminate from these general rules specific instructions which might come under the head of specifications for carrying out detailed work which we believe properly belong to the several standing committees handling those special subjects.

E. M. Hastings (Richmond, Fredericksburg & Potomac): We have another chairman here who is a modest chap. He is beckoning to me to do some talking. I didn't expect to do any on this particular matter this morning. You will notice that the chairman has rather adroitly worded the sentence which he just read to you. I am going to be very frank and give you my opinion. The material presented represents a considerable amount of intensive work on the part of the committee. It is not my view that it is Manual material. My view is that the Manual of the American Railway Engineering Association should not contain material such as has been promulgated by this committee at this time. Therefore, I am offering a motion that it be received as information.

(The motion was seconded.)

Chairman Dorrance: Mr. Hastings moved that the report be received as information to give an opportunity for any further study and comments that might be made during the next year. The committee is willing to accept that.

Vice-President Bond: I think the committee can offer that statement without a motion, Mr. Dorrance.

C. H. Mottier (Illinois Central): Mr. Browne made only one specific criticism of these rules. As I had a small part in the preparation of the rule criticized, I would like the privilege of answering his criticism. His criticism was directed at Rule 30 on page 516. That Rule 30 appears under Responsibilities and Restrictions and reads as follows: "Employees whose duties are prescribed by these rules and regulations must provide themselves with copies. They must familiarize themselves with the rules and regulations affecting their duties, whether or not they appear under the head of their specific duties, and must be prepared to pass an examination on them at any time. If in doubt as to the exact meaning of any rule or regulation they must apply to the proper authority for explanation."

I understood Mr. Browne's criticism to be that the responsibility should rest on the supervisory officer and not be unloaded, if you please, on the employee.

The basis on which these rules have been prepared should be explained. They are grouped under certain functional subjects; that is trackmen rules are grouped together; bridge men's rules are grouped together, etc. In the first section are grouped general rules applicable to all employees, so as to avoid repeating the same rule several times, as is done in many books of rules.

If you turn to page 519 you will find the heading "Supervisory Officers and Foremen." All such general rules applicable, we will say, to a section foreman, a bridge foreman or any supervisory officer, are grouped under this heading and should be read and observed by them. If a rule is applicable to all foremen, it will be found in this one section, not in five or six different places. Then if there is a rule applicable to a section foreman and to no other foreman, that rule should appear under the Track section. Listen to rule No. 90 on page 519. "Books of Rules and Regulations.—Supervisory employees must be fully conversant with the rules and regulations, must see that subordinates who should have copies are supplied, and see that they are receipted for, understood and complied with by those under them."

This answers Mr. Browne's criticism.

W. C. Barrett (Lehigh Valley): I think now that the question has come up it is only fair to have the members of the Association—I am not sure but perhaps I am giving you some information you already have, understand what the problem is that this committee is facing. It is really a question of whether or not this Association wants to have printed in the Manual any rules whatever for the conduct of maintenance of way work. That is the question which I think should be in the minds of all of the members of this Association between the end of this convention and the convention next year, because the committee will bring before you next year these same rules which have been printed in the bulletin this year, with the request that they be approved for printing in the Manual. I just wanted to present that as clearly as I know how, so you could keep that in mind between now and next year, because next year you will have to decide whether or not you want this committee to do anything.

W. G. Arn (Illinois Central): There are one or two points I would like to mention. I am glad that this is being carried over at least for another year because there are some parts that pertain to various other committees, that should be studied by those committees. I am wondering whether the Association, if it should publish this ultimately in the Manual or merely in the Proceedings, will want to go on record as endorsing a rule which is not now enforced on most of the railroads, will not be enforced and probably cannot be enforced. I think, therefore, that the committee should give further consideration to the wording, and whether or not there should be such a rule as Rule 22 on page 516, which reads as follows:

Use of Intoxicants and Narcotics.—The use of intoxicants or narcotics is prohibited.

There is no limitation whatever on that. If one of the largest railroad companies in the country can't discharge a locomotive engineer who is drunk on his locomotive so he can't do his duty, I doubt if such a rule could be enforced, even if it were put in.

Chairman Dorrance: This is reprinted from the standard code of the AAR.

Colonel Arn: That is a good point but I don't think that should be binding on this Association. If it is binding, it might be taken up with the proper authority to see if that shouldn't be changed. We shouldn't stultify ourselves.

There is another point to which I think the committee should give consideration. It has recommended on page 532, under First Aid to Injured: See "First Aid Instructions for Railroad Employees," approved and published by Operating-Transportation Division, Association of American Railroads.

This, I understand, was prepared by the Medical and Surgical Section of the AAR, and that should govern in this Association, but I think that this committee should go over those rules carefully to see if it has any suggestions as to changes before we adopt them. Possibly we might have changes to suggest that would be acceptable to the Medical and Surgical Section.

Chairman Dorrance: The committee has gone over these rules and makes the recommendation as it stands.

Mr. Browne: There are many matters I could touch on in that report. We only got it lately, and I have been busy. I only used one instance. I have had twenty years on the committee, and I have an idea of what it is about. I have met all these various committees at times, and it is pretty hard to get them to go along. I am in favor of what Mr. Barrett said.

I am not opposing the rules but I think they should be fine-tooth combed by every committee, and their criticisms and reports and everything should be published, so the membership could be informed. After that I am in favor of having these rules published. I am 100 percent for that. I looked through the rules as published here, and in my opinion there is one rule which my own committee approved, but which I didn't think should be approved, and that is the one I referred to.

What I would suggest is that all the various committees study these rules and inform someone of their views. The next year those rules should be presented as information, and, after they go through that, the third year they should be adopted, that is, either adopted or rejected.

Chairman Dorrance: The committee will welcome any criticisms from any members or any other committees during the next year.

Vice-President Bond: If there is no further discussion, the report is received with the thanks of the Association and the committee is excused. (Applause)

[At a meeting on March 18, 1941, just after the conclusion of the convention, the Board of Direction, by a unanimous vote of those present, discontinued the Committee on Rules and Organization—Secretary]

Discussion on Wood Bridges and Trestles

(For Report, see pp. 247–293.)

(Vice-President Bond presiding)

Chairman H. M. Church (Chesapeake & Ohio): The committee presents reports on subjects 1, 2, 4, 6, and 8, and reports progress on subjects 3, 7, 9, and 10. The committee has in the course of preparation, under Subject 7, plans for revision of the designs for trestles that are now in the Manual.

Subjects 1 and 2 have been handled together and are being treated as a revision to the Manual. Mr. L. W. Smith, who has taken very active part in the handling of this matter in connection with the American Lumber Standards, will present the report.

L. W. Smith (National Lumber Manufacturers' Association): In the revision of those sections of the Manual, pages 7–11 to 7–15 of the present Manual, which pertain to the Specifications of Lumber and Timbers, the wording of the Manual material and the American Lumber Standards were brought into agreement. Most of the revisions of the Manual are editorial. The arrangement also has been changed, resulting, we believe, in a more logical organization of the material. It will be necessary to make a few additional changes that are not shown in the report, but they are merely editorial and involve no particular difficulty.

The major changes that have been made, which are not of an editorial nature are, first, those pertaining to paragraphs 135 and 140 in which the permissible sum of sizes of knots in joists and planks, beams and stringers is defined. In the former specifications, the sum of the size of all knots within the middle half of the length of a joist, for example, was limited to four times the size of the largest knot admitted, without regard to the length of the piece. Therefore more severe knot restrictions were placed on long joists than on short ones.

The new specification defines the sum of the sizes of all knots as a variable depending on the length of the piece, with due safeguards against closely spaced knots. It is believed the new specifications provide a more equitable limitation of knots and, at the same time, provide adequately for the desired quality.

Second, in paragraph 106 in the former specification, slope of grain was not limited to posts and timbers. In the revision, such limitation is provided.

Third, paragraph 860, specifications for shingles are very much simplified and condensed. Fourth, sections pertaining to factory and shop lumber have been eliminated. Fifth, definitions have been improved by cross references. In the former specifications some terms were defined in the body of the text but not in the definitions. In the revision, proper cross references have been made.

This report is presented for adoption as Manual material, and I move its adoption.

(The motion was seconded, put to a vote and carried.)

Chairman Church: Under subject 4 we offer tentative specifications for the design of wood bridges and trestles. This matter has been handled by Mr. Hart, and he will present the report.

R. P. Hart (Missouri Pacific): We have been building wood bridges and trestles for a long time, and it looks as if we ought to have specifications for doing it. This specification is not new to many of you, and a large part of it you will note has been taken from the Manual, page 7–107 under the heading "Notes on the Use of Stress Grades." Those notes were prepared sometime ago, after extensive tests in the Forest Products Laboratory at Madison and, we feel, form a sound basis for this specification.

Some paragraphs have been added to cover loads to be considered and the method of treating those loads. Those paragraphs that have been added follow very closely the material in the Manual under masonry and steel bridges. In other words, we proposed to have our wood bridges and trestles designed fully as efficiently and effectively as any other type of structure. We realize that there are some features concerning the application of load which need a little further study. We propose to give the specification that further study during the coming year. We will welcome any suggestions that you have to offer as to the application of those specification requirements.

I would like to call to your attention one correction in particular in Section 1015 on page 276. The formula under sub-section (d) is incorrect in that there has been deleted the factor 9L from the denominator. That should appear immediately below the factor 10P in the numerator.

This report is submitted as information with the thought that, after further study, we may be able to present to you for adoption as Manual material in another year a specification acceptable to you.

F. R. Smith (Union Railroad): In connection with the design of timber structures, and particularly bridge ties on open decks, the question of longitudinal shear in timbers under beam action has always been a problem. I have discussed the subject with men in the design field, and no one seems to know just exactly how to handle the problem economically. We figure the maximum longitudinal shear at the points of support from the theory of mechanics, which perhaps does not hold true because we assume a plane section before bending remains a plane section after bending, and at these points this assumption probably is not true.

Then the other feature that complicates the problem is the amount of tie or beam existing beyond the point of support, where there is no theoretical horizontal shear. I would appreciate knowing whether or not the chairman has made any tests or knows of anyone who has made tests pertaining to the subject of longitudinal shear resulting from bending under the conditions mentioned.

Mr. Hart: I do not know of any tests in that particular form but there have, of course, been numerous tests on beams at the Forest Products Laboratory to determine the value in shear, and that is the basis of this specification 1015. You will find under section (a) and (d) basic formulas which we propose to use. Under (d) the formula is a modification based on the latest tests made at the Forest Products Laboratory and it allows a little more leeway than the older formula found in sub-section (a). You will be able to secure through Mr. John A. Newlin, in charge of Section on Timber Mechanics at Madison, copies of tests on the beams, which may give you the information that you desire.

Mr. Smith: I have one more question. Do you feel that a timber tie can initially fail from longitudinal shear? In my opinion, it is quite difficult to conceive of initial failure in longitudinal shear.

Mr. Hart: I not only believe they can fail in longitudinal shear, I know they can fail, because I have seen them fail. That is a feature which must be particularly watched in timbers. Douglas fir timbers will not take the stress in longitudinal shear that certain other timbers will take. Of course, Douglas fir has its advantages in other ways. You will find in the section now in the Manual on stress grades that the shear values vary with different kinds of timber, and it is just as important to consider the shear in timber as in any other material. In fact, longitudinal shear stresses are governing in certain classes of timber.

A. B. Chapman (Chicago, Milwaukee, St. Paul & Pacific): Under Section 1009, in the last paragraph, the effect of centrifugal force, and so forth—may we disregard if the track is superelevated to compensate for curvature? Do you consider that all tracks should be compensated for theoretical curvature, or should it be proportional?

Mr. Hart: My thought is that that is a matter which the designer will have to consider with judgment, knowing the speeds that will obtain and the conditions under which he will get the maximum load condition. If the track is fully superelevated for maximum load condition, then your resultant load will be applied normally to your stringers and your longitudinal effect will be relieved.

Mr. Chapman: Will we have any trouble if we slope the cap and the floor of a ballasted deck with the ballast moving out to the low side?

Mr. Hart: You may if the superelevation is more than four or five inches. I have known of some complaint where a superelevation of five to six inches was used in the floor, and trouble was experienced with the ballast crowding downgrade.

Mr. Chapman: But up to that height you haven't found any difficulties?

Mr. Hart: Not so much up to that height.

Chairman Church: Subject 5, Bearing power of wood piles and Subject 6, Recommended relationships between the energy of hammer and the weight or mass of pile for proper pile driving, have been handled under one subject. The chairman of this submittee, Mr. Heinlen, will present the report.

H. C. Heinlen (Atchison, Topeka & Santa Fe): A report was made on this subject last year in general terms, referring only to the energy of steam hammers. We find, after further study and consideration, that it is desirable to place some additional limitations on pile driving equipment and we have revised the material under the heading of Steam Hammers accordingly. You will note especially the limitations of unit energy and total energy required in the hammer and that we have limited the size of the concrete pile to that which can be handled by standard pile driving equipment on the market.

We have also placed a lower limit on the weight of the ram and we have limited the speed of the hammer. This is to prevent a contractor from trying to substitute equipment and telling us he can get the required foot-pounds energy with a light hammer operated at high speed. With these lower limits placed on the ram and limiting the speed to the normal rate of operation, we feel that we have a recommendation that will protect the engineer, and serve as a guide for the selection of pile driving equipment.

The latter part of the assignment is a series of tables made up to show the supporting capacity of piles driven by various weights and types of hammers in common use. These tables are self-explanatory and are corrected to take into account the efficiency of the hammer. The committee is aware, of course, that we cannot depend entirely upon a formula for computing the capacity of piles, but they do serve to give a general idea of what may be expected, and they also serve the further purpose of bringing out some interest and discussion of the subject.

One person has already reported that he has made a comparison of the tables in this bulletin with some actual pile driving data and tests, and has found they agree quite closely. The committee would appreciate it if the members of the AREA who are driving test piles and have complete driving a..d test loading data, would cooperate with the committee by furnishing copies of such data to the chairman so that after a period of years we will have a definite check on the value of the formulas now in common use. This revision or redraft of material and additional material is presented as information.

Chairman Church: Subject 8, Fireproofing wood bridges and trestles including the placing of fire stops is submitted in final form. Due to the fact that none of the members of the committee is present, Mr. Oliver will explain the report.

W. A. Oliver (University of Illinois): The sub-committee, after enumerating ways of decreasing the fire hazards in wooden trestles, which it recognizes exists, recommends that paragraphs 2, 5 and 6, now in the Manual under the heading Best Method of Fireproofing Wood Bridges and Trestles be changed in accordance with the material which is presented at the bottom of page 291 of the report.

A reference to the Manual will show that these changes in every case consist of added material. No changes have been made to the material which at present is in the Manual. As the committee recommends, I move that these changes be accepted for inclusion in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Church: This completes the report of Committee 7.

Vice-President Bond: The committee is excused with the thanks of the Association. (Applause)

Discussion on Impact

(For Report, see pp. 393–483.)

(Vice-President Bond presiding)

Chairman J. B. Hunley (New York Central): Due to the lack of necessary equipment for making additional tests, it was not possible to report any definite progress on the special assignments of this committee. However, due to the generosity of the Association of American Railroads, which provided certain funds, and the Pennsylvania Railroad which provided us with the test data which has been obtained on some very interesting tests at Chester, Pa., the committee was able to analyze those tests and, I think, submit certain data which will be of interest to the Association. It certainly is a contribution to the whole subject of impact.

These tests were very carefully made. It is the first time that we have had, as far as I know, tests in which both electric and steam locomotives were operated at very high speeds.

This report embraces a description and analysis of tests made on two plate girder spans 55 ft. 10 in. and 122 ft. long. Stresses, vertical deflections, and lateral deflections were measured at the center of each span under four different types of locomotives, running at speeds ranging from approximately five m.p.h., which may be considered static loading, up to maximum speeds of 105 m.p.h. for the two types of electric locomotives, 80 m.p.h. for the freight type steam locomotive, and 90 m.p.h. for the passenger type steam locomotive.

The electrical measuring equipment consisted of electrical deflectometers, accelerometers which were used for measuring lateral deflections and about 20 magnetic strain gages, which were recorded on four six-element oscillographs. In other words, 24 simultaneous readings on stresses and deflections were obtained. In addition to this, we had the mechanical deflectometers which were used in the Big Four tests, as reported in Bulletin 380.

The results of these tests are of particular interest to railway engineers generally, for two reasons: First because the higher speeds, which are considerably higher than in any previous test, give information of value with respect to present-day speeds of operation and, second, because comparison is afforded between the effects of locomotives with and without the so-called hammer blow resulting from the overbalance in the driving wheels of steam locomotives.

The total impact effect produced by each of these locomotives, in percent of stress measured at a speed of approximately five miles per hour, that is at static loading, is shown in Figs. 45 to 51, and so on.

In the digest of the report there is a comparison of the impact effect from the various locomotives at high speeds on both spans, and it will be noted from the tabulation and figures that there was no marked reduction of impact with the electric locomotives even though they had no unbalanced counterweight. This perhaps may seem a little strange, but it can be explained by the fact that the two types of steam locomotives used were especially well counterbalanced. That is, if those locomotives had had the amount of overbalance provided for in our design specifications, or the large overbalance that a great many locomotives now in service have, the comparative impact from the electric locomotives would have been far more favorable.

In addition to the total dynamic effects, data were also analyzed for the purpose of studying the magnitude of the individual impact effects which make up the total impact effect. These individual effects, expressed in percentage of static stress as found in the study, are as follows:

No. 1: A definite increase due to speed and termed speed effect was found throughout the tests, and this was entirely distinct from the vibration that was developed by the moving load. The probable explanation of this speed effect is the centrifugal force developed by the locomotive while following the path of the deflected span.

This raises the famous old questions of "why do we have a camber", and "is camber necessary?" While camber is usually provided, it is customary to frame it out in the deck. This speed effect is due to the span deflection, and in addition to the centrifugal force of the load following the deflected path, there is present the inertia of the masses of the span and live load falling through that distance. When there is no camber in the span, perhaps it will become the practice to provide for it in the deck framing, however offensive to the eyes of the track men this may be.

If I may refer you to Figs. 28 to 35 on pages 457 to 463, you will note that these speed effects increase, as they should, with the square of the speed. They are somewhat higher than the theoretical curves based on an approximate formula and, in some instances as much as 10 to 15 percent. This has not been taken into account in any impact formula. While it did occur to a marked extent on these two spans, it is something which we need to investigate a little further.

No. 2: The effect of roll was found as in other tests, and the results are shown on the diagrams on pages 457 to 464. I need only say here that the roll effect generally is less than the design specification or the rating rules call for. On the 55-ft. span, the girders are only five feet apart, or directly under the rail, where maximum effect would occur.

No. 3: With the electric locomotives we had a very good chance to segregate the track effect from the total impact effect because there were no unbalanced parts on these locomotives. This track effect can be due to out-of-round wheels or flat spots on wheels or track irregularities. Supposedly, the track effect should increase with the square of the speed, but it will be noticed, from Figs. 36 to 39, inclusive, that it reaches a maximum at speeds of 30 or 40 or 50 miles, with little or no increase at higher speeds. Possibly the rating rules, which provide for track effect increasing with the square of the speed, can later be revised. This would be fortunate as the track effect is quite an important factor in the total impact on short spans.

It might be of interest to know that Professor Ingliss, who is probably the foremost authority in England on this subject, told me, when he was in my office about a year and one-half ago, that, from a theoretical analysis and tests which he had made at Cambridge University, he is convinced that the maximum effect occurs at between 20 and 30 m.p.h. I questioned this at that time but it has been verified, to a certain extent, by these tests.

No. 4: Combined track and hammer blow effect of the steam locomotive: These effects could not be separated, due to the presence of overbalance, but they were found to be about what could be expected and were lower than provided for in the design specifications.

As in former tests, locomotive spring damping was apparent. I would like to refer to Figs. 42 and 43 on pages 471 and 472. You will note in Fig. 42, on either diagram, at a speed of about three revolutions per second, or about 42 m.p.h. the oscillations, instead of following the upper curve as we would expect when the springs remained locked, suddenly decreased in magnitude and later increased, approaching a second peak. This is due solely to spring damping. As soon as the sprung weight of the locomotive is set in motion, the spring friction damps out the primary oscillations, but at higher speeds a second critical frequency may occur.

You will note as represented by the dotted line, that the oscillations do increase, but they never reach the magnitude that would have been expected if the springs remained locked. The same effect is shown in Fig. 43 on page 472.

These tests gave some information as to two other dynamic effects about which little is known. From the lateral deflection of the spans as determined by the accelerometers it was possible to compute the lateral force which would be necessary to produce that deflection, and this force was probably due largely to nosing of the locomotives.

In the various tables given on pages 477 to 480 it is found that, assuming the force was concentrated at the center or distributed over other points on the span, the lateral forces necessary to produce the measured deflections were quite high. In Table 35 values as high as 46,000 lb. are found. It is interesting to note that the maximum force does not always occur at the maximum speed. In some instances they are quite as high at 40 m.p.h., as at 80 and 90 m.p.h. Both the design and the rating rules provide for this nosing effect, but whether the amount provided for at present is large enough it is impossible to say.

Another thing which is mentioned in the report but for which no values are given, is the action of the web at the end of the spans. Magnetic strain gages were placed on the web plate, for the purpose of measuring dynamic shear. It was found that the web vibrated laterally at very high frequencies, so that it was impossible to determine the shear. The total stress was quite high; and was a combination of direct shear and a lateral bending of the web. These webs are not especially thin. On the short span they were $\frac{7}{16}$ in. thick and on the long span $\frac{5}{8}$ in. It may be desirable to give some consideration to this lateral bending in webs, in addition to the shearing stresses.

The report bristles with tables which may appear uninteresting, but they contain a great deal of interesting information. However, for the sake of easy interpretation, the results have been shown in the various diagrams. After careful consideration of these data, the committee has reached these conclusions:

(Chairman Hunley then read the conclusions on page 482.)

Chairman Hunley. That concludes the report of the Committee on Impact.

Vice-President Bond: If there is no discussion, the committee is excused with the thanks of the Association. (Applause)

Discussion on Iron and Steel Structures

(For Report, see pp. 355–368.)

(Vice-President Bond presiding)

Chairman R. A. Van Ness (Atchison, Topeka & Santa Fe): Your committee has no report to offer this year on Assignments 2, 4, 5, 6, 7 and 8. Assignment 1, Revision of Manual, will be presented by Mr. O. E. Selby, chairman of that subcommittee.

O. E. Selby (Cleveland, Cincinnati, Chicago & St. Louis): The revisions of the Manual are confined mostly to revisions of the Specifications for Steel Railway Bridges.

On page 356, article 301 (b): Delete the words "Shoes and Pedestals" in the first line.

Article 425: Add a paragraph to read: For stringers, the gage of the outstanding legs of the connection angles over the top one-third of the stringer depth shall be not less than the quantity: square root of lt over eight.

$l =$ length of stringer span, in inches.

$t =$ thickness of angle, in inches.

The length of stringer span in inches is correct, as read, and not in feet, as printed. In addition the letter L as printed under the radical and in the nomenclature, should be a lower case l instead of capital L.

The revision of 432 as proposed on page 356 has been withdrawn by the committee. That is: Stiffeners at Points of Bearing, article 432—everything to the bottom of the page.

On page 357, articles 504, 505 and 506 are revised, and I will read the subtitles. These three numbers were submitted last year for revision but were withdrawn before being acted upon because the committee was not satisfied with the wording. We have gone over them again and now think that the wording expresses what we mean. There is no intention to change the meaning of the specifications; it is merely to make the intended meaning clearer.

(Mr. Selby then read the paragraph headings on pages 357 and 358 down to 1611, page 15-48.)

Mr. Selby: In addition, I offer a similar change on page 15-27 of the Manual. Change the serial designation A141-33 to A141-39, with a similar change in Article 825.

(Mr. Selby then read the revision on Welding.)

Mr. Selby: I move the adoption and insertion in the Manual of the revisions of the Specifications for Steel Railway Bridges which have been read and referred to.

(The motion was seconded, put to a vote and carried.)

Mr. Selby: The following revision of the Rules for Rating Existing Iron and Steel Bridges is recommended:

108: Under (c) Hammer Blow Effect, Clause 3, substitute the numeral 5 for the quantity n_s^2 in the denominator of the last term in both formulas (a) and (b).

This is merely to clear up and simplify the formula without any substantial change in its meaning or results. There is a typographical error on page 358. The expression n^s should read n_s^2.

I move the adoption of the revision.

(The motion was seconded, put to a vote and carried.)

Mr. Selby: Instructions for the Maintenance Inspection of Steel Bridges. These instructions were thrown back on this committee. They constitute a revision of similar instructions that formerly appeared in Chapter 12 of the Manual, and are now offered for insertion in the Manual.

(Mr. Selby then read the paragraph numbers on pages 358 to 363, calling attention to the fact that the word "very" in the sixth line from the bottom of page 362 should be deleted.)

Mr. Selby: I move the adoption and insertion in the Manual of the Instructions for the Maintenance Inspection of Steel Bridges which have just been read by reference.

(The motion was seconded, put to a vote and carried).

Chairman Van Ness: Assignment 3, Non-ballast type metal floor steel bridges: The report will be presented by Mr. Haggander.

G. A. Haggander (Chicago, Burlington & Quincy): In our investigation we found that, while a large number of these structures had been constructed early in this century, not many are being built at the present time, and much of the development has been along the lines of altering and improving the earlier structures. New developments such as corrosion-resisting steel, use of rubber products for insulation and reducing noise, will no doubt overcome many of the present objections to this type.

Because of the briefness of the report, it will be desirable to read it rather than to try to summarize it.

(Mr. Haggander then read the report on Assignment 3, pages 363 to 365.)

Mr. Haggander: This report is presented as information.

Chairman Van Ness: This completes the report of Committee 15.

Vice-President Bond: The committee is excused with the thanks of the Association for this very fine presentation. (Applause)

Discussion on Buildings

(For Report, see pp. 225-245.)

(Vice-President Bond presiding)

Chairman L. H. Laffoley (Canadian Pacific): Although our report this year may appear more brief than is our usual custom, I think some of the subject matter found therein will be pertinent to anyone in the transportation industry, particularly the second report which we are to make.

Of the six assignments, we are reporting this year only on two. Assignments 1 and 2, namely, Revision of Manual and Preparation of specifications for railway buildings, are permanent assignments for this committee. A certain amount of work was done, but we have nothing to report on those two assignments at this time.

Subject 3, Requirements and design of garage buildings for railway service. We are making a final report on this subject at this time. I will ask Mr. J. P. Gallagher, chairman of the subcommittee, to present this report.

(J. P. Gallagher, New York Central, read the report on Assignment 3.)

G. C. Crites (Baltimore & Ohio): At a time when we take our family automobile into our own home, I wonder why, under Location, it says: "Garages, whether small or large, should be isolated from other structures in order to reduce to a minimum the hazard of exposure from fire". Just what does the word "isolated" mean? Considerably removed or fireproofed away from them?

Mr. Gallagher: The word "isolated" is used in a broad sense. It may be isolated in the structure, depending upon the risk to the plant or the location. In your home you actually have your garage isolated from the rest of the building by cement, plaster, or what-not—cut off from it.

Chairman Laffoley: On Subject No. 4, we make no report at this time.

Subject No. 5: This subject has been before Committee 6 for some time, and we now have what I think is a very thorough report on this subject, Methods of determining the protective value of paints. There is probably no material which we all have to deal with, that is in more common use than paint, and without any reflection on anybody I venture to state it is a subject that most of us know least about. You know that it is paint, but when you come down to finally finding out what it is, or how to find out what you are getting, you begin to appreciate that it is a considerable problem. It is our sincere hope that this report may answer a few of the questions on that subject. I think it is worthy of your attention. I will ask Mr. Angel, chairman of the subcommittee, to present this report.

C. M. Angel (Chesapeake & Ohio): The introduction of the report gives a summary of a survey of 39 railroads to ascertain the manner in which various railroads purchase paints and what tests are made of the paint product before use. Attention is called to the importance of the paint manufacturers' research to develop better paints, and standardized methods of paint test by the railroads to ascertain the comparative qualities of the paints before application. The paint testing procedure explains the care that must be exercised to conduct tests under conditions similar to those to which the paint will be subjected after application.

From the middle of page 229 to page 235 a description is given of various paint failures and the causes. Also, photographs are included illustrating the failures described.

Starting with the Physical Characteristics on the bottom of page 235 and ending at the top of page 242 a suggested test of paints is described, explaining how the physical characteristics of the paint in the beginning determine whether it is even worth while to make extensive tests. The text also outlines and describes the chemical analysis, accelerated weathering tests, outside exposure tests, and various special tests.

In connection with the accelerated weathering tests of paints, it has been called to the committee's attention that the word "weatherometer" used in the report is a trade name for a machine to conduct accelerated weathering tests. Therefore, the word "weatherometer" where used in the report should be changed to "accelerated weathering machine".

The report in conclusion gives a general description of paint testing equipment and staff required should a railroad desire to conduct tests of paints; also, a suggested plan for the correlation of test data accumulated and a suggested method of paint purchases.

The tests outlined are offered as suggested means through which paint can be tested to ascertain their comparative qualities, and this report has been presented by your committee primarily as a guide for those who use paints.

The report is presented as information.

Mr. Crites: I notice that the caption under the illustration on page 235 states that "Puddles of water were formed in the basement, because tree roots clogged the sewer." I wonder if that had anything to do with the failure of the paint.

Mr. Angel: I think that failure was caused by the moisture arising from the basement and saturating the wood. That would be the explanation I would offer to that.

Mr. Crites: That is, water came from the sewer and went up into the second story?

Mr. Angel: No, I would say that the moisture traveled up through the wood, into the paint, behind it. I think that the moisture could easily have gone up between the outside boarding and the inside wall of the structure.

Chairman Laffoley: As no report is being made at this time on Assignment No. 6, this concludes the report of Committee 6.

Vice-President Bond: If there is no further discussion, the committee will be excused with the thanks of the Association.

Discussion on Waterproofing of Railway Structures

(For Report, see p. 353.)

(Vice-President Bond presiding)

Chairman J. A. Lahmer (Missouri Pacific): As indicated in the printed report on page 353, we recommend changes in two sections of the Manual. These changes do not involve any change in practice or in the intent of the specifications. They are as follows:

Change heading of Section 203 from "Asphalt for Mopping Below Ground" to "Asphalt for Saturant and Mopping Below Ground." Immediately after the heading, add the following paragraph:

Asphalt for saturant below ground shall meet the requirements of Section 202.

In other words, the same asphalt is used for saturant above ground and for saturant below ground.

The other change is in the first paragraph of Section 207 relating to fabric, which is to be changed to read as follows:

Fabric shall consist of high-grade cotton cloth saturated thoroughly and uniformly with asphalt specified in Section 202 or either type of coal tar pitch specified in Section 204.

These changes are for clarification and I move their adoption.

(The motion was seconded, put to a vote and carried.)

Chairman Lahmer: The other subject assigned is: Waterproofing of railway structures. Under that we report that we are continuing the comparative study of ASTM specifications for waterproofing materials and corresponding requirements in our specifications for membrane waterproofing. We have suggested that the ASTM make certain changes in its specifications and have also asked for further information about the details of some of the present requirements in those specifications.

Representatives of ASTM have indicated that they would like to continue the negotiations with a view of ultimately agreeing on specifications for waterproofing materials which will be satisfactory to the ASTM, the American Association of State Highway Officials, Federal Specifications Board and the AREA.

That concludes our report.

Vice-President Bond: We are much obliged to you for a very comprehensive report, and this last portion will be accepted as progress and for information.

Chairman Lahmer: I would like to say one thing further. We have recently been informed by several producers and dealers that they are not able to furnish a five-ounce fabric for membrane waterproofing such as is stipulated in our specifications. AREA specifications also include requirements for a four-ounce fabric. The committee would be glad to know whether any of the members of the Association are interested in the use of five-ounce fabric for purposes that would not be served by the four-ounce fabric. As a matter of information, I will say that our requirements for four-ounce fabric are very similar to the ASTM requirements which include a minimum weight of three and one-half ounces instead of four.

Vice-President Bond: You and your committee are excused with the thanks of the Association. (Applause)

Discussion on Masonry

(For Report, see pp. 295–352.)

(Vice-President Clarke presiding)

Chairman J. F. Leonard (Pennsylvania): The report of Committee 8—Masonry covers 15 assignments. The first report is on Revision of Manual. It embraces minor revisions in the Specifications for Portland Cement Concrete and the Specifications for Shotcrete. Mr. G. E. Boyd, chairman of this committee, will present the report.

G. E. Boyd (Railway Age): The report of the subcommittee is made up almost entirely of editorial revisions. There are two types: One embraces revisions that are necessary to bring our specifications, where we refer to the specifications of the American Society For Testing Materials, up to date; the others are purely editorial.

(Mr. Boyd then read the revisions to Article 102.1, on pages 296 and 297.)

Mr. Boyd: I move the adoption of these revisions.

(The motion was seconded, put to a vote and carried.)

(Mr. Boyd then read the recommended changes in Article 104 and deletion of separate references to steel for bridges and buildings.)

Mr. Boyd: I move the approval of these revisions.

(The motion was seconded, put to a vote and carried.)

(Mr. Boyd then read the recommended revisions for High Early Strength Cement down to and including the deletion of footnote on page 8-7.)

Mr. Boyd: I move the approval of these revisions.

(The motion was seconded, put to a vote and carried.)

(Mr. Boyd then read the substitution for Section 5 of the Specification for Shotcrete.)

Mr. Boyd: I move the adoption of this revision.

(The motion was seconded, put to a vote and carried.)

Chairman Leonard: Assignment No. 2, Specifications and principles of design of plain and reinforced concrete for use in railway bridges, building and culverts, collaborating with Committees 1—Roadway and Ballast, 5—Track, 6—Buildings, 7—Wood Bridges and Trestles, 13—Water Service, Fire Protection and Sanitation, and 15—Iron and Steel Structures: In the case of the first of these subjects, Composite columns and pipe columns, the committee has a report to present which involves, incidental to its presentation, certain revisions in the Manual, but since it is also substantially an adoption of certain subject matter in the joint committee report, it is being presented here for action.

In the case of the other two subjects, we have progress to report. Mr. A. N. Laird, chairman of assignment 2, Design of columns, will present this report.

A. N. Laird (Grand Trunk Western): This committee has had the assignment of composite columns and pipe columns for several years. A previous final report on the subject has not been made because the matter was under consideration in great detail by the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, on which the American Railway Engineering Association was represented by members of the Masonry committee.

The Joint Committee report was published in AREA Bulletin 419 for September-October, 1940,* and the subject matter which is indicated, extending from the middle of page 298 to the middle of page 305 is substantially identical with the material in the joint committee report, with only such editorial changes as are necessary to coordinate it with the subject matter now in the Manual.

* See page 27 of the monograph section of this issue of the Proceedings.

The committee recommends that subject matter of Section 307, Design of Columns, of the Specifications for Portland Cement Concrete, Plain and Reinforced, be withdrawn and that it be replaced by new Section 307, Design of Columns.

The present form has not been printed in this committee report because of its length and because there is such a substantial change in form as to make direct comparison by paragraphs impractical.

I would like to read a portion of the first article under the proposed section because it gives a very clear picture of the viewpoint of the Joint committee and of the Masonry committee in its approach to this column design. It involves a substantial change in some respects, particularly with relation to spiral reinforced columns.

(Mr. Laird then read paragraphs (a) and (b) on pages 298 and 299.)

Mr. Laird: In view of the length of this subject matter, unless there is some objection, I will just read the headings.

(Mr. Laird then read the paragraph headings on pages 299 to 305.)

Mr. Laird: I move the deletion of Section 307 in the present Manual and the substitution of the proposed form.

(The motion was seconded, put to a vote and carried.)

Chairman Leonard: Assignment No. 3 carries the general heading, Progress in science and art of concrete manufacture. One of the specific assignments under this general heading, which this committee has carried for several years past, is entitled, Needed adjustments in field practice to use present day cements to best advantage. This subject was assigned to this committee at its own request and, after it accepted the assignment, it found that it had quite a problem on its hands to present the matter in detail. The committee is not now presuming to state that what it is now presenting is a complete handling of the subject.

However, it so happens that Committee C-1 of the ASTM during the past year adopted tentative specifications for five types of Portland cement, and since no doubt it intends to progress those to final specifications in due time, it was felt that under this assignment it was now the proper time for us to bring up to date, so far as we could, those things incidental to the subject that developed in connection with these five types of cement now being given a great deal of publicity. The report is for information purposes. It appears on page 305. The chairman of this committee, Mr. C. P. Marsh, was unable to be present at the meeting. We, however, are very fortunate in having with us today Mr. L. W. Walter who served very ably for many years as chairman of this same subcommittee until relinquishing the job within the last year due to his retirement. He will present the report.

L. W. Walter (Jersey City, N. J.): Our chairman, Mr. Leonard, has covered the subject about as fully as I had in mind attempting to do, so that what few remarks I have to make may, to some extent, be a repetition of what he has already said.

At the time of our last annual convention it was reported that ASTM Committee C-1 on Concrete was developing specifications intended to apply to five different types of Portland Cement. Those specifications were presented to that society at its June 1940, annual convention and were approved by the society as tentative specifications bearing the serial designation C-150-40.

Mr. Leonard has said, in dealing with the problem of needed adjustments in field practice to use present day cements to best advantage, the subcommittee has limited its studies and this report to the five types of Portland cement and to the new tentative specifications for them.

Since these are tentative specifications, they do not set aside the present standard specifications for Portland cement and high early strength Portland cement. However, it seems probable that during this calendar year the present tentative specifications for the five types of cement, with such minor revisions as may seem desirable, may be advanced to standard specifications, thereby and then superseding the present standard specifications for Portland cement and for high early strength Portland cement now listed under serial designation C9-38 and C74-39.

The report is presented as information.

Chairman Leonard: The next subject is No. 4 entitled Maintain contact with Joint Committee on Concrete and Reinforced Concrete. The chairman of this committee, Mr. Hirschthal, is unable to be here, but since the speaker was also a member of the joint committee, he will present the report. The report of the joint committee was published as information in Bulletin 419, Part 1 for September-October, 1940 and will appear on page 27 in the monograph section of the Proceedings for 1941.

As a matter of information I will read the foreword prepared by Committee 8 in presenting this report.

(Chairman Leonard then read the foreword of the Joint Committee report.)

Chairman Leonard: The next assignment is No. 5, Specifications for foundations, including excavation, cofferdam, piling, etc., collaborating with Committee 1—Roadway and Ballast on soil mechanics, and with Committee 7—Wood Bridges and Trestles on bearing power of wood piles and pile driving. The committee has no report to present at this time since the activity on the subject of foundation was concentrated in another report on the subject of test borings which you will receive later.

Assignment 6. Methods and practices of lining and relining tunnels, collaborating with Committee 1—Roadway and Ballast: The chairman of this committee, Mr. I. L. Pyle, is unable to be present, and most of the other members of this committee who have been for some time past active on the committee are also not present. Therefore I will present the report.

The report is in two parts. The first part is entitled Specifications for Lining Railway Tunnels with Metal Liner Plates and Shotcrete. You will note that while it is entitled Specifications, it is submitted at the present time as information, with the object of presenting it later for adoption and publication in the Manual, with the expectation that the members during the current year will have an opportunity to review the subject matter and give Committee 8 the benefit of any criticisms which they have to offer.

Therefore I will not attempt to read the report. I will refer you to the descriptive matter on page 308, with the plate showing the drawing of the recommended type of such construction. This is submitted as information.

The second part of this report is in the form of a revision of the Manual and is shown on page 309.

(Chairman Leonard read the first paragraph under Revision of the Manual on page 309.)

Chairman Leonard: Therefore, that which follows is an addition and a revision of the existing Manual material to give the Association the benefit of this alternate type of tunnel floor which is now in use, and very successfully, in some recent construction.

(Chairman Leonard then read the matter from the change in title of Section 202 on page 309 down to the end of that page.)

Chairman Leonard: You will note the section referred to at the top of page 310 entitled Supplement to Figures 835 and 836. You will note the other descriptive matter which is merely a word description of the construction dimensions as shown on the sketch plan accompanying the proposed form.

I move the revision of the Manual accordingly.

(The motion was seconded.)

J. B. Hunley (New York Central): In the figure on page 310 for the double-track section, you would have only $\frac{5}{16}$ in. of, let us say, "toehold" of the tie for the inner rail. On the curved track, it states that the tie block shall be thickened for superelevation. Is the committee convinced that this $\frac{5}{16}$-in. encasement at the end of that tie would be sufficient to take the horizontal thrust due to the centrifugal force?

Chairman Leonard: That $\frac{5}{16}$ in. is at the center and not at the end of the tie. The amount of concrete at the end of the tie will be increased by the slope of the concrete between the center and the end of the tie.

Mr. Hunley: On the one end of the tie you show a five-inch depression of the concrete. That would give about three inches at the gage end of the tie. You are sloping down from that, to $7\frac{11}{16}$ in. at the center. It would be more than $\frac{5}{16}$ in. at the outer end of that tie, but certainly not over $\frac{3}{4}$ in. Are you convinced that that is enough for the outer rail of a curve?

Chairman Leonard: The slope is $\frac{3}{4}$ in. in 12 in., and the distance from the center to the end of the tie is 2 ft. 9 in. so that is about 2 in. plus $\frac{5}{16}$ in., which would be the thickness of the concrete shoulder on the inner end of the tie.

Mr. Hunley: You think that would be enough?

Chairman Leonard: That was our conclusion. Naturally we adopted that from certain practice which has been constructed and which, up to the present time, we are advised, has worked most satisfactorily. I regret very much that Mr. Pyle isn't here because Mr. Pyle himself is one of the pioneers in the adoption of this type of floor for tunnel work.

Mr. Hunley: I suspect the C. & O. has curves in tunnels, so it is probably all right for such tracks. In many cases it is desirable, of course, to keep it to a minimum, but two inches looks pretty thin to me. I will have to leave that to the judgment of the committee.

Vice-President Clarke: Is your question answered?

Mr. Hunley: In a way. I think that experience is really the best answer. If they have been in service long enough in these tunnels and where they are running at a balanced speed, it is probably all right, but it does look small to me. I am just asking for information.

(Chairman Leonard's motion was then put to a vote and carried.)

Chairman Leonard: The next assignment is: Review specifications for overhead highway bridges of the American Association of State Highway Officials, insofar as they relate to masonry, conferring with that association, and Committee 15—Iron and Steel Structures. We have no report. We were unable to obtain any collaboration with the AASHO until late in the fall when we were furnished by that body with an advanced copy of a proposed new specification which, since that time, we have had under study. However, lack of time precluded the inclusion of any comment thereon as a part of this report since it had to go to press the first of December.

The next subject is No. 8. Progress in cement manufacture and testing. This is a factual report, as information, describing the five types of Portland cement recently adopted by the ASTM as tentative. You will note that this report gives the facts of the physical and chemical provisions of these five types of cement. Mr. C. P. Marsh, chairman of this committee, is unable to be present, and Mr. F. W. Capp who is an active member of this committee will present this report.

F. W. Capp (Portland Cement Association): The background of this report has already been given by the chairman and by Mr. Walter on Assignment No. 3. I would call attention to the paragraph in small type at the top of page 311.

(Mr. Capp then read the note at the top of page 311.)

Mr. Capp: In Tables I and II on page 312, the physical and chemical characteristics of these various types of cement are given. I understand these are to be changed in minor detail for presentation to the ASTM convention in June of this year.

In the matter of testing you will note that the autoclave test is included. A specification for fineness determined by the turbidimeter tests for types I, II, IV and V are given, and the compressive test on mortars is to be continued as it has been heretofore.

(Mr. Capp read the second and third paragraphs on page 313.)

Mr. Capp: The remaining material in this report is taken from a paper by L. A. Wagner, chief research chemist, Missouri Portland Cement Company, presented at the meeting of ASTM Committee C1 on Cement held on March 18 and 19, 1940.

The use of additions of this sort is being actively investigated at the present time, and some rather striking results have been obtained both in the laboratory and on field installations. During the coming year we expect to receive performance reports on a number of these installations, and we hope to be able, if these are available, to present a digest of them in our next report. This is given as information.

Chairman Leonard: The next subject is: Specifications for culvert pipe. The specifications for placement which were submitted last year as information are now proposed for inclusion in the Manual. The chairman, Mr. Doll, is unable to be present, and I am asking Professor Vawter, a member of this committee, to present this report.

Jamison Vawter (University of Illinois): As Mr. Leonard said, these specifications were presented last year as information, and they are now offered for publication in the Manual. They cover specifications, also, for jacking pipe through fills and placing in tunnels, and some sketches of different methods of bedding and for filling in backfill, are given on pages 316, 317 and 318. I will merely read the article headings.

(Mr. Vawter then read the paragraph headings on pages 315 to 319.)

Mr. Vawter: I move that these Specifications for the Placement of Concrete Culvert Pipe be adopted and published in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Leonard: Incidental to the assignment just reported on, your committee has to recommend that the subject be continued under the following designation: Maintain contact with ASTM Committee C-13 on Concrete Pipe. In other words, it is felt that the purpose which this committee set out to accomplish has now been accomplished with the exception of maintaining contact through representation on Committee C-13, so that we may keep in touch with any further developments in this field.

The next subject is No. 10. Bibliography and review of current engineering literature pertaining to railroad masonry work. While the committee within itself did considerable work on this subject, there is nothing which we have to report at the present time.

The next assignment is No. 11. Pressure grouting. Specifications for Solidification of Masonry Structures by Pressure Grouting are submitted as information. Mr. Ray, who is chairman of this committee, will present this report.

W. M. Ray (Baltimore & Ohio): Last year this subcommittee on pressure grouting submitted as information illustrations of various applications of pressure grouting and descriptions of the application of this method to various purposes. We are now presenting a specification which is confined to the solidification of masonry structures, and it is presented as information this year with the intention of recommending its adoption and publication in the Manual next year. I will read the titles of the paragraphs.

(Mr. Ray then read the paragraph headings on pages 319 and 320.)

Chairman Leonard: The next subject is: Specifications for concrete and reinforced concrete railroad bridges and other structures. This is the biggest assignment Committee 8 has and there is a brief report on page 321. I am going to ask Mr. Splitstone, who is chairman of this committee, to read this brief report with the idea that, if the members have any suggestions incidental to this undertaking, we would be glad to hear from them now or in writing during the coming year.

(C. H. Splitstone, Erie, read the report on assignment 12, on page 321.)

Mr. Splitstone: I might add the committee has continued activity since the submission of this report for publication.

Chairman Leonard: The next is 13. Specifications for test borings, collaborating with Committee 1—Roadway and Ballast. Mr. Wilson, chairman of this subcommittee, will present this report.

W. R. Wilson (Atchison, Topeka & Santa Fe): Your committee, in addition to preparing specifications for test borings, decided it should present considerable supporting data. The steel, concrete or timber entering into a structure is subjected to numerous tests to determine its properties. No engineer would think of building a structure without knowing the strength of the material going into it, but in many cases this same structure is placed upon a foundation material about which little is known and, in some cases, nothing is known until the excavation is made. This is equivalent to designing a bridge without knowing the material of which it is to be built.

Test borings and the identification and classification of the soil serve a similar purpose for the foundation material as do the usual tests for other structural materials. The results of such sub-surface investigation play a very important part in the determination of the most economical and stable structure for a given site.

In many cases where test borings are made, the records are not adequate and the field identification of the soils is inaccurate. It is a waste of money to make test borings without proper identification of the soil encountered and the keeping of adequate records. In fact, such a procedure might be dangerous, in that it would give a false picture of sub-surface conditions which could lead to the design of an inadequate or even an unsafe foundation.

To help correct this situation, your committee is presenting as information a brief description of the usual ways of making test borings and a table showing the various methods of underground exploration, with their approximate cost. It is intended to introduce the table as Manual material next year.

The various agencies interested in soil mechanics and foundation design are especially anxious to standardize the field classification and identification of soils so that all concerned will be speaking the same language. An example of this is quicksand. Many people think of quicksand as a type of soil, and it is often so shown on sounding data. However, quicksand is a natural phenomenon in which any fine, granular soil, with grains of nearly uniform size, is subjected to a flow of water through it in such a manner as to cause each particle to be suspended in the water.

To help advance the cause of standardization, a description of the various types of soils and methods of identifying them, in line with the latest practices, is presented as information.

The best of test borings are useless unless records are kept which will enable the engineer designing the foundation to visualize the actual existing conditions. The need for comprehensive and accurate test borings cannot be too highly stressed. A list of the data needed and a sample page of such test boring data is presented as information

The specification for test borings is submitted at this time as information. It is intended to present it next year for publication in the Manual. This draft of the specification has been reviewed by several engineers who are actively engaged in sub-surface exploration and is in line with the latest developments of test boring procedure. It necessarily covers a variety of methods for sub-surface exploration but only those methods consistent with the information it is desired to obtain, should be used on any particular job.

The committee requests comments from members of this Association during the coming year, with the object of clarifying any point which may be open to discussion, before it is presented as Manual material next year.

Chairman Leonard: The next subject is No. 14. Specifications for concrete placed under water. Since we have certain matter now in the Manual, on this subject, this report takes the form of a replacement of present Manual matter by the new matter as indicated in the report. Mr. T. L. Condron, who is chairman of this committee, is unable to be present, due to an accident. I will quote Mr. Condron's own words by telephone a few moments ago. Committee 8 extended our sympathy to Mr. Condron for having broken his leg. Mr. Condron replied: "Not at all. The man who drove the other car is the man who broke my leg."

Due to Mr. Condron's absence, Mr. Boyd will present this report.

Mr. Boyd: The specification which is presented for adoption and publication in the Manual is partly a revision of the material now appearing in the Manual and, to a small extent, is an addition to that material.

(Mr. Boyd read paragraphs two to four on page 332.)

Mr. Boyd: The specification, as the committee presents it, is made up of a number of articles, the headings of which I will read.

(Mr. Boyd then read the paragraph headings of Section 306 on pages 332 to 334.)

Mr. Boyd: I move the adoption of this specification for publication in the Manual.

(The motion was seconded, put to a vote and carried.)

Chairman Leonard: The report just presented involved a great deal of work on Mr. Condron's part. I know he canvassed the entire country for his matter.

The next and last subject is: Durability of Concrete, which is presented as a progress report and is submitted as information. Mr. L. M. Morris, chairman of this subcommittee, is unable to be present since he is now Major Morris of the U. S. Engineers. Mr. Maurice Coburn will present this report for Mr. Morris.

Maurice Coburn (Indianapolis, Ind.): The report is rather long, and it is worth study in detail. The aggregate comprises the major portion of concrete, and its soundness is essential to durable concrete. Recently an extended investigation of the durability of highway concrete has brought out the fact that the older pavements that have stood up well were those that did not have too much of the larger aggregate. Consideration is being given to grading of the sizes of cement. The modern cements, with their tendency toward early strength, increasing the amount of lime, fine grinding, and warehousing have not improved the tendency toward durability. The cement paste is the part of the concrete from which we can expect trouble as to durability, and, therefore, it should be kept to the minimum. Neat cement is not as durable as concrete. The quality of the gel is primarily dependent upon the water-cement ratio, and the voids in it are a function of the water-cement ratio.

There is more interest right now in the subject of admixtures, and this report has some information on that subject.

The deterioration of concrete occurs primarily because of the action of water and materials which it carries. Concrete grows with the deposit of material brought by water which enters it, but water also dissolves the constituents of the concrete, and if water runs through concrete continuously, it will destroy it completely. The action of constituents of the water entering the concrete sometimes is serious from the mechanical action of the materials deposited rather than from the solution of the constituents of the cement.

Chairman Leonard: I commend Major Morris and his committee on this report on durability. It was an enormous undertaking. I suggest that the membership give particular attention to F. Conclusion, on page 351, particularly to the bottom of this page in which five items are indicated as the high points in the procedure to obtain durable concrete. I would add, also, that these items are not listed in order of importance, since all five of them really belong first.

That completes the report of Committee 8.

Vice-President Clarke: If there is no discussion, the committee is excused with the thanks of the Association. (Applause)

MONOGRAPHS

Mechanization in the Maintenance of Way Department

Special Report Prepared by a Subcommittee of Committee 22—Economics of Railway Labor on Testimony Presented by the Railroad Carrier Industry Committee at Hearings on the Fair Labor Standards Act

F. S. Schwinn (chairman, subcommittee), Lem Adams, F. J. Bishop, W. H. Brameld, Armstrong Chinn, W. E. Cornell, E. A. Craft, G. H. Harris, W. E. Heimerdinger, W. H. Hillis, E. T. Howson, T. Z. Krumm, J. M. Miller, G. M. O'Rourke, H. M. Stout, R. R. Strother, J. C. Wallace, W. H. Woodbury.

In accordance with the provisions of the Fair Labor Standards Act of 1938, public hearings were held during the early months of 1940 by the Railroad Carrier Industry committee (Committee No. 9) for the purpose of investigating conditions in the railroad industry and recommending the highest minimum wage rate (up to 40 cents per hour) which might be made effective at this time without substantially curtailing employment. The carriers realized that any advance in the hourly earnings of labor would accelerate the mechanization of labor operations, especially in maintenance of way departments and have a particular effect upon track labor.

The carriers' special committee appointed a subcommittee under the chairmanship of Robert Faries,* assistant chief engineer—maintenance, Pennsylvania Railroad, and including L. H. Bond, chief engineer—maintenance of way, Illinois Central System; G. M. O'Rourke, district engineer, Illinois Central Railroad; and F. S. Schwinn, assistant chief engineer, Missouri Pacific Lines, for the purpose of exploring the possible extent of further mechanization, measuring the increasing economic justification of such mechanization at increasing hourly earnings, and reviewing other means by which offsetting labor economies might be effected through capital expenditures for heavier rail, roadbed stabilization and similar improvements. The results of this subcommittee's studies were presented by Mr. Faries in the form of testimony and statements at the public hearings referred to. Frequent reference was made to the reports of AREA Committee 22 as published in the Proceedings.

Your committee has undertaken to review Mr. Faries' testimony and quote such portions thereof which deal directly with labor economics and the curtailment in labor resulting from mechanization and other causes. The statements included show comparable hand and machine organizations, annual costs based on hourly labor rates varying from 30 cents to 40 cents per hour, and both force and expenditure curtailments resulting from mechanization. The excerpts from the testimony follow.

> I wish to present for your consideration certain facts and information relating to the effect of increased labor costs upon employment in the maintenance of way department of the railroad industry. I have confined this study to track maintenance forces, principally to clarify it, and also because this class is affected to the greatest extent in these proceedings. However, I wish to state that under pressure of increased costs the railroad industry must, of necessity, consider all fields for curtailment of expenses in all departments, and the same principles with which I will deal here apply to all railroad employment. . . .
>
> As wage costs rise the railroad industry, faced with a ceiling of rates for the services which it performs and, therefore, having a fixed gross revenue varying

* Mr. Faries died September 8, 1940.

only with the amount of business offered, is forced in a struggle for existence to resort to all possible means to avoid increasing current unit costs. The effects of the economic depression, and increasing losses of traffic to subsidized competitors, have intensified this problem.

Allotments for maintenance must not and do not exceed a definite or fixed portion of the total operating revenues, which for some years past has been approximately eleven percent. There is a definite relationship between labor and material used and financed under these maintenance allotments, and the allowance for labor will be found to be a definite proportion of the maintenance allotment. There is, therefore, only a certain amount of money that can be spent for labor, so that when the hourly wage is increased it is plain that less man-hours can be utilized, thus curtailing employment. The railroads must find a way to accomplish maintenance work with the reduced number of man-hours available. They are forced to use mechanical aids and to make capital expenditures for heavier rail, better ballast, treated ties and track drainage and stabilization projects, all of which result in a more permanent roadbed and track.

With a diminishing power to employ, and the necessity of providing adequate maintenance, it becomes necessary to extend the use of machinery. I have drawn and present herewith certain statements which show the breakdown of costs as between hand work and work with machines, and the effect which these machines have as a substitute for hand labor.

In practice, when considering projects for mechanization that show less than 15 to 20 percent return on the investment, there is less incentive to mechanize than when considering projects with greater returns on the invested money. Thus there are a number of what might be called "border line" cases, where even a slight increase in the economic value of the machine, resulting from a higher labor wage will definitely put such border line cases in the economically justified class.

In order to show how we arrived at the value of the machines at the different hourly wages (30 cents, 31 cents, 32 cents and up to 40 cents) we have made our calculations for 30 cents, 35 cents and 40 cents per hour; and, from these calculations are derived the resulting values for all intermediate wages. . . . The cost figures on the following statements include repairs, interest on the capital investment at 5 percent, depreciation, and supplies. . . .

Portable Power Track Nutters (See Statement 1)

This machine is used to remove and apply nuts in rail joints, replacing men with hand wrenches. The value of this outfit (two machines) for curtailing expenditures, at the 30-cent wage, is $628; and this value increases to $1,713 at the 40-cent wage. Six men are displaced by the use of this outfit.

Rail Power Drill (See Statement 2)

This machine consists of a gas-engine-powered drill for boring bolt holes in rail, replacing the hand drills which were slow, and required two men to operate them. The machine is used particularly in renewals of turnouts and crossovers, in interlockings, yard ladders, and where considerable cutting and boring of rail is necessary. One machine displaces three men and as the field for their use is large and many machines are in use throughout the country, the total displacement of labor in the aggregate is large.

The value of the machine for avoiding expenditures is $190 annually at the 30-cent wage, and this value increases to $395 annually at the 40-cent wage.

Rail Laying by Use of Machinery (See Statement 3)

This is a large and important operation. Where a full complement of machines is used they consist of power nutters, spike pullers, adzing machines, rail laying cranes and spike drivers. The value of this outfit for curtailing expenses at the 30-cent wage is $36,416, increasing to $47,407 at the 40-cent wage. There are 80 men displaced in mechanizing the rail laying operation.

The amount of maintenance of way machinery which would be assigned to a rail laying organization would necessarily vary, being dependent upon the extent of the rail laying program and the speed at which the rail is to be laid, as well as upon certain other factors, such as whether the track is placed at the disposal of the rail laying forces or if it must be kept in operation. On inquiry I find that the value of the equipment which we have set up, based on our actual experience, is reasonable by comparison with other railroads.

Burro Crane (See Statement 4)

This is a small gas-powered crane operating on the track, but easily removed, and equipped for loading and unloading dirt, rail and other material. It has many uses, particularly around yards and terminals. A record, covering a working period of 180 days on a large eastern railroad, shows 37 days loading scrap; 22 days loading and unloading rail; 100 days ditching, including loading and unloading dirt; and 21 days handling heavy miscellaneous material. The comparative costs indicate an annual curtailment of expenditure of $3,133 at the 30-cent wage and $4,812 at the 40-cent wage, and 11 men are displaced by the use of this machine.

Air Mechanical Tamping Outfit (See Statement 5)

Our field tests, in which cost records are carefully kept, indicate the necessity of considering all costs for maintaining track over the cycle of years during which the mechanical or comparative hand tamping will last before another general rehabilitation of the track surface becomes necessary. The initial cost of machine tamping is about equal to or a little greater than that for hand tamping, but our records show that, where traffic amounts to approximately 16,000,000 gross tons annually on 131-lb. rail, machine tamping lasts six years and hand tamping four years, and that approximately 30 percent more intermediate or spot tamping is necessary on the hand-tamped track during the cycle.

The output for one tamping machine for the season's work is, therefore, calculated and reduced to an annual cost, and the annual cost of the necessary intermediate work added. Thus, one tamping machine has a value for curtailing expenditures annually of $1,186 at the 30-cent wage and $1,678 at the 40-cent wage, displacing three men annually.

Portable Gasoline Driven Unit Tie Tamper (See Statement 6)

This tie tamper is used in the same manner as the compressed air tie tamping machine, except that it is used more as a spot surfacing tool—that is, one that is moved from place to place to tighten track in various spots or short stretches, rather than being used in a continuous operation. You will note the rapidly increasing value of the machine as the wage rises—namely, $187 at 30 cents and $493 at 40 cents. Each outfit of four machines displaces two men.

Ditching in Cuts With 8-Ton Gasoline-Operated Cranes (See Statement 7)

A common practice in ditching and banking was to use a work train unit with a battery of cranes and dump cars. The necessity for curtailing expenses has brought about greater use of off-track crawler cranes with drag lines and the use of bulldozers, operated by a few men. This method preserves the slopes in better shape and eliminates considerable hand work in trimming slopes and cleaning up after the material is roughed out of cuts by the drag lines. The value of an outfit of this kind for reducing costs is $21,825 at the 30-cent wage, increasing to $23,455 at the 40-cent wage. It displaces 17 men and one work train crew. This kind of work is a substantial portion of the account "Roadway Maintenance".

However, there are many other uses to which this type of machine is assigned. One railroad reports its use in excavating and filling bridge ends; and in this operation displaces 23 men with a daily value of $47.15 when calculated at the 40-cent wage. In another case 25 men were displaced in unloading 20-ft. and 30-ft. poles with a daily value of $51, when calculated at the 40-cent wage. In both these cases a work train was used with the cranes.

Discer (See Statement 8)

Power operated cars for discing and uprooting weeds from along the border of tracks have been greatly improved within the past few years. A machine of this kind, with a foreman, operator, and 3 laborers, does the equivalent work of a foreman, 2 assistant foremen and 87 laborers doing this work by hand. The value of the machine for eliminating expenditures is $10,957 at the 30-cent wage, and $14,660 at the 40-cent wage, and 85 men are displaced by the use of this machine.

Scarifier and Ballast Leveler (See Statement 9)

This machine is used to break away the ballast that becomes foul, caked, and non-draining, about the ends of ties. This condition results in pumping track, in which case water is held in the depression around the tie, and with the movement and vibration of passing traffic pumps in and out, displacing the ballast under the tie.

Before the introduction of this machine this work was done by men with picks bleeding these water pockets. The machine does similar work and reshapes the ballast on the shoulder. The reduction in expenditures due to this machine is very substantial, even at the lower rates for labor—being $18,173 at 30 cents, and increasing to $24,516 at the 40-cent wage. Ninety men are displaced by the use of this machine.

Weed Burner (See Statement 10)

This car disposes of weeds along the track by buring them with an oil flame. Two burnings per season are usually required to kill the weeds. Compared with hand labor, the relative annual value of the machine is $25,402 at the 30-cent wage, and $34,815 at the 40-cent wage. These values are dependent upon the density of vegetation. The values which I have used, and which represent my experience, are those achieved in a territory where the average normal precipitation is low and where the vegetation is not rank.

Weed Mowers (See Statement 11)

Hand mowing of weeds along the track has been supplemented, in many cases, by power weed mowers running on the track, and by tractor power mowers operating on the right-of-way (off-track machines). The value of the track-mounted machine for curtailing expenditures is $3,569 at the 30-cent wage, increasing to

$5,095 at the 40-cent wage. Each machine displaces 30 men, and there are many such machines already in use.

The relation of fully mechanized operations at the different wages does not show substantial differences due to the relatively small number of men necessary with mechanical operation, yet at the 40-cent wage it means that approximately one more man is displaced for each additional machine put into use. Due to climatic conditions, there is more need for discers, weed burners and weed mowers in the south and southwest than in other parts of the country.

Power Jack and Power Tamper (See Statement 12)

These machines are used together in large reballasting or track raising jobs. The value of 4 power jacks and 2 power tampers for curtailing expenditures is $37,244 at the 30-cent wage, increasing to $52,576 at the 40-cent wage. This combination of these machines displaces 106 men. These machines have been developed within the past few years and are not as yet in general use. A few of them have been in use for sufficient time to prove their value. . . .

Auto Truck Crane (See Statement 13)

This machine is used to considerable advantage around large terminals. The statement is based on an actual record of performance for 252 days, and the results are shown to be a curtailment of expenditure of $7,405 at the 30-cent wage and $9,350 at the 40-cent wage. An average of eight men were displaced in this operation. The machines are programmed in accordance with the working season on my own railroad, where climatic conditions interfere to a considerable extent. In southern and southwestern territories, where a 12-month working season is possible, it is apparent that the value of the machine is increased. . . .

Use of Heavier Rail (See Statement 14)

The problem of selecting the economically justified weight of rail for a certain line of railroad carrying a known amount of traffic per year involves consideration of relative annual investment and maintenance costs, and these costs are affected by the life of the different weights of rail.

The AREA Committee on Economics of Railway Labor, of which F. S. Schwinn was chairman, appointed a subcommittee, E. T. Howson, chairman, to study this subject. Quoting from this report, which is recorded in Proceedings, Vol. 40, page 340: "For lines of heavy traffic, savings by use of 112-lb. and 131-lb. rail in place of 100-lb. or lighter rail may reach 40 percent of the total expenditure for track labor. As volume of traffic decreases, savings and labor costs decrease until factors other than labor saving must justify the use of heavier rail."

The AREA Committee on Economics of Railway Location, of which H. M. Stout is chairman, appointed a subcommittee under C. H. R. Howe to study this subject. Quoting from this report, which is recorded in Proceedings, Vol. 40, page 130: "As maintenance costs per unit of traffic handled are greater in proportion to the inferiority of the track's physical structure, it is evident that the remedy lies in bettering conditions. In any given case it is obvious that the limit of justifiable additional investment is reached when the extra annual interest and replacement charges exceed the yearly savings that may be obtained."

The statement which I have prepared is based upon known facts as to life of 100-lb. and 131-lb. rail in our tracks at locations where the annual traffic amounted to 16,500,000 gross tons per mile, and where the cost of current maintenance is a matter of record. These details check very closely with similar information developed in the committee studies to which reference is given above. . . . You will note that the curtailment of expenditures at the 30-cent wage is $95 and at the 40-cent wage is $133 per mile of track annually.

Stabilization of Roadbed (See Statements 15 and 16)

By stabilization I mean providing a roadbed of uniform weight and supporting ability, free of slides and soft spots due to poor drainage and other causes. Track maintenance costs per mile vary to a considerable extent as between one mile and another in the same territory. In order to show this clearly I have had prepared two statements—one for an important high speed, dense traffic territory and the other for a less important branch line. These statements show both the normal maintenance per mile and the excess maintenance per mile caused by improperly drained and unstable roadbed—these figures being taken from actual records and experience of the track foremen and supervisors in both instances. The statements show the annual man-hours of maintenance per foot of soft track before stabilization work, after stabilization work, and for normal maintenance, the gross cost of the projects at the different wages, number of men displaced, and annual curtailment of expenditures at various wages.

Statements showing specific stabilization work on the International–Great Northern Railroad at Long Lake, Texas, (Statement 17) and on the Gulf Coast Lines at Beaumont, (Statement 18) are typical of many selected points throughout the country. You will note the curtailment of expenditures in the first case is $1,109 at 30-cent labor, and $1,441 at 40 cents. In the second case the curtailment is $2,461 at 30-cent labor; and $3,046 at 40 cents.

During the past seven years one railroad has effectively stabilized approximately 185 miles of roadbed by various methods, such as driving ties, poles and piling, and by use of concrete and timber slabs. The curtailment in man-hours obtained as a result of the stabilization of these "soft spots" is 25 percent, as follows:

To maintain one mile of track having unstable roadbed	12,800	man-hours	per	year
Maintaining same mile after stabilization	9,600	"	"	"
Curtailment per mile	3,200	"	"	"
Curtailment on 185 miles	592,000	"	"	"

The annual displacement was 242 men. Curtailment of expenditures at the 30-cent wage would have been $177,600, and at the 40-cent wage would have been $236,200.

Further in Mr. Faries' testimony, he found it desirable to evaluate the effect of what might be considered complete and properly balanced mechanization, using equipment now available, and to compare this with all hand labor. He said, in part:

I have, therefore, taken an assumed railroad having 1,200 miles of main track, provided with necessary ballast cars, derrick cars and similar equipment, but without any of the more modern types of maintenance of way machinery, and based upon my knowledge of average requirements, assigned the proper balanced number of the different types of machines which I would consider desirable and economical in mechanizing such a railroad. This list of machines is given on Statement 19.

During the several working periods assigned to the different machines they would displace 714 men, and this would be equal to 270 men for a complete year. The investment required to accomplish this, based upon present costs of the machines, would amount to $160,970, equivalent to an investment of $603 in maintenance of way machinery for each man displaced for an entire year and for convenience, I have used the sum of $600 for the calculations. . . .

Toward the end of his testimony, Mr. Faries gave an interesting review of the entire subject, which follows:

Reorganization of Maintenance Work

The introduction of machinery displaces labor in considerable numbers, varying with the type of machine and the size of the gang, and this, coupled with the introduction of heavier rail, better ballast, treated ties, drainage and stabilization improvements, has permitted and in fact necessitated a change in maintenance of way work organizations. Large specialized gangs with adequate machine equipment frequently take care of the bulk of the heavier work. The work of the section forces has been in many cases reduced to patrolling and inspection and what might be classed as minor running repairs. This has permitted a considerable lengthening of foremen's sections, thereby abolishing many such sections.

In the report of AREA Committee 22—Economics of Railway Labor—on the subject "Effect of Recent Developments in Maintenance of Way Practices on Gang Organization", which extended over a period of years and was concluded in Vol. 39, pages 589 to 594, there will be found many cases covering representative roads in all parts of the country indicating the justification for reorganization of forces such as I have described. The final conclusions of this committee were:

"1. The specialized gang is an economical maintenance of way unit.

2. Continued use of such gangs by any railroad, results in increased efficiency of the gangs.

3. Specialized gangs permit maximum use of power tools and best justify the investment in such tools."

In reviewing the actual experience of one railroad in the eastern district, as reported by Committee 22 in Vol. 33, pages 372, 380, a detailed assignment of man-hours displaced by the several causes involved is given. There had been a reduction of 4,385,302 man-hours per year and the major portion of this reduction was definitely assigned as follows:

Use of treated cross and switch ties	703,432	man-hours
Use of heavy rail	365,610	" "
Reduction in mechanical wear to ties and improved cross-tie distribution	317,776	" "
Change in methods of patrolling	500,000	" "
Reduction through use of specialized extra gangs	981,612	" "
Reduction in repairs to roadbed as a result of stabilization, improved ditching and similar causes	484,386	" "

The results for this road indicate the extent to which it has availed itself of the several labor displacing influences to which I have referred.

It is also of interest to quote from the AREA Manual of recommended practices. On pages 22–2 and 22–3 we find:

"Recent developments in maintenance of way practices, such as the use of improved materials and labor-saving devices, have reduced the amount of track labor required for adequate maintenance. These developments permit the transferring

Text continued on page 25.

STATEMENT 1. PORTABLE POWER TRACK NUTTERS

Cost Per Unit - Including Stores - $829.
Cost of Outfit - Consisting of 2 Machines - $1658.
Working Period 160 Days (8 Months) Per Year.

CHANGING SPLICES - (6 HOLE) 130 LB. - 200 PAIRS PER DAY

By Use of One Outfit - (2 Machines)

# Organization			
1 Foreman - Monthly Rate	$ 153.	$ 153.	$ 153.
2 Operators - Hourly Rate	.59	.59	.59
12 Laborers - Hourly Rate	.30	.35	.40
15 Men			
Wages	$7,342.	$8,110.	$8,878.
3% Federal Pension) 6%	440.	487.	533.
3% Federal Unemployment Insurance)			
Total Wages	$7,782.	$8,597.	$9,411.
Work Train Labor	-	-	-
Work Train Expense	-	-	-
Interest - 5% on $1,658.	$ 83.	$ 83.	$ 83.
Depreciation 9.9% on $1,658.	164.	164.	164.
Supplies	184.	184.	184.)
Running Repairs	386.	386.	386.)
Annual Overhaul	226.	226.	226.
Total Cost	$8,825.	$9,640.	$10,454.

By Hand

# Organization			
1 Foreman - Monthly Rate	$ 153.	$ 153.	$ 153.
20 Laborers - Hourly Rate	.30	.35	.40
21 Men			
	$8,904.	$10,184.	$11,464.
6% Tax	534.	611.	688.
....	$9,438.	$10,795.	$12,152.
10 Wrenches @ $1.50	15.	15.	15.
....	$9,453.	$10,810.	$12,167.

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF ONE OUTFIT FOR THE PERIOD - 8 MONTHS

	Force	Expenditures
At 30¢ Rate	6	$ 628.
At 35¢ Rate	6	1,170.
At 40¢ Rate	6	1,713.

# Organization	Machine	Hand
Foreman	1	1
Flagmen	2 Laborers	2 Laborers
Phoneman	1 Laborer	1 Laborer
Removing Splices	(1 Operator) (1 Laborer)	6 Laborers
Oiling Rail & Bolts	1 Laborer	1 Laborer
Applying Splices	6 Laborers	6 Laborers
Tightening Bolts	(1 Operator) (1 Laborer)	4 Laborers
	1 Foreman 2 Operators 12 Laborers	1 Foreman 20 Laborers

STATEMENT 2. RAIL POWER DRILL

Cost per Unit - $632.
Working Period - 60 days (3 months) per year.

2 Machines - Paulus Drills
Cost per Unit $66 = $132.

DRILLING HOLES FOR BOLTS - 60 HOLES PER DAY - 3600 HOLES PER YEAR

By Use of Power Drill

Organization			
1 Operator - 480 manhours - hourly rate	$.59	$.59	$.59
1 Watchman - 480 manhours - hourly rate	.30	.35	.40
2 Men			
Wages	$427	$451	$475
3% Federal Pension)			
3% Federal Unemployment Insurance) 6%	26	27	28
Total Wages	$453	$478	$503
Work Train Labor	-	-	-
Work Train Expense	-	-	-
Interest - 5% on $632	32	32	32
Depreciation - 9.9% on $632	63	63	63
Supplies	25	25	25
Running Repairs - chucks & bits	132	132	132
Annual Overhaul	25	25	25
Total Cost	$730	$755	$780

By Hand Drill

# Organization			
4 Laborers (50 holes per day) or equivalent of 5 laborers to drill 60 holes per day - 2400 manhours - hourly rate	$.30	$.35	$.40
5 Men			
	$720	$840	$960
6% Tax	43	50	58
	$763	$890	$1018
Interest - 5% on $132	7	7	7
Depreciation - 9.9% on $132	13	13	13
Supplies	-	-	-
Running repairs (72 bits at $1.63)	117	117	117
Annual Overhaul (2 drills at $10.)	20	20	20
Total Cost	$920	$1047	$1175

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF ONE RAIL POWER DRILL - FOR THE PERIOD OF 60 DAYS.

	FORCE	EXPENDITURE
At 30¢ Rate	3	$ 190
At 35¢ Rate	3	292
At 40¢ Rate	3	395

\# Hand Organization

2 Groups) One Paulus drill operated by
4 Laborers) 2 Laborers drill 25 holes per day.

STATEMENT 3. RAIL LAYING BY USE OF MACHINERY

INSTALLING 131-LB. RAIL
Working Period – 160 Days.
Production – 300 – 39 Ft. Rails, 228 Tons Per Day.

	MACHINERY					HAND				
	Man Hrs.	Man Hrs.	For Labor Rate of			Men Hrs.	Man Hrs.	For Labor Rate of		
Organization	1 Day	160 Days	.30 Per Hr.	.35 Per Hr.	.40 Per Hr.	1 Day	160 Days	.30 Per Hr.	.35 Per Hr.	.40 Per Hr.
General Foreman	8	1,280	$ 1,723.20	$ 1,723.20	$ 1,723.20	8	1,280	$ 1,723.20	$ 1,723.20	$ 1,723.20
Clerk	8	1,280	755.20	755.20	755.20	8	1,280	755.20	755.20	755.20
M.W. Repairman	8	1,280	1,113.60	1,113.60	1,113.60	-	-	-	-	-
" " Helper	8	1,280	755.20	755.20	755.20	-	-	-	-	-
Oxy-Acetylene Cutter	8	1,280	755.20	755.20	755.20	-	-	-	-	-
Foreman	48	7,680	5,606.40	5,606.40	5,606.40	80	12,800	9,408.00	9,408.00	9,408.00
Asst. Foreman	-	-	-	-	-	40	6,400	3,776.00	3,776.00	3,776.00
Engineer Work Equipment	8	1,280	947.20	947.20	947.20	-	-	-	-	-
Machine Operator	96	15,360	9,062.40	9,062.40	9,062.40	-	-	-	-	-
Laborer	992	158,720	47,616.00	55,552.00	63,488.00	1,640	262,400	78,720.00	91,840.00	104,960.00
Signalman	16	2,560	2,227.20	2,227.20	2,227.20	16	2,560	2,227.20	2,227.20	2,227.20
Signalman Helper	16	2,560	1,587.20	1,587.20	1,587.20	64	10,240	6,348.80	6,348.80	6,348.80
Total Wages	1,216	194,560	$72,149.	$80,085.	$88,021.	1,856	296,960	$102,958.	$116,078.	$129,198.
3% Federal Pension, 3% Fed. Unemployment Insurance (6%)			$ 4,329.	$ 4,805.	$ 5,281.			$ 6,177.	$ 6,965.	$ 7,752.
Total – Excl. Labor			$40,810.	$40,810.	$40,810.			$ 44,569.	$ 44,569.	$ 44,569.
GRAND TOTAL			$117,288.	$125,700.	$134,112.			$153,704.	$167,612.	$181,519.

	By Machinery	By Hand
Interest – 5%	$ 5,197.	$ 5,706.
Depreciation	6,323.	4,917.
Annual Overhaul	5,589.	3,174.
Running Repairs	3,866.	525.
Tools and Supplies	10,982.	15,338.
Commissary Cost	8,853.	14,909.
Total – Excl. Labor	$40,810.	$44,569.

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF RAIL LAYING MACHINERY

	Force	Expenditures
At 30¢ Rate	80	$36,416.
At 35¢ Rate	80	41,912.
At 40¢ Rate	80	47,407.

NOTE—Remainder of Statement 3 appears on the folded insert.

11

THE PENNSYLVANIA RAILROAD COMPANY

COMPARISON OF COST OF LAYING RAIL • USING MACHINERY VS HAND LABOR

CAPACITY 300 - 39 FT. RAILS PER DAY - 1.1 MILES OF TRACK - 228 TONS RAIL

DAILY COST

	BY MACHINE				MACHINERY COST						BY HAND				MACHINERY & TOOL COST					
	Units	No. of Men	Rate	Labor Cost	Interest	Depreciation	Annual Overhaul	Running Repairs	Supplies	Total Cost	Units	No. of Men	Rate	Labor Cost	Interest	Depreciation	Annual Overhaul	Running Repairs	Supplies	Total Cost
UNLOADING NEW RAIL AND O.T.M.																				
Work Train Labor			$	$ 26.00	$	$	$	$	$	$ 25.08			$	$ 26.00	$	$	$	$	$	$ 26.00
Work Train Expense					.61	1.03	2.06	4.83	16.57	26.00					.61	1.03	2.06	4.83	16.57	26.08
Crawler Crane	2	2	.74)	7.40	2.72	3.56	2.68	1.60	4.28	22.14	2	2	.74)	7.40	2.72	3.56	2.68	1.68	4.28	22.14
Laborers		8	.48)5/8	19.28						19.20		8	.48)5/8	19.28						19.20
Foreman		3	162.96)Day	13.03						13.03		3	162.96)Day	13.03						13.03
Laborers		23	.48)	55.20						55.20		23	.48)	55.20						55.20
Total		36	(22½ men)	119.83	3.23	4.69	4.74	6.33	20.86	169.67		36	(22½ men)	119.83	3.23	4.59	4.74	6.33	20.86	169.67
LAYING RAIL																				
Flagmen		2	.48	7.68						7.68		2	.48	7.68						7.68
Whistlemen		6	.48	23.04						23.04		9	.48	34.66						34.66
Removing Rail Anchors		1	.48	3.84						3.84		1	.48	3.84						3.84
Pulling Spikes	2	(2 (4	.69) .48)	) 24.88)	1.64	3.06	3.34	4.88.	1.05	38.66		22	.48	84.48						84.48
Pulling Missed Spikes		2	.48	7.68						7.68										
Demutting	2	2	.59	9.44	.66	1.29	1.41	2.41	.84	16.04		12	.48	46.88						46.08
Oxy-Acetylene Cutter	1	1	.59	4.72	.01	.03	.06	-	9.00	13.82										
Removing Splices		2	.48	7.68						7.68		2	.48	7.68						7.68
Throwing Out Rail		1	.48	3.84						3.84		1	.48	3.84						3.84
Removing Tie Plates		2	.48	7.68						7.68		2	.48	7.68						7.68
Removing Ballast (for Adzers)		11	.48	42.24						42.24										
Driving Down Spike Stubs		4	.48	16.36						16.36										
Setting Tie Plugs		5	.48	19.20						19.20		5	.48	19.20						19.28
Driving Tie Plugs		4	.48	15.36						16.36		4	.48	16.36						15.36
Adzing Ties	4	(4 (1	.59) .48)	22.72	2.98	5.89	7.43	6.70	6.30	52.02		32	.48	122.88						122.88
Creosoting Adzed Ties		2	.48	7.68						7.68		3	.48	11.52						11.52
Laying on Tie Plates		2	.48	7.68						7.68		2	.48	7.68						7.68
Gauging Tie Plates		2	.48	7.68						7.68		2	.48	7.68						7.68
Setting in Rail (Burro Crane)	1	(1 (3	.74) .48)	17.44	2.39	4.73	4.70	.68	2.70	32.64		18	.48	69.12						69.12
Grinding Adzer Bits	1	(1 (1	.69) .48)	8.66			.18	.60	.09	9.25		2	.48	7.68						7.68
Lubricating Rail Ends		2	.48	7.68						7.68		2	.48	7.68						7.68
Applying Splices		6	.48	23.04						23.04		6	.48	23.04						23.04
Applying Bolts	2	(2 (1	.69) .48)	13.28	.62	1.03	1.41	2.41	.84	19.49		8	.48	30.72						30.72
Gauging Rail		30	.48	115.20						116.20		30	.48	115.20						115.20
Starting Spikes		16	.48	61.44						61.44										
Driving Spikes (Compressor)	1	1	.69	4.72)																
" " (Spike Driver)	4	4	.48	15.36)	1.66	3.68	2.68	1.67	4.47	34.41		28	.48	107.52						107.52
Driving Missed Spikes		2	.48	7.68						7.68										
Applying Rail Anchors		4	.48	15.36						16.36		4	.48	15.36						16.36
Applying Bond Wires	2	(2 (2	.87) .62)	23.84	.21	.36	.10	1.69	.14	28.24		(2 (8	.87) .62)	53.60						65.60
M.W. Repairman		1	.87	6.96						6.96										
" " Helper		1	.69	4.72						4.72										
Water Boy		4	.48	16.36						15.36		6	.48	23.04						23.04
Asst. Foreman												6	.69	23.60						23.60
Foremen		6	162.96	41.70						41.70		10	162.96	69.60						69.60
General Foreman		1	237.00	10.77						10.77		1	237.00	10.77						10.77
Clerk		1	.59	4.72						4.72		1	.59	4.72						4.72
Power Rail Drill (by Nutter Operator)	1				.20	.39	.16	1.07	.42	2.24		2	.48	7.68						7.68
Totals		152		$636.16	$10.36	$20.46	$21.36	$21.91	$25.86	$736.08		232		$949.59						$949.59
LOADING OLD RAIL, O.T.M. AND SCRAP																				
Work Train Labor				26.00						26.00				25.00						26.00
Work Train Expense					.61	1.03	2.06	4.83	16.67	26.00					.61	1.03	2.06	4.83	16.67	25.80
Crawler Crane	2	2	.74)	7.48	2.72	3.66	2.68	1.60	4.28	22.14	2	2	.74)	7.40	2.72	3.56	2.68	1.68	4.28	22.14
Laborers		8	.48)6/8	19.20						19.20		8	.48)6/8	19.20						19.28
Foremen		3	162.96)Day	13.03						13.03		3	162.96)Day	13.03						13.03
Laborers		23	.48)	55.20						55.20		23	.48)	55.20						55.20
Totals		36	(22½ men)	$119.83	$ 3.23	$ 4.69	$ 4.74	$ 6.33	$28.85	$169.67		36	(22½ men)	$119.83	$ 3.23	$ 4.69	$ 4.74	$ 6.33	$ 20.86	$159.67
Commissary Cost (.364. per man)									55.33	55.33									93.18	93.18
Laundry, etc.									6.90	6.90									11.10	11.10
Fuel and Oil for Camp Train									6.60	6.60									12.08	12.00
Camp Train - 16 Bunk, 4 Utility, 4 Dinners, 1 Kitchen, 8 Box and 6 Flat Cars (35 Cars)					21.69	18.20	12.38	2.06	9.57	63.90	26 Bunk, 7 Utility, 7 Diners, 2 Kitchen, 4 Box and 2 Flat Cars (48 Cars)				36.81	29.40	16.00	3.00	15.08	100.49
Track Cars	2				.31	.63	.66	.19	1.60	3.19	3				.47	.96	.84	.26	2.26	4.79
Trailer Cars	6				.12	.24	.63			.99	8				.18	.38	1.00			1.65
Hand Tools (for 64)									19.32	19.32	Hand Tools ($6.00 per Mo.) ($ .25 per Day) for 241								65.43	65.43
Totals					$22.12	$19.07	$13.67	$ 2.25	$98.12	$156.13					$36.66	$30.73	$19.84	$3.28	$189.04	$278.66
GRAND TOTAL		197		$876.81	$36.94	$48.70	$44.41	$36.82	$165.67	$1,210.36		277		$1,189.06	$42.12	$59.91	$29.32	$16.94	$230.74	$1,547.08
COST - PER TON (EXCLUDING MATERIAL)										$5.29										$6.79
COST - PER RAIL (EXCLUDING MATERIAL)										$4.02										$6.16

Cost 1939 Labor Rate, $.48 per hour, without adding Federal Pension and Unemployment Insurance.

MACHINERY OUTFIT FOR LAYING RAIL

3	Spike Pullers	$ 4,923.	(1 Spare)
6	Portable Power Track Nutters	4,146.	(1 Spare)
6	Tie Adzers	9,620.	(1 Spare)
1	Burro Crane	7,640.	
1	Compressor - 210 cu. ft.	4,603.	
6	Air Spike Drivers	1,347.	(2 Spare)
3	Power Bonding Machines	1,311.	(1 Spare)
1	Power Rail Drill	532.	
1	Oxy-Acetylene Outfit	62.	
1	Power Grinder	100.	
	Total	$34,273.	

STATEMENT 4. BURRO CRANE

Cost of Crane - $7641. - 3/8 Yard Bucket - $382.
Cost of Outfit - $8,023.
Working Period - 180 Days (9 Months) Per Year.

MISCELLANEOUS WORK

Loading Heavy Scrap; Unloading, Loading and Laying Rail; Ditching; Distributing and Unloading Heavy Material

By Use of One Machine				By Hand			
Organization				Organization			
1 Engineer Work Equipment - Hourly Rate	$.74	$.74	$.74	1 Foreman - Monthly Rate	$153.	$153.	$153.
1 Laborer - Hourly Rate	.30	.35	.40	12 Laborers - Hourly Rate	.30	.35	.40
2 Men				13 Men			
Wages	$1,498.	$1,570.	$1,642.	Wages	$6,561.	$7,425.	$8,289.
3% Federal Pension) 6% / 3% Federal Unemployment Insurance)	90.	94.	98.	6% Tax	394.	445.	497.
Total Wages	$1,588.	$1,664.	$1,740.	....	$6,955.	$7,870.	$8,786.
Work Train Labor	-	-	-				
Work Train Expense	-	-	-				
Interest - 5% on $8,023.	$ 401.	$ 401.	$ 401.		$	$	$
Depreciation (6.6% on $7,641. ($504.) (9.9% on $382. ($38.)	542.	542.	542.				
Supplies	486.	486.	486.)	Tool -$10.00 Per Man	130.	130.	130.
Running Repairs	108.	108.	108.)				
Annual Overhaul	827.	827.	827.				
Total Cost	$3,952.	$4,028.	$4,104.	....	$7,085.	$8,000.	$8,916.

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF ONE BURRO CRANE WITH BUCKET

	Force	Expenditures
At 30¢ Rate	11	$3,133.
At 35¢ Rate	11	3,972.
At 40¢ Rate	11	4,812.

180 Day - Hand Organization
Miscellaneous

37 Days	Loading Scrap	- 1	Foreman	- 12	Laborers
22 "	Loading, Unloading & Laying Rail	- 1	"	9	"
70 "	Ditching (Straight)............	- 1	"	11	"
30 "	Ditching, Loading & Unloading...	- 1	"	19	"
21 "	Distributing Heavy Material.....	- 1	"	7	"

STATEMENT 5. AIR MECHANICAL TAMPING OUTFIT

Cost Of Air Tamping Outfit - $7,269.
Working Period - 190 Days (9 Months) Per Year.

OUT OF FACE TAMPING OF TRACK - 700 FEET PER DAY - 25 MILES PER YEAR

By Use Of Mechanical Air Tamping				Hand Tamping			
Organization				Organization			
1 Foreman - Monthly Rate	$153.	$153.	$153.	1 Foreman - Monthly Rate	$153.	$153.	$153.
1 Operator - Hourly Rate	.59	.59	.59				
12 Laborers - Tamping - Hourly Rate) 4 " - Jacks - " ") 1 Laborer-Forking Bal.- " ")	.30	.35	.40	14 Laborers - Tamping - Hourly Rate) 4 " - Jacks - " ") 1 Laborer-Forking Bal.- " ")	.30	.35	.40
19 Men				20 Men			
Wages	$10,026.	$11,318.	$12,610.	Wages	$10,041.	$11,485.	$12,929.
3% Federal Pension) 3% Federal Unemployment Insurance) 6%	602.	679.	757.	6% Tax	603.	689.	776.
Total Wages	$10,628.	$11,997.	$13,367.	....	$10,644.	$12,174.	$13,705.
Work Train Labor (Inc.Trk.Labor)	$ 27.	$ 29.	$ 31.		-	-	-
Work Train Expense	15.	15.	15.		-	-	-
Interest - 5% on $7,269.	$ 363.	$ 363.	$ 363.		$	$	$
Depreciation - 9.9% on $7,269.	720.	720.	720.				
Supplies	815.	815.	815.)	14 Tamping Picks @ $8.12	114.	114.	114.
Running Repairs	120.	120.	120.)				
Overhaul	790.	790.	790.				
Total Periodical Cost	$13,478.	$14,849.	$16,221.	....	$10,758.	$12,288.	$13,819.
Cycle of Tamping = 6 Years				Cycle of Tamping = 4 Years			
Average Cost Per Year (Labor	$ 1,771.	$ 2,000.	$ 2,228.	Average Cost Per Year	$ 2,689.	$ 3,072.	$ 3,455.
(Mach.	475.	475.	475.				
Man Hours Working Track Between) Cycles - 234 Man Hours Per Mile) Per Year For 25 Miles)	2,195.	2,466.	2,738.	Man Hours Working Track Between) Cycles - 313 Man Hours Per Mile) Per Year For 25 Miles)	2,938.	3,301.	3,664.
Total Average Annual Cost	$ 4,441.	$4,941.	$ 5,441.	....	$ 5,627.	$ 6,373.	$ 7,119.

CURTAILMENT OF FORCE AND EXPENDITURES THROUGH USE OF ONE AIR MECHANICAL TAMPING OUTFIT FOR PERIOD OF 190 DAYS

	Force	Expenditures
At 30¢ Rate	3	$1,186.
At 35¢ Rate	3	1,432.
At 40¢ Rate	3	1,678.

STATEMENT 6. PORTABLE GASOLINE DRIVEN UNIT TIE TAMPER

Cost of Outfit - 4 Units - $297. Ea. - $1188.
Working Period - 180 Days (9 Months) Per Year.

HEAVY SPOT TAMPING

SPOT TAMPING AT ROAD CROSSINGS, STATION PLATFORMS, FROGS AND SWITCHES, WATER TROUGHS, WATER PLUGS

By Use Of Gasoline Driven Tie Tamper				By Hand			
Organization				Organization			
1 Foreman - Monthly Rate	$153.	$153.	$153.	1 Foreman - Monthly Rate	$153.	$153.	$153.
1 Jackman Laborer - Hourly Rate	.30	.35	.40	1 Jackman Laborer - Hourly Rate	.30	.35	.40
4 Laborers Tamping - Hourly Rate	.30	.35	.40	6 Laborers Tamping - Hourly Rate	.30	.35	.40
6 Men				8 Men			
Wages	$3,537.	$3,897.	$4,257.	Wages	$4,401.	$4,905.	$5,409.
3% Federal Pension) 3% Federal Unemployment Insurance) 6%	212.	234.	255.	3% Federal Pension) 3% Federal Unemployment Insurance) 6%	264.	294.	325.
Total Wages	$3,749.	$4,131.	$4,512.	....	$4,665.	$5,199.	$5,734.
Work Train Labor	-	-	-		-	-	-
Work Train Expense	-	-	-		-	-	-
Interest - 5% on $1,188.	$ 59.	$ 59.	$ 59.		$	$	$
Depreciation - 9.9% on $1,188.	118.	118.	118.				
Supplies	164.	164.	164.)	6 Tamping Picks @ $8.12	49.	49.	49.
Running Repairs	313.	313.	313.)				
Annual Overhaul	124.	124.	124.				
Total Cost	$4,527.	$4,909.	$5,290.	....	$4,714.	$5,248.	$5,783.

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF ONE OUTFIT OF 4 PORTABLE GASOLINE DRIVEN TIE TAMPERS

	Force	Expenditures
At 30¢ Rate	2	$187.
At 35¢ Rate	2	339.
At 40¢ Rate	2	493.

STATEMENT 7. DITCHING IN CUTS WITH 8-TON GASOLINE-OPERATED CRANES

DITCHING IN CUTS OF LESS THAN 20 FEET IN DEPTH - 360 CUBIC YARDS PER DAY

By Using 2 Cranes With Drag Lines and 1 Bulldozer

Cost of M.W. Equipment = $22,301.
Working Period - 120 Days (6 Months) Per Year

M.W. Organization			
1 Foreman - Monthly Rate	$ 153.	$ 153.	$ 153.
2 Crane Operators - Hourly Rate	.81	.81	.81
1 Bulldozer Operator - Hourly Rate	.59	.59	.59
4 Trackmen - Hourly Rate	.30	.35	.40
8 Men			
Wages	$ 4,191.	$ 4,383.	$ 4,575.
3% Federal Pension, 3% Federal Unemployment Insurance — 6%	251.	263.	275.
Total Wages	$ 4,442.	$ 4,646.	$ 4,850.
Work Train Labor	-	-	-
Work Train Expense	-	-	-
Interest - 5%	$ 1,115.	$ 1,115.	$ 1,115.
Deprec. - (6.6% on 2 Cranes - $17,320.) (9.9% on 2 Buckets - 1,324.) (9.9% on 1 Bulldozer - 3,657.)	1,636.	1,636.	1,636.
Supplies	992.	992.	992.
Running Repairs	560.	560.	560.
Annual Overhaul	1,204.	1,204.	1,204.
Total Cost	$ 9,949.	$10,153.	$10,357.

By Using Work Train, 4 Cranes With Clam Shells & 8 Clark Dump Cars

Cost of M.W. Equipment, Excluding Work Train = $66,888.
Work Period - 120 Days (6 Months) Per Year.

M.W. Organization			
1 Foreman - Monthly Rate	$ 153.	$ 153.	$ 153.
4 Crane Operators - Hourly Rate	.81	.81	.81
20 Trackmen - Hourly Rate	.30	.35	.40
25 Men			
Wages	$ 9,788.	$10,748.	$11,708.
6% Tax	587.	645.	702.
Total Wages	$10,375.	$11,393.	$12,410.
Work Train Labor	$ 4,800.	$ 4,800.	$ 4,800.
Work Train Expense	4,800.	4,800.	4,800.
Interest	$ 3,344.	$ 3,344.	$ 3,344.
Deprec.	3,288.	3,288.	3,288.
Supplies	1,642.	1,642.	1,642.
Running Repairs	1,440.	1,440.	1,440.
Annual Overhaul	2,088.	2,088.	2,088.
Total Cost	$31,777.	$32,795.	$33,812.

CURTAILMENT OF M.W. FORCE AND EXPENDITURES BY USING 2 CRANES WITH DRAG LINES AND 1 BULLDOZER IN LIEU OF USING WORK TRAIN, WITH 4 CRANES WITH CLAM SHELL BUCKETS AND 8 CLARK DUMP CARS FOR THE PERIOD - 6 MONTHS

	M.W. Force	M.W. Wages	Machinery and Work Train Cost	Total Expenditures
At 30¢ Rate	17	$5,933.	$15,895.	$21,825.
At 35¢ Rate	17	6,745.	15,895.	22,640.
At 40¢ Rate	17	7,560.	15,895.	23,455.

STATEMENT 8. DISCER

Cost - $1242.
Working Period - 52 Days. (2½ months)

CUTTING OUT VEGETATION ON BALLAST SHOULDER - 385 MILES OF TRACK - 6.89 MILES PER DAY

By Use of Discer				By Hand			
Organization				# Organization			
1 Foreman - Monthly Rate	$153.	$153.	$153.	1 Foreman - Monthly Rate	$153.	$153.	$153.
1 Operator - Hourly Rate	.59	.59	.59	2 Asst. Foremen-Hourly Rate	.59	.59	.59
3 Laborers - Hourly Rate	.30	.35	.40	87 Laborers - Hourly Rate	.30	.35	.40
5 Men				90 Men			
Wages	$1001.	$1064.	$1126.		$11731.	$13541.	$15350.
3% Federal Pension / 3% Federal Unemployment Insurance) 6%	60.	64.	68.	6% Tax	704.	812.	921.
Total Wages	$1061.	$1128.	$1194.	....	$12435.	$14353.	$16271.
Work Train Labor	-	-	-				
" " Expense	-	-	-				
Interest - 5% on $1242.	$ 62.	$ 62.	$ 62.		$	$	$
Depreciation - 9.9% on $1242.	123.	123.	123.				
Supplies	38.	38.	38.	83 Scuffle Hoes at $.80	66.	66.	66.
Running Repairs	12.	12.	12.				
Annual Overhaul	248.	248.	248.				
Total Cost	$1544.	$1611.	$1677.	....	$12501.	$14419.	$16337.

CURTAILMENT OF FORCE AND EXPENDITURES BY THE USE OF ONE DISCER - FOR A PERIOD OF 52 DAYS

	Force	Expenditures
At 30¢ Rate	85	$10957.
At 35¢ Rate	85	12808.
At 40¢ Rate	85	14660.

Hand Organization

1 Foreman)
2 Asst. Foremen) Scuffle Hoe - Weeding
87 Laborers) Border - 6.9 Miles per Day.

STATEMENT 9. SCARIFIER AND BALLAST LEVELER

Cost - $8 097
Working Period - 85 Days (4 Months)

PLOWING SHOULDER AND INTERTRACK FOR DRAINAGE - 380 MILES - 4.47 MILES PER DAY

By Use of Scarifier — Organization				By Hand — Organization			
1 Conductor - Daily Rate	$8.10	$8.10	$8.10	4 Foremen - Monthly Rate	$153	$153	$153
1 Work Equipment Engr. - Hourly Rate	.74	.74	.74				
1 Laborer - Hourly Rate	.30	.35	.40	89 Laborers - Hourly Rate	.30	.35	.40
3 Men				93 Men			
Wages	$1 396	$1 430	$1 464		$20 604	$23 630	$26 656
3% Federal Pension) 6% 3% Federal Unemployment Insurance)	84	86	88	6% Tax	1 236	1 418	1 599
Total Wages	$1 480	$1 516	$1 552	....	$21 840	$25 048	$28 255
Work Train Labor	-	-	-				
Work Train Expense	-	-	-				
Interest - 5% on $8 097	$ 405	$ 405	$ 405		$	$	$
Depreciation - 9.9% on $8 097	802	802	802				
Supplies	209	209	209	) 89 Picks @ $67.64) 178 Shovels @ 178.00	246	246	246
Running Repairs	164	164	164				
Annual Overhaul	853	853	853				
Total Cost	$3 913	$3 949	$3 985	....	$22 086	$25 294	$28 501

CURTAILMENT OF FORCE AND EXPENDITURES BY THE USE OF ONE SCARIFIER & BALLAST LEVELER

	Force	Expenditures
At 30¢ Rate	90	$18 173
At 35¢ Rate	90	21 345
At 40¢ Rate	90	24 516

Hand Organization

1 Foreman) 1 Mile per Day Bleeding
20 Laborers) Shoulder for Drainage

STATEMENT 10. WEED BURNER

Cost - $9,354.
Working Period - 75 Days. (4 months)

BURNING WEEDS IN TRACK AND ON BALLAST SHOULDER - 803 MILES - 10.7 MILES PER DAY

By Use of Weed Burner: ¢ Organization				By Hand: # Organization			
1 Conductor - Daily Rate	$ 8.10	$ 8.10	$8.10	4 Foremen - Monthly Rate	$153	$153	$153
1 Work Equipment Engr. - Hourly Rate	.74	.74	.74	4 Asst.Foremen - Hourly Rate	.59	.59	.59
3 Machine Operators - Hourly Rate	.59	.59	.59	152 Laborers - Hourly Rate	.30	.35	.40
1 Foreman - Monthly Rate	153	153	153				
4 Laborers - Hourly Rate	.30	.35	.40				
10 Men				160 Men			
Wages	$3,445	$3,565	$3,685		$31,224	$35,784	$40,344
3% Federal Pension; 3% Federal Unemployment Insurance — 6%	207	214	221	6%	1,873	2,147	2,420
Total Wages	$3,652	$3,779	$3,906	....	$33,097	$37,931	$42,764
Work Train Labor	-	-	-				
Work Train Expense	-	-	-				
Interest - 5% on $9,354.	$468	$468	$468		$	$	$
Depreciation - 9.9% on $9,354	926	926	926				
Supplies	1,851	1,851	1,851	150 Scuffle Hoes at $.80	102	120	120
Running Repairs	128	128	128				
Annual Overhaul	790	790	790				
Total Cost	$7,815	$7,942	$8,069	....	$33,217	$38,051	$42,884

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF ONE WEED BURNER - FOR A PERIOD OF 75 DAYS

	Force	Expenditures
At 30¢ Rate	150	$25,402
At 35¢ Rate	150	30,109
At 40¢ Rate	150	34,815

¢ Weed Burner Organization

1 Engr. Work Equipment) Operate Burner
1 Machine Operator)
2 Operators - Drive Motor Car Hauling Trailers with Tanks of Water.
1 Foreman) Extinguisher Crew.
4 Laborers)

Hand Organization

4 Foremen (Scuffle Hoes
4 Asst.Foremen (Weeding Track -
152 Laborers (10.7 Miles Per Day.

STATEMENT 11. WEED MOWERS

Cost - $1821.
Working Period - 60 Days. (3 Months)

MOWING RIGHT OF WAY - 450 MILES OF TRACK - 7.5 MILES PER DAY

By Use of Weed Mower: Organization				By Hand: # Organization			
1 Foreman - Monthly Rate	$153	$153	$153	1 Foreman - Monthly Rate	$153	$153	$153
1 Operator - Hourly Rate	.59	.59	.59	1 Asst.Foreman - Hourly Rate	.59	.59	.59
2 Laborers - Hourly Rate	.30	.35	.40	32 Laborers - Hourly Rate	.30	.35	.40
4 Men				34 Men			
Wages	$1030	$1078	$1126		$5350	$6118	$6886
3% Federal Pension) 6% 3% Federal Unemployment Insurance)	62	65	68	6% Tax	321	367	413
Total Wages	$1092	$1143	$1194	....	$5671	$6485	$7299
Work Train Labor	-	-	-				
Work Train Expense	-	-	-				
Interest - 5% on $1821	$91	$91	$91		$	$	$
Depreciation 9.9% on $1821	180	180	180				
Supplies	50	50	50)	30 Scythes at $.92	28	28	28
Running Repairs	62	62	62)				
Annual Overhaul	655	655	655				
Total Cost	$2130	$2181	$2232	....	$5699	$6513	$7327

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF ONE WEED MOWER - FOR A PERIOD OF 60 DAYS

	Force	Expenditures
At 30¢ Rate	30	$3569
At 35¢ Rate	30	4332
At 40¢ Rate	30	5095

\# Hand Organization

1 Foreman)
1 Asst.Foreman) Mow 2 Swathes Wide
32 Laborers) 7.5 Miles per Day.

STATEMENT 12. POWER JACK AND POWER TAMPER

Cost of Outfit - $21,100. - 4 Power Jacks - $1,863. Ea.
2 Power Tampers $6,824. Ea.
Working Period - 160 Days (8 Months) Per Year.

REBALLASTING TRACK - 1760 FEET (1/3 OF ONE MILE) PER DAY - 53 MILES PER YEAR

Raising Track 8" On Stone Ballast - By Use of Power Jacks & Power Tampers			
Organization			
1 General Foreman - Monthly Rate	$ 237.	$ 237.	$ 237.
6 Foremen - Monthly Rate	153.	153.	153.
5 Asst. Foremen - Hourly Rate	.59	.59	.59
5 Machine Operators - Hourly Rate	.59	.59	.59
2 Engineers Work Equipment - Hourly Rate	.74	.74	.74
119 Laborers - Hourly Rate	.30	.35	.40
138 Men			
Wages	$64,382.	$71,998.	$79,614.
3% Federal Pension) 6% / 3% Federal Unemployment Insurance)	3,863.	4,320.	4,777.
Total Wages	$68,245.	$76,318.	$84,391.
Work Train Labor ($40. Per Day)	$ 6,400.	$ 6,400.	$ 6,400.
Work Train Expense ($40. Per Day)	6,400.	6,400.	6,400.
Interest - 5% on $21,100.	$ 1,055.	$ 1,055.	$ 1,055.
Depreciation - 9.9% on $21,100.	2,089.	2,089.	2,089.
Supplies (Incl. Tools $5. Per Man Per Mo.)	5,474.	5,474.	5,474.)
Running Repairs	300.	300.	300.)
Annual Overhaul	2,006.	2,006.	2,006.
Total Cost	$91,969.	$100,042.	$108,115.

Raising Track 8" On Stone Ballast - By Use Of Hand Jacks & Tamping By Hand			
Organization			
1 General Foreman - Monthly Rate	$ 237.	$ 237.	$ 237
5 Foremen - Monthly Rate	153.	153.	153.
6 Asst. Foremen - Hourly Rate	.59	.59	.59
232 Laborers - Hourly Rate	.30	.35	.40
244 Men			
	$101,635.	$116,483.	$131,331.
6% Tax	6,098.	6,989.	7,880.
....	$107,733.	$123,472.	$139,211.
Work Train Labor ($40. Per Day)	$ 6,400.	$ 6,400.	$ 6,400.
Work Train Expense ($40. Per Day)	6,400.	6,400.	6,400.
	$	$	$
Tools - $5. Per Mo. for 217 Men	8,680.	8,680.	8,680.
....	$129,213.	$144,952.	$160,691.

CURTAILMENT OF FORCE AND EXPENDITURES BY USE OF POWER JACKS AND POWER TAMPERS FOR REBALLASTING TRACK

	Force	Expenditures
At 30¢ Rate	106	$37,244.
At 35¢ Rate	106	44,910.
At 40¢ Rate	106	52.576.

STATEMENT 13. AUTO TRUCK CRANE

Cost of Auto Truck-Crane - $12,410.
Working Period - 252 Days (12 Mos.) Per Year.

BY USE OF AUTO TRUCK-CRANE

	Organization	Man Hours	Rate			
1	Chauffeur	2,016	Hourly	$ .59	$ .59	$ .59
1	(Crane Operator	933	"	.74	.74	.74
	(Crane Operator	1,083	"	.81	.81	.81
.33	Laborer (Average)	666	"	.30	.35	.40
2.33	Men	4,698				
	Wages			$2,957.	$2,990.	$3,023.
3%	Federal Pension)		6%	177.	179.	181.
3%	Federal Unemployment Insurance)					
	Total Wages			$3,134.	$3,169.	$3,204.
	Work Train Labor			-	-	-
	Work Train Expense			-	-	-
	Interest - 5% on $12,410			$ 621.	$ 621.	$ 621.
	Depreciation - 6.6% on $12,410.			819.	819.	819.
	State License (Registration)			352.	352.	352.
	Supplies			687.	687.	687.
	Running Repairs			783.	783.	783.
	Annual Overhaul			301.	301.	301.
	Total Average Annual Cost			$6,697.	$6,732.	$6,767.

BY HAND LABOR AND HAND LABOR WITH WORK TRAIN

	Organization	Man Hours	Rate			
	Foreman	1,627	Monthly	$ 153.	$ 153.	$ 153.
	(Crane Operator	328	Hourly	.74	.74	.74
	(Crane Operator	16	"	.81	.81	.81
	Laborer	19,004	"	.30	.35	.40
	T.& T. Foremen	10	Monthly	262.	262.	262.
	T.& T. Lineman	25	Hourly	.87	.87	.87
	T.& T. Linemen Helper	25	"	.63	.63	.63
10.43	Men	21,035				
				$ 7,486.	$ 8,437.	$ 9,387.
	6% Tax			449.	506.	563.
	....			$ 7,935.	$ 8,943.	$ 9,950.
				$ 1,765.	$ 1,765.	$ 1,765.
				1,765.	1,765.	1.765.

	Crawler Crane Used 83 Days	#Steam Snow Sweeper			
Interest	$361.	$145.	$ 506.	$ 506.	$ 506.
Depreciation	473.	122.	595.	595.	595.
Supplies	564.	10.	574.	574.	574.
Running Repaire	199.	71.	270.	270.	270.
Annual Overhaul	356.	50.	406.	406.	406.
Hire of Equipment:-					
Horses and Carts .... $ 91.					
Truck .... 170.					
Caterpiller Crane .... 25.			286.	286.	286.
....			$14,102.	$15,110.	$16,117.

\# Necessary for Steam Snow Sweeper (with locomotive) eliminated by use of Auto Truck-Crane with Snow Plow attached.

CURTAILMENT OF FORCE AND EXPENDITURE THROUGH USE OF ONE AUTO TRUCK-CRANE FOR PERIOD OF 252 DAYS

	Force	Expenditures
At 30¢ Rate	8	$7,405.
At 35¢ Rate	8	8,378.
At 40¢ Rate	8	9,350.

MISCELLANEOUS WORK

91 Days loading and unloading dirt, cinder, etc. ... - 1 Foreman, 14 Laborers.
40 Days ditching .... - 1 Foreman, 17 Laborers.
77 Days handling rail, frogs & switches .... - 1 Foreman, 3 Laborers, 1 Crane Operator.
12 Days loading and unloading heavy timbers or steel - 1 Foreman, 2 Laborers, 1 Crane Operator.
4 Days operating snow sweeper on street tracks .... - 1 Machinist, 1 Laborer, 1 Car Inspector.
1 Day erecting telephone poles .... - 1 Foremen, 2 Linemen, 2 Linemen Helpers.
27 Days miscellaneous hauling & delivering materials - 4 Laborers (Average)

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STATEMENT 14. USE OF HEAVIER RAIL

ANNUAL COST PER MILE OF TRACK, WITH TRAFFIC OF 16.5 MILLION GROSS TONS PER YEAR [illegible], USING 131-LB. RAIL IN LIEU OF 100-LB. RAIL

[illegible]

131 LB. RAIL

	Man Hours Labor	Materials	Pay Roll Wages 30¢ Labor	Pay Roll Wages 35¢ Labor	Pay Roll Wages 40¢ Labor	Interest	Machinery and Materials Depreciation	Machinery and Materials Annual Overhaul	Machinery and Materials Repairs	Tools & Supplies	Total 30¢ Labor	Total 35¢ Labor	Total 40¢ Labor
[illegible] Rail [illegible] Track Materials	$	$	$	$	$	$716.50	$369.72	$	$	$	$1 086.22	$1 086.22	$1 086.22
[illegible] by use of Machinery	79.[illegible]		29.15	32.69	36.18	1.84	2.21	2.02	1.36	6.64	43.22	46.76	50.25
[illegible]			2.51	2.51	2.51	.05	.10	.21	.49	1.66	5.02	5.02	5.02
[illegible] Compensation Insurance & Unemployment Insurance			1.90	2.11	2.32						1.90	2.11	2.32
Total Annual Cost - For Installation	$ 79.[illegible]	$	$ 33.56	$ 37.31	$ 41.01	$718.39	$372.03	$2.23	$ 1.85	$8.30	$1 136.36	$1 140.11	$1 143.81
1st General Working - Immediately after Installing													
[illegible] Track, Renew and Replace Crossties - [illegible] Foremen and [illegible] Laborers - 40[illegible] per day	1[illegible]3.2[illegible]		4[illegible].36	4[illegible].22	52.09					3.37	43.73	49.59	55.46
Tamp by Machine and Lining Track - [illegible] Foreman, [illegible] Operators and [illegible] Laborers - [illegible] per day	64.28		22.01	25.05	28.06	.81	1.60	1.76	.27	1.81	28.26	31.30	34.31
Work Train - Wages			.03	.03	.03						.03	.03	.03
Work Train - Expense									.01	.02	.03	.03	.03
Ballasting - Applying & Leveling 1/18 of 800 tons	16.22	40.40	5.83	6.54	7.25					.16	46.39	47.10	47.81
Work Train - Wages 1/18 day			2.22	2.22	2.22						2.22	2.22	2.22
Work Train - Expense 1/18 day						.05	.09	.18	.43	1.47	2.22	2.22	2.22
2nd General Working - 8 Years after 1st													
Work Raise Track - Renew Crossties - [illegible] Foreman and [illegible] Laborers - 6[illegible] per day	82.13		26.90	30.82	34.73					2.25	29.15	33.07	36.98
Tamp by Machine and Lining Track - [illegible] Foreman, [illegible] Operators and [illegible] Laborers - 70[illegible] per day	64.28		22.01	25.05	28.06	.81	1.60	1.76	.27	1.81	28.26	31.30	34.31
Work Train - Wages			.03	.03	.03						.03	.03	.03
Work Train - Expense									.01	.02	.03	.03	.03
Ballasting - Applying & Leveling 1/18 of 800 tons	16.22	40.40	5.83	6.54	7.25					.16	46.39	47.10	47.81
Work Train - Wages 1/18 day			2.22	2.22	2.22						2.22	2.22	2.22
Work Train - Expense 1/18 day						.05	.09	.18	.43	1.47	2.22	2.22	2.22
Joint Bar Renewals with 10% New Bars and 90% Reformed Bars - by use of Power Track Butter - [illegible] Foreman, [illegible] Operators and 12 Laborers - 200 prs. per day	9.02	32.10	3.34	3.76	4.17	.04	.08	.05	.09	.04	35.74	36.16	36.57
Grinding Rail by Rail Grinding Train - 1 Foreman, [illegible] Operators and [illegible] Grind 4.9 Miles of Track per day	1.22		1.19	1.24	1.29	.42	.79	.19	.10	1.47	4.16	4.21	4.26
3rd General Working - 8 Years after 2nd													
Work Raise Track, Renew Crossties - [illegible] Foreman and [illegible] Laborers - 60[illegible] per day	82.13		26.90	30.82	34.73					2.25	29.15	33.07	36.98
Tamp by Machine and Lining Track - [illegible] Foreman, [illegible] Operators and [illegible] Laborers - 70[illegible] per day	64.28		22.01	25.05	28.06	.81	1.60	1.76	.27	1.81	28.26	31.30	34.31
Work Train - Wages			.03	.02	.03						.03	.03	.03
Work Train - Expense									.01	.02	.03	.03	.03
Ballasting - Applying & Leveling 1/18 of 800 tons	15.22	40.40	5.83	6.54	7.25					.16	46.39	47.10	47.81
Work Train - Wages 1/18 day			2.22	2.22	2.22						2.22	2.22	2.22
Work Train - Expense 1/18 day						.05	.09	.18	.43	1.47	2.22	2.22	2.22
Joint Bar Renewals with 10% New Bars and 90% Reformed Bars - by use of Power Track Butter - [illegible] Foreman, [illegible] Operators & 12 Laborers - 200 prs. per day	9.02	32.10	3.34	3.76	4.17	.04	.08	.05	.09	.04	35.74	36.16	36.57
Grinding Rail by Rail Grinding Train - 1 Foreman, [illegible] Operators and [illegible] Grind 4.9 Miles of Track per day	1.22		1.19	1.24	1.29	.42	.79	.19	.10	1.47	4.16	4.21	4.26
Intermediate Working	234.00		82.62	93.07	103.32					6.15	88.97	99.22	109.47
			$276.31	$312.45	$348.47								
[illegible] Compensation Insurance & Unemployment Insurance			16.58	18.75	20.91						16.58	18.75	20.91
Total [illegible] Maintenance	$789.44	$185.40	$292.89	$331.20	$369.38	$3.50	$6.81	$6.30	$2.51	$27.42	$524.83	$563.14	$601.32
[illegible] Total	$868.45	$185.40	$326.45	$368.51	$410.39	$721.89	$378.84	$8.53	$4.36	$35.72	$1 661.19	$1 703.25	$1 745.13

Life of Rail - [illegible] Years (16,500,[illegible] Gross Ton Miles Per Year)
Life of Rail - 16[illegible],000,000 Gross Ton Miles

100 LB. RAIL

	Man Hours Labor	Materials	Pay Roll Wages 30¢ Labor	Pay Roll Wages 35¢ Labor	Pay Roll Wages 40¢ Labor	Interest	Machinery and Materials Depreciation	Machinery and Materials Annual Overhaul	Machinery and Materials Repairs	Tools & Supplies	Total 30¢ Labor	Total 35¢ Labor	Total 40¢ Labor
[illegible] Rail [illegible] Track Materials	$	$	$	$	$	$513.95	$457.00	$	$	$	$ 970.95	$ 970.95	$ 970.95
[illegible] by use of Machinery	142.22		52.46	58.84	65.12	3.30	3.98	2.64	2.45	11.96	77.79	84.17	90.45
[illegible]			4.51	4.51	4.51	.09	.19	.37	.87	2.99	9.02	9.02	9.02
[illegible] Compensation Insurance & Unemployment Insurance			3.42	3.80	4.18						3.42	3.80	4.18
Total Annual Cost - For Installation	142.22	$	$ 60.39	$ 67.15	$ 73.81	$517.34	$461.17	$ 4.01	$ 3.32	$ 14.95	$1 061.18	$1 067.94	$1 074.60
1st General Working	221.76		72.64	83.20	93.76					6.07	78.71	89.27	99.83
Tamp by Machine and Lining Track	115.52		39.56	45.03	50.44	1.45	2.88	3.16	.48	3.26	50.79	56.26	61.67
Work Train - Wages			.06	.06	.06						.06	.06	.06
Work Train - Expense								.01	.01	.04	.06	.06	.06
Ballasting	32.80	72.72	10.49	11.77	13.05					.29	83.50	84.78	86.06
Work Train - Wages			4.00	4.00	4.00						4.00	4.00	4.00
Work Train - Expense						.09	.16	.33	.77	2.65	4.00	4.00	4.00
2nd General Working	147.84		48.43	55.47	62.51					4.05	52.48	59.52	66.56
Tamp by Machine and Lining Track	115.52		39.56	45.03	50.44	1.45	2.88	3.16	.48	3.26	50.79	56.26	61.67
Work Train - Wages			.06	.06	.06						.06	.06	.06
Work Train - Expense								.01	.01	.04	.06	.06	.06
Ballasting	32.80	72.72	10.49	11.77	13.05					.29	83.50	84.78	86.06
Work Train - Wages			4.00	4.00	4.00						4.00	4.00	4.00
Work Train - Expense						.09	.16	.33	.77	2.65	4.00	4.00	4.00
Joint Bar Renewals	16.24	31.56	6.02	6.77	7.51	.07	.14	.10	.16	.08	38.13	38.88	39.62
Grinding Rail	2.20		2.14	2.24	2.33	.75	1.42	.35	.18	2.65	7.49	7.59	7.68
Crossties - Account of 3 Years Less Life (20-17) or 26 Ties per Mile per Year		42.64									42.64	42.64	42.64
Labor Applying 26 Ties	26.00		7.80	8.10	10.40						7.80	8.10	10.40
Intermediate Working	418.00		148.02	166.32	184.62					10.98	159.00	177.30	195.60
			$393.27	$443.62	$496.23								
[illegible] Compensation Insurance & Unemployment Insurance			23.60	26.63	29.77						23.60	26.63	29.77
Total [illegible] Maintenance	$1 129.68	$219.64	$416.87	$470.45	$526.00	$3.90	$7.64	$7.45	$2.66	$36.31	$694.67	$743.25	$803.80
[illegible] Total	$1 270.90	$219.64	$477.26	$537.60	$599.81	$521.24	$468.81	$11.46	$6.18	$51.26	$1 755.85	$1 816.19	$1 875.40

STATEMENT 15. STABILIZATION OF ROADBED

CONSTRUCTION OF IMPROVED DRAINAGE TO STABILIZE 480 LINEAL FEET OF ROADBED
LANHAM, MD.

	With Labor At 30¢ Per Hour		With Labor At 35¢ Per Hour		With Labor At 40¢ Per Hour	
Total Capital Expenditure	$3,438.		$3,532.		$3,626.	
Annual Costs Prior To Stabilization						
Track Labor - 4,576 Man Hours	$1,373.		$1,601.		$1,830.	
Track Foreman - 458 " "	337.		337.		337.	
	$1,710.		$1,938.		$2,167.	
Federal Pension 3%	51.		58.		65.	
Federal Unemployment Insurance 3%	51.		58.		65.	
	$1,812.		$2,054.		$2,297.	
Increased Tie Consumption - 23 ea. @ $1.64	38.		38.		38.	
Increased Ballast Consumption - 110 tons @ $1.00	110.		110.		110.	
Work Train Expenses	15.	$1,975.	16.	$2,218.	17.	$2,462.
Annual Costs After Stabilization						
Normal Track Labor - 1939 - 121 Man Hours	$ 36.		$ 42.		$ 48.	
Excessive TrackLabor Required - 1939 - 338 Man Hours	101.		118.		135.	
Track Foreman - 57 Man Hours	42.		42.		42.	
	$ 179		$ 202.		$ 225.	
Federal Pension 3%	5.		6.		7.	
Federal Unemployment Insurance 3%	5.		6.		7.	
	$ 189.		$ 214.		$ 239.	
Interest On Increased Capital 5%	172.		176.		181.	
Depreciation 2% On Capital Expenditure for Replacement	52.	$ 413.	53.	$ 443.	54.	$ 474.
Annual Curtailment Of Expenditure		$1,562.		$1,775.		$1,988.
Annual Curtailment Of Track Labor	4,117 Man Hours Annually or 2 Men.					
Percent Of Curtailment To Capital Expenditure	45.4%		50.2%		54.9%	

STATEMENT 16. STABILIZATION OF ROADBED

CONSTRUCTION OF IMPROVED DRAINAGE TO STABILIZE 1,335 LINEAL FEET OF ROADBED
FORT WAYNE BRANCH - M.P. 75 TO 76

	With Labor At 30¢ Per Hour		With Labor at 35¢ Per Hour		With Labor at 40¢ Per Hour	
Total Capital Expenditure.	$2,308		$2,424		$2,540	
Annual Costs Prior to Stabilization						
Track Labor 1,657 Man Hours	497		580		663	
Track Foreman - 414 " " @ $0.735	304		304		304	
	801		884		967	
Federal Pension 3%	24		27		29	
Federal Unemployment Insurance 3%	24		27		29	
	849		938		1,025	
Increased Gravel Ballast Consumption 149T @ $0.42	63		63		63	
Work Train Expenses	12	924	12	1,013	12	1,100
Annual Costs After Stabilization						
Normal Track Labor. 148 Man Hours	44		52		59	
Excessive Track Labor Required. 114 Man Hours	34		40		46	
Track Foreman - 74 Man Hours @ $0.735	54		54		54	
	132		146		159	
Federal Pension 3%	4		4		5	
Federal Unemployment Insurance 3%	4		4		5	
	140		154		169	
Interest On Capital Expenditures 5%	115		121		127	
Depreciation 2% On Capital Expenditure For Replacement	46	301	48	323	51	347
Annual Curtailment of Expenditure		623		690		753
Percentage of Curtailment to Capital Expenditure		27.0%		28.5%		29.6%

Annual Curtailment of Maintenance - 1,735 Man Hours or 0.9 Men.

STATEMENT 17. STABILIZATION OF ROADBED

ANNUAL CURTAILMENT OF EXPENDITURES RESULTING FROM STABILIZING EMBANKMENT BY INSTALLATION OF CROSS DRAINS, NEAR LONG LAKE, TEXAS. 3,065 TRACK FEET.

COST OF PROJECT - $5,250.

	30¢ LABOR	35¢ LABOR	40¢ LABOR
Before Installing Drains:			
Proportion of section gang employed equivalent of 2 men	$1,752	$1,956	$2,160
3% Federal Pension 3% Federal Unemployment Insurance } 6%	105	117	130
Total	$1,857	$2,073	$2,290
After Installing Drains:			
Proportaion of section gang employed, equivalent of 0.4 men	$ 292	$ 340	$ 389
3% Federal Pension 3% Federal Unemployment Insurance } 6%	18	20	22
Interest - 5%	263	263	263
Depreciation (30 years life)	175	175	175
Total	$ 748	$ 798	$ 849
ANNUAL CURTAILMENT OF EXPENDITURES	$1,109	$1,275	$1,441

STATEMENT 18. STABILIZATION OF ROADBED

ANNUAL CURTAILMENT OF EXPENDITURES RESULTING FROM STABILIZING 1-1/2 MILES OF ROADBED BY DRIVING POLES NEAR BEAUMONT, TEXAS.

COST OF PROJECT - $5,500.

	30¢ LABOR	35¢ LABOR	40¢ LABOR
ANNUAL MAINTENANCE COST BEFORE STABILIZING:			
Assistant Foreman - 1 at $91.80	$1,102	$1,102	$1,102
Laborers - 3	2,203	2,570	2,938
Total wages	$3,305	$3,672	$4,040
3% Federal Pension 3% Federal Unemployment Insurance } 6%	198	220	242
Total	$3,503	$3,892	$4,282
ANNUAL MAINTENANCE COST AFTER STABILIZING:			
Proportion of regular section gang maintaining same section of track equivalent of 0.75 men	$ 551	$ 643	$ 734
3% Federal Pension 3% Federal Unemployment Insurance } 6%	33	38	44
Interest - 5%	275	275	275
Depreciation (30 years life)	183	183	183
Total	$1,042	$1,139	$1,236
ANNUAL CURTAILMENT OF EXPENDITURES	$2,461	$2,753	$3,046

STATEMENT 19. A TYPICAL MAIN TRACK RAILROAD

1 200 Miles Main Track

No. of Machines	Requirement Type	Days operated in one year	Cost	Interest	Depre- ciation	Supplies and repairs	Operating cost and fixed charges	Men displaced	Man days
6	Power track nutters	160	$ 4 974	$ 249	$ 492	$ 2 388	$ 3 129	18	2 880
2	Power rail drills	60	1 264	64	126	364	554	6	360
.	Rail laying - 4 tie adzers only	120	7 616	358	707	2 452	3 517	35	4 200
.2	Burro cranes	180	16 046	802	1 084	2 842	4 728	22	3 960
8	Air tamping outfits	190	58 152	2 904	5 760	13 800	22 464	24	4 560
20	Unit tie tampers	180	5 940	295	590	3 005	3 890	10	1 800
2	Drag line crane and 1 bulldozer	120	22 301	1 115	1 636	2 756	5 497	17	2 040
2	Discers	52	2 484	124	246	596	966	170	8 840
1	Scarifier	85	8 097	405	802	1 226	2 433	90	7 650
1	Weed burner	75	9 354	468	926	2 769	4 163	150	11 250
2	Weed mowers	60	3 642	182	360	1 534	2 076	60	3 600
4	Power jacks and 2 power tampers	160	21 100	1 055	2 089	7 780	10 924	106	16 960
	Total		$160 970				$64 341		68 100

255 working days per year on 5-day week basis:

$\frac{68\ 100}{255}$ 267 total men displaced by above mechanization.

$\frac{160\ 970}{267}$ 603 or for each $603 invested in M. W. machinery one man will be displaced.

Continued from page 7.

of the heavier routine maintenance work from section gangs to specialized gangs equipped with modern labor-saving machinery, with large resulting economies.

"The economy derived through the use of such equipment as motor cars, weed killers, rail cutting and building-up devices, tie tampers, rail layers, ditchers and locomotive cranes, has been demonstrated and their use is recommended."

From Page 22–4 we quote:

"The use of heavy rail in heavy-traffic, high-speed lines reduces the amount of labor necessary to maintain a given standard of track excellence.

"This reduction is both direct and indirect. The items affected directly include line, surface, gage, joint maintenance and laying rail. The items affected indirectly include tie renewals, cleaning ballast and ballast renewals."

The foregoing quotations have been selected for the purpose of illustrating the economic value of mechanization. All of the testimony having a direct bearing upon the controversial question—the effect of increasing wages upon employment—has been omitted.

It should be added that, although all but two of the statements here reproduced represent Pennsylvania Railroad experience, Mr. Faries' subcommittee checked these with similar data obtained from a number of other railroads and with reports appearing in AREA Proceedings during recent years. The statements used were found to approximate average experience closely.

Your committee feels that the matter here related represents a fair picture of mechanization. Unfortunately, it was impossible to include every type of equipment, but sufficient examples were included by Mr. Faries to demonstrate clearly the fact that large economies have been effected by those railroads that have used such equipment intensively.

Report of the

Joint Committee on Standard Specifications for Concrete and Reinforced Concrete

Submitting

Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete

Affiliated Committees of the

American Concrete Institute
American Institute of Architects
American Railway Engineering Association
American Society of Civil Engineers
American Society for Testing Materials
Portland Cement Association

Submitted to Constituent Organizations, June, 1940

TABLE OF CONTENTS

Foreword

The report of the Joint Committee is a very valuable document designed to cover specifications for every phase of concrete and reinforced concrete construction in widely divergent fields and, while within its scope it necessarily includes the design and construction of structures for railway purposes, it does so only in a general way without emphasis of the specific problems entering into the features entailed in such design. The report is more of the type of a master specification and recommended practice which may form a basis for any particular specification to cover specified types of structures such as those required for locomotive loadings. Viewed in that light, it serves as an excellent guide for the formulation of a specification for concrete masonry structures for railway uses.

This report is presented to the Association as information.

COMMITTEE 8—MASONRY

Preface

For more than thirty years the design and building of concrete and reinforced concrete structures have been guided and deeply influenced by the work of Joint Committees as expressed in their reports.

These committees have been composed of members appointed by national engineering and technical organizations which were primarily interested in a safe and sound development of the use of concrete. The reports indicate broadly the progress that had taken place during preceding years and reflect the developments in the art in recommended practice and specifications.

The periods represented are clearly indicated in the reports. The first Joint Committee was organized in 1904, a time which marks approximately the beginning of reinforced concrete construction in this country. At that time concrete construction was principally in the hands of a few specialists whose methods varied with their experience. But by 1916, when that committee submitted its final report, a great quantity of test data and an extensive literature had been accumulated which found expression in the recommendations of the committee.

The first Joint Committee organized the available information into a code of practice based on fundamental principles and concerned itself with details only insofar as it was necessary to indicate the limits of sound practice. The essence of the first report is embodied largely in the sections on design which crystallized engineering practice and served as the basis for building code and specification requirements throughout the country.

The second Joint Committee, organized in 1920, was charged with the duty of preparing standard specifications for concrete and reinforced concrete, using as a basis the former Joint Committee report, with such modifications as were necessary to make its recommendations agree with current practice and such new data as marked progress in the art. The report submitted in 1924 in specification form indicated that a considerable advance had taken place in the method of producing concrete. The improvements had developed to the point where variability in the quality of concrete could be reduced by means of preliminary strength tests and controlling the quantity of mixing water through the control of the slump. The compressive strength of concrete could now be estimated with a reasonable degree of accuracy. On the basis of this improvement the committee recommended a general increase in the ratio of working stress to ultimate strength of the concrete and permitted a corresponding increase in the steel stress where high yield point steel could be used. By standardizing grades of materials, methods of producing concrete, and the details of design procedure, the newly acquired knowledge could be utilized and concrete construction placed on a more definite basis. The committee completed its report after a series of field tests had demonstrated that its recommendations were substantially justified.

The present, or third Joint Committee, was organized in 1930 to study the extent and character of the advances in knowledge since the 1924 report, and make such recommendations with respect to practice and standard specifications as might be warranted in view of recent developments.

Of the advances made in recent years, relating to concrete as a material, the most significant are the increase in the strength of cement, a more widespread understanding of the basic principles of mixtures with increasing attention to field control, and an increasing use of ready-mixed concrete.

In the field of design, the major development has been the increased interest in rigid frame analysis which recognizes the essentially monolithic character of reinforced concrete construction and provides a more accurate method of stress computation and hence a more uniform factor of safety.

With these possible improvements in the quality of concrete and the new tools which elastic frame analysis places in the hands of the designing engineer, very material advances in reinforced concrete construction are now possible. In this report, the committee has attempted to provide a means of applying this new knowledge through the combination of recommended practice and standard specifications.

The committee was organized at a meeting held in Atlantic City, June, 1930, at which time there were present duly appointed representatives from the American Society of Civil Engineers, the American Society for Testing Materials, the American Railway Engineering Association, the American Concrete Institute, and the Portland Cement Association. In December, 1932, the American Institute of Architects was added to the group of organizations associated in the work of the Joint Committee.

The Joint Committee has held seventeen general meetings and numerous working committee meetings in the intervals between the general meetings. The reports of the working committees have been formally presented to the general committee for action in detail and the material has been assembled and edited by a committee appointed for that purpose.

In view of the extensive changes in form and substance of the report, as compared with those of the 1924 report, the committee deemed it desirable to submit its work for criticism and discussion. To this end a progress report was given a limited circulation and presented for general discussion at a meeting in New York of the American Concrete Institute, February 26 and 27, 1937. The discussion brought out at that meeting and a considerable volume of written comments directed to the committee have been carefully considered and such changes made in the report as seemed justified.

The last, or seventeenth, meeting of the Joint Committee was held in Atlantic City on June 27 and 28, 1938. At the conclusion of this meeting there still remained uncompleted a few items concerned with design and one on the general treatment of the chapter on Waterproofing and Protective Treatments. The completion of these items and some major and minor changes in the text have been accomplished through one meeting of the Working Committee on Design and by the efforts of the editorial committee through correspondence and personal interviews with members of the Joint Committee. Revisions of Chapters 6 and 8 to which major additions and changes were made were approved by the working committees responsible for these chapters. These revised chapters and appendices, and other miscellaneous revisions of the text, were submitted to letter ballot of the 29 members of the Joint Committee on December 27, 1939. Twenty-six members returned ballots. The revised chapters and appendices received substantial majorities. Some of the members, however, indicated reservations with respect to individual sections or appendices, but the report as a whole was accepted by the unanimous vote of the 26 members returning ballots.

The committee submits this report, not as the final word on concrete design and construction, but with a feeling that it reflects fairly the state of the art as represented by the best practice of the day.

Respectfully submitted,

A. E. LINDAU, *Chairman.*

F. E. RICHART, *Vice-Chairman*
F. R. MCMILLAN, *Secretary–Treasurer*
J. G. AHLERS
P. H. BATES
H. P. BIGLER
A. J. BOASE
J. H. CHUBB
M. N. CLAIR
H. G. FARMER
CHARLES M. GAY
H. J. GILKEY
A. T. GOLDBECK
M. HIRSCHTHAL
S. C. HOLLISTER
J. B. HUNLEY
F. H. JACKSON
CLARENCE A. JENSEN
A. R. KETTERSON
CHARLES W. KILLAM
J. F. LEONARD
L. S. MOISSEIFF
B. MOREELL
PAUL W. NORTON
C. L. POST
N. M. STINEMAN
M. A. SWAYZE
STANTON WALKER
L. W. WALTER

June, 1940

A

Representation of Constituent Organizations

American Society of Civil Engineers

W. A. Slater, *Chairman (June 1930 to October 1931, deceased);* Director, Fritz Engineering Laboratory, Lehigh University *(Chairman of Joint Committee, June 1930 to October 1931)*

A. E. Lindau, Consulting Engineer, Chicago *(Succeeded Mr. Slater as Chairman of A.S.C.E. group and of Joint Committee, October 1931)*

M. N. Clair, Vice-President, Thompson and Lichtner Co., Inc., Boston

H. J. Gilkey *(appointed June 1932),* Head, Dept. Theoretical & Applied Mechanics, Iowa State College

C. L. Post *(appointed June 1932),* Chairman, Advisory Committee on Engineering, Federal Works Agency, Public Buildings Administration, Washington, D. C.

F. E. Richart, Research Professor of Engineering Materials, University of Illinois

W. S. Thomson *(resigned June 1932),* Chief Engineer, Kalman Steel Co., Chicago

American Society for Testing Materials

P. H. Bates, *Chairman;* Chief, Clay and Silicate Products Division, National Bureau of Standards, Washington, D. C.

H. P. Bigler *(appointed April 1938),* Director, Rail Steel Bar Association, Chicago

C. M. Chapman *(resigned June 1932),* Consulting Engineer, New York City

A. T. Goldbeck, Engineering Director, National Crushed Stone Association, Washington, D. C.

E. E. Hughes *(resigned April 1938),* President, Rail Steel Bar Association, Chicago

L. S. Moisseiff, Consulting Engineer, New York City

Stanton Walker *(appointed January 1932),* Director, Engineering and Research Division, National Sand and Gravel Association, Washington, D. C.

Portland Cement Association

F. R. McMillan, *Chairman;* Director of Research, Portland Cement Association, Chicago

D. A. Abrams *(resigned June 1932),* Consulting Engineer, New York City

Ernest Ashton *(resigned June 1931),* Vice-President, Lehigh Portland Cement Co., Allentown, Pa.

A. J. Boase *(appointed March 1937),* Manager, Structural Bureau, Portland Cement Association, Chicago

J. H. Chubb, Manager, Service Bureau, Pennsylvania–Dixie Cement Corp., New York City

H. G. Farmer, Technical Service Director, Universal Atlas Cement Co., New York City

J. C. Pearson *(appointed June 1931, resigned March 1937),* Director of Research, Lehigh Portland Cement Co., Allentown, Pa.

M. A. Swayze *(appointed June 1932),* Chief Research Engineer, Lone Star Cement Corp., Hudson, N. Y.

American Concrete Institute

S. C. Hollister, *Chairman;* Dean, College of Engineering, Cornell University

J. G. Ahlers, Ahlers Construction Co., New York City

F. H. Jackson, Senior Engineer of Tests, Public Roads Administration, Washington, D. C.

REAR ADMIRAL B. MOREELL (C.E.C.) U.S.N., Chief, Bureau of Yards and Docks, Navy Dept., Washington, D. C.

N. M. STINEMAN, Editor, *Concrete*, Chicago

American Railway Engineering Association

C. P. RICHARDSON, *Chairman (resigned June 1933);* Engineer, Capital Expenditures, C. R. I. & P. Railway, Chicago

M. HIRSCHTHAL, Concrete Engineer, D. L. & W. Railroad, Hoboken, *(Succeeded Mr. Richardson as Chairman, June 1933)*

J. B. HUNLEY, Engineer Structures, N. Y. C. Railroad, Chicago

A. R. KETTERSON, Engineer of Bridges, Canadian Pacific Railway, Montreal

J. F. LEONARD, Engineer, Bridges and Buildings, Pennsylvania Railroad, Pittsburgh

L. W. WALTER *(appointed June 1933),* Inspecting Engineer, Erie Railroad, Jersey City

American Institute of Architects

PAUL W. NORTON, *Chairman;* Consulting Engineer, Boston

J. C. BOLLENBACHER *(deceased 1939),* Architect, Chicago

CHARLES M. GAY *(appointed May 1936),* Associate Director, Franklin Institute, Philadelphia

CLARENCE A. JENSEN, Architect, Chicago

CHARLES W. KILLAM *(appointed June 1934),* Professor Emeritus, Department of Architecture, Harvard University

A. T. NORTH *(deceased 1933),* Architect, New York City

F. LEO SMITH *(deceased 1935),* Secretary, Structural Bureau, American Institute of Architects, Washington, D. C.

Committee Organization

A. E. LINDAU, *Chairman* F. E. RICHART, *Vice-Chairman*
F. R. MCMILLAN, *Secretary–Treasurer*

Executive Committee

A. E. Lindau, *Chairman*
P. H. Bates
M. Hirschthal
F. R. McMillan, *Secretary*
S. C. Hollister
P. W. Norton

The work of the committee has been organized by the appointment of the following working committee personnel:

1. Cement and Aggregates

F. H. JACKSON, *Chairman*
A. T. GOLDBECK, *Vice-Chairman*
J. B. HUNLEY, *Secretary*
*D. A. ABRAMS
*ERNEST ASHTON
P. H. BATES
*C. M. CHAPMAN
C. A. JENSEN
*J. C. PEARSON
M. A. SWAYZE
STANTON WALKER
L. W. WALTER

2. Metal Reinforcement

L. S. MOISSEIFF, *Chairman*
H. P. BIGLER
S. C. HOLLISTER
***E. E. HUGHES
J. B. HUNLEY

* Resigned. ** Deceased. *** Resigned; since deceased.

J. F. Leonard
A. E. Lindau
**A. T. North

3. Proportioning and Mixing
F. E. Richart, *Chairman*
*D. A. Abrams
J. G. Ahlers
M. N. Clair, *Secretary*
H. J. Gilkey
A. T. Goldbeck
F. H. Jackson
C. A. Jensen
A. R. Ketterson, *Vice-Chairman*
F. R. McMillan
B. Moreell
**W. A. Slater
M. A. Swayze
Stanton Walker
L. W. Walter

4. Forms and Placing
H. G. Farmer, *Chairman*
M. N. Clair, *Secretary*
J. G. Ahlers
J. H. Chubb
J. B. Hunley
C. L. Post
*C. P. Richardson
N. M. Stineman

5. Design
S. C. Hollister, *Chairman*
F. E. Richart, *Vice-Chairman*
N. M. Stineman, *Secretary*
A. J. Boase
H. J. Gilkey
M. Hirschthal
A. R. Ketterson
Chas. W. Killam
A. E. Lindau
F. R. McMillan
L. S. Moisseiff
B. A. Moreell
Paul W. Norton
C. L. Post
**W. A. Slater
***W. S. Thomson

6. Details of Construction and Fireproofing
J. F. Leonard, *Chairman*
J. G. Ahlers, *Vice-Chairman*
H. P. Bigler
**J. C. Bollenbacher
J. H. Chubb
Chas. M. Gay
S. C. Hollister
***E. E. Hughes
Chas. W. Killam
L. S. Moisseiff
Paul W. Norton
C. L. Post
**F. Leo Smith
***W. S. Thomson

7. Waterproofing and Protective Treatment
*Ernest Ashton
P. H. Bates
*C. M. Chapman
H. G. Farmer, *Secretary*
Chas. M. Gay
M. Hirschthal
Chas. W. Killam
B. Moreell
**A. T. North
*J. C. Pearson
C. L. Post
*C. P. Richardson
**F. Leo Smith

8. Surface Finishes
J. H. Chubb, *Chairman*
N. M. Stineman, *Secretary*
P. H. Bates
**J. C. Bollenbacher
*C. M. Chapman
H. G. Farmer

9. Form of Specification
All Chairmen of Working Committees

* Resigned. ** Deceased. *** Resigned; since deceased.

Introduction

In submitting its report, the committee thinks that it should not depend entirely on the specification form for presenting its recommendations. It believes that in covering those subjects on which the information is sufficiently crystallized, some advantage is gained by having the recommendation in the form of definite specifications. The report, therefore, consists of two interdependent parts: Recommended Practice and Standard Specifications. These two must be considered jointly as representing the recommendations of the committee. Some of the more important departures from the 1924 report are as follows:

Materials.—The recommendations provide for the use of high early strength cement and recognize that special cements may be desirable for special uses.

The subject of aggregates is treated much more comprehensively than was possible in the specifications of 1924. A working specification for general application is submitted with suggestions for modifications where necessary to meet special requirements.

The use of lightweight aggregates and the classification of aggregates on the basis of fire resistance are included.

Proportioning.—Emphasis is placed on durability of concrete. The increased strength of cement and improvement in concrete technology make it possible to produce concrete having a strength sufficient for ordinary design purposes with a water content too high for many types of exposure. The committee is of the opinion that a classification or grading of concrete based on the character of exposure will be more generally useful than if based on the common requirements of minimum strength. Special emphasis is also placed on those factors which affect workability and the production of dense, homogeneous concrete.

Alternate Specifications.—Two types of specifications covering the proportioning of concrete are presented: One, in which the contractor is required to produce concrete of a specified quality (exposure and strength considered) with considerable freedom of procedure within certain limits; and the other, in which the engineer specifies the proportions required, including a minimum cement content. Where the strength is specified the test procedure is given together with a basis for enforcement of the strength requirements.

New Developments in the Art.—Developments such as ready-mixed concrete, mechanical vibration, and new methods of transporting, are covered either as recommendations or in the specifications.

Design.—The committee has given special consideration to the increasing use of the principle of continuity and the elastic frame analysis in the design of reinforced concrete structures. Since reinforced concrete construction is essentially monolithic in character, it is felt that these newer methods are not merely refinements, but an attempt to produce a more rational and better balanced design. Several well recognized methods of frame analysis are available to the designer and approximate methods have been developed that permit their use in ordinary building design without an undue amount of computation.

Columns.—The column provisions take into account the results of researches not available when the 1924 report was published, particularly the American Concrete Institute column investigation reported in the Proceedings of the Institute, 1930–1933. The safe loads on columns are based on the ultimate strength of the concrete and the yield point strength of the longitudinal reinforcement, including in the calculations the full gross area of the column. Spirals are not given consideration in computing the safe loads unless they are present in an amount sufficient to provide an increase in the ultimate strength of the core equal to or greater than the ultimate strength added by the shell surrounding the core. When present in this amount, the toughness, added by the spiral in event that the shell spalls or fails, is recognized by an increase in the safe load 25 percent over that for colunms without this full amount of spiral.

Flat Slabs.—The section dealing with flat slabs has been somewhat expanded with respect to details incident to this type of construction, but has not been altered in the basic design requirements. Since no new test data have been available, the committee has retained the principal limitations of the 1924 report. The formulas for slab thickness have been simplified and so modified as to apply to concrete of any 28-day strength.

Two-Way Slabs.—For the design of two-way slabs, the committee has adopted a method which recognizes the elastic plate action as a dominant factor in moment distribution and stress intensity. Considering the limitations of theory and the available test data, however, the committee has placed principal emphasis on the simplicity of application.

Design Formulas.—The standard formulas for rectangular and T-beams and standard notations have become so widely recognized that they are omitted from the report.

Recommended Practice for Use of Concrete and Reinforced Concrete

Chapter I—Scope and Definitions

101. Scope

This report is intended to cover the use of concrete and reinforced concrete in general. In such structures as arches, tanks, reservoirs, chimneys, etc., where specialization relates principally to the mechanics of design and details of construction, the general provisions of the report may be applied with the modifications necessary to suit the special conditions.

102. Definitions

No attempt is made here to define all the terms current in concrete technology. Only those expressions which have particular application to the report and are not thoroughly established in the literature are included.

Anchorage.—That portion of a reinforcing bar, and any attachment thereto, designed to resist pulling out or slipping of the bar when subjected to stress.

Bleeding.—The escape of water from freshly placed concrete, commonly observed as an accumulation upon a horizontal surface.

Cantilever Retaining Wall.—A reinforced concrete wall having a vertical section and a base, each of which resists by cantilever action the pressure to which it is subjected.

Buttressed Retaining Wall.—A retaining wall with brackets or buttresses on the side opposite the pressure face uniting the upright section with the toe of the base.

Columns.—A compression member, vertical or nearly vertical, the height of which exceeds three times its least lateral dimension.

Column Capital.—In flat slab construction, the head or uppermost portion of a column or pilaster, designed and built to act as a unit with the column and the slab.

Column Strip.—A portion of a flat slab or two-way panel embracing the area over the column, usually one-half panel in width, used for convenience in distributing the bending moments in the slab.

Combination Column.—A column in which a structural steel section, designed to carry the principal part of the load, is wrapped with wire and encased in concrete of such quality that some additional load may be allowed.

Composite Column.—A reinforced concrete column with a core of structural steel or cast iron, in which the core is designed to carry a portion of the column load.

Consistency.—A general term used to designate the relative mobility of freshly mixed concrete or mortar.

Counterforted Retaining Wall.—A reinforced concrete wall with brackets or ribs on the pressure side of the vertical wall and designed to act with it in resisting overturning and sliding.

Creep.—See Plastic Flow.

Deformed Bar.—Reinforcement bar with projections, shoulders or lugs on the surface of the bar formed during rolling.

Diagonal Band.—A group of reinforcing bars placed parallel to one of the diagonals of a panel in a flat slab reinforced in four directions.

Direct Band.—A group of reinforcing bars placed parallel to the edge of a panel in a flat slab reinforced in four directions.

Drop Panel.—The structural portion of a flat slab which increases the thickness of the slab in the area surrounding the column capital.

Effective Area of Reinforcement.—The area obtained by multiplying the normal cross-sectional area of the reinforcement by the cosine of the angle between its direction and the direction for which the effectiveness is to be determined.

Effective Depth of Beam.—The distance from the compression face to the centroid of the area of the tensile reinforcement.

Fineness Modulus.—An empirical factor obtained by taking 1/100 of the sum of the percentages of a sample of aggregate retained on each of a specified series of sieves. The sieves used are No. 100, 50, 30, 16, 8, 4, 3/8-in., 3/4-in., 1½-in., and larger, increasing in the ratio of 2 to 1.

Flat Slab.—A concrete slab reinforced in two or more directions without beams or girders to transfer the loads to supporting columns.

Honeycomb.—A surface or interior defect in a concrete mass characterized by the lack of mortar between the coarse aggregate particles.

Laitance.—Extremely fine material of little or no hardness which may collect on the surface of freshly placed concrete or mortar, resulting from the use of excess mixing water.

Middle Strip.—The middle portion of a flat slab or two-way panel, usually one-half panel in width, and symmetrical with respect to the center line of the panel, used for convenience in distributing the bending moments in the slab.

Modular Ratio.—The ratio of the modulus of elasticity of steel to that of concrete.

Pedestal.—A compression member, generally vertical, whose height does not exceed three times the least lateral dimension.

Pipe Column.—A steel pipe filled with concrete.

Plastic Flow.—The inelastic deformation in concrete resulting from the continued application of load.

Ratio of Reinforcement.—The ratio of the effective area of the reinforcement to the effective area of the concrete at any section of a structural member.

Saturated and Surface Dry.—A term used to describe the condition of an aggregate in which the pores of all the particles are completely filled with water, but their surfaces are free from moisture.

Slump.—The shortening of a standard test mass of freshly mixed concrete, used as a measure of consistency in accordance with the standard method.

Strut.—A compression member other than a column or pedestal.

Stiffness Factor.—The value obtained by dividing the moment of inertia of a member by its length.

Vibration.—A method of compacting concrete by mechanically producing wave motion of high frequency in the concrete.

Chapter II—Materials

201. General

The recommendations of this committee covering the quality of materials—cements, admixtures, water, aggregates and reinforcing steel—are embodied in the accompanying specifications. The following comments indicate the basis and limitations of the specification requirements.

202. Cement

(a) In the case of normal Portland cement and high early strength Portland cement, reference is made to the current ASTM Specifications C 9–38 and C 74–39. No specifications are recommended for cements for various special purposes other than where high early strength is required. Although a number of specifications are now in use covering such special requirements as low heat of hydration, sulphate resistance, etc., the committee feels that it should refrain from sponsoring any specifications of this nature until they have received the endorsement of the American Society for Testing Materials, which is the affiliated body usually relied upon to sponsor national standards in this field. Until such standards are available, the Engineer should satisfy himself either by means of his own tests or by reference to reliable sources of information that the material which he proposes to use will adequately fulfill his special requirements.

(b) Specifications for special cements, when required, should be inserted in Sec. 203–S of the specifications.

203. Admixtures

(a) The committee considers that the benefits to be derived from the use in concrete of other than the essential ingredients (cement, aggregates, and water) depend so much upon the conditions surrounding the individual project that it is virtually impossible to write an adequate general specification for these materials. This applies particularly to admixtures which are employed for the purpose of promoting workability. The desirability of using an admixture as well as the amount to be used depends greatly on the characteristics of the essential ingredients, especially aggregate grading, as well as on the proportions in which they are to be combined. Before permitting the use of an admixture the Engineer should inform himself thoroughly as to the advantages or disadvantages to be derived from its use considering both quality and economy. He should determine definitely the effect of the proposed admixture on the strength, volume change, durability, and density of the concrete. The possibility of securing the desired results in other ways, such as by the use of additional cement, better aggregate gradation, closer water control during construction, etc., should be investigated.. The committee recognizes that admixtures, under certain conditions, may impart desirable characteristics which cannot be secured as economically by other methods. However, it should be emphasized that the use of admixtures cannot be considered a panacea for any of the ills which result from ignoring the fundamental principles governing the making of good concrete.

(b) Specifications for admixtures, when required, should be inserted in Sec. 204–S of the specifications.

204. Water

The mortar strength test is intended to assure the use of mixing water of satisfactory quality from the standpoint of concrete strength. The test may be waived in cases where the water to be used is of known satisfactory quality. Practical experience as well as results of laboratory investigations indicate, in general, that any water which can be safely used for drinking purposes will be satisfactory for use in concrete.

Aggregates

205. General

In preparing its aggregate specifications the committee has utilized, insofar as possible, the specifications of the federal government and the existing standards of such specification writing bodies as the American Society for Testing Materials, the American Association of State Highway Officials, and the American Railway Engineering Association. Attention is directed particularly to the fact that in the case of many of the requirements for quality two test limits are shown, a recommended limit and an outside permissible limit. This arrangement is in recognition of the fact that specifications for such locally occurring materials as aggregates must be based, to a certain extent, upon the available material. The recommended limit should be specified in all cases where it is economically practicable to secure materials conforming thereto. When it is considered necessary to use aggregates not meeting the recommended limits, less restrictive limits may be specified, but this fact should be recognized in the design of the concrete mixture and in the control of the concrete during construction. In no case should limits beyond the maximum permissible values indicated be specified.

206. Fine Aggregate Grading

Attention is called to the fact that the relatively wide range in grading which is shown in Sec. 208–S, should be permitted only when it is economically impracticable to obtain materials meeting more restrictive requirements. The most desirable grading will depend upon the type of work and class of concrete. For the leaner mixes, or when a small size coarse aggregate is used, in cases where the degree of workability is important, it is desirable to further restrict the allowable ranges in sizes shown in Sec. 208–S so as to insure a grading approaching the maximum percentage passing each sieve. On the other hand, for the richer mixes, in the interest of maximum strength and economy, a grading as coarse as is consistent with the requirements for workability should be specified. However, in no case should a range in grading be specified more restrictive than indicated below:

Passing No. 16 sieve—range 20 percent or less
Passing No. 50 sieve—range 15 percent or less
Passing No. 100 sieve—range 5 percent or less

207. Coarse Aggregate Grading

The requirements for size of coarse aggregate specified in Sec. 215–S are those recommended by the Joint Technical Committee of the mineral aggregates associations. They have been adopted for use in certain federal specifications and by the American Association of State Highway Officials and as Simplified Practice Recommendation R 163–39 of the Division of Simplified Practice of the Department of Commerce. The sizes seem to cover adequately the usual requirements for concrete. The grading limitations also are believed to be reasonable from the standpoint of both producer and consumer. The committee recommends that these sizes, with the corresponding grading limits, be used wherever it is practicable to do so.

208. Deleterious Substances

The requirements covering deleterious substances as given in Sec. 210–S and 216–S are, of necessity, quite general. Broadly speaking, the term "deleterious substances," as applied to aggregates, includes any material contained therein which will adversely affect the quality of the concrete in any way. This would include a great variety of materials such as shale, unsound chert, coal, ochre, excessively flat or elongated fragments, etc., coatings of various kinds which would affect the bond, and materials which would adversely affect the hardening of the cement. Except for certain general limits which are recognized in most specifications, reliance must be placed upon the judgment of the Engineer based on past experience with the types of material which will be encountered and with due regard to the economic considerations involved. With these considerations in mind, the Engineer should list in Sec. 210–S and 216–S the additional deleterious substances which in his judgment should be controlled, together with appropriate limits, based wherever possible upon recognized test procedures, reference to which should be made in Sec. 229–S.

209. Soundness

When the concrete is to be exposed to the weather and other destructive agencies, care should be exercised to select aggregates of durability adequate for the degree of exposure. As indicated in Sec. 213–S and 217–S of the specifications, principal reliance should be placed on service records, when adequate information in that regard is available. In the absence of such information, the accelerated soundness test specified in Sec. 213–S and 217–S should be utilized. Methods for accelerated soundness tests involving controlled freezing and thawing in the laboratory and the use of salts, principally magnesium sulphate ($MgSO_4$) and sodium sulphate (Na_2SO_4), to simulate freezing and thawing, have been used. The committee has suggested the accelerated soundness test using sodium sulphate (Na_2SO_4) and has recommended requirements based on a relatively limited amount of information resulting principally from experience in climates where considerable freezing and thawing is encountered.

210. Lightweight Aggregates

Comparatively limited experience in the field of lightweight aggregates justifies a more conservative specification at the present time than may be desirable later, particularly in those cases where exposure to wear and weather are not major factors. Therefore, practically no concession is made for this type of aggregate in the general aggregate requirements other than that of lower compressive strength in the mortar strength test. It is suggested, however, that coarse aggregate weighing less than normal aggregates and more than 55 lb. per cu. ft. (recommended as the maximum weight for lightweight aggregates), and meeting all requirements for lightweight aggregates except weight, may be used where lightweight concrete is permissible when in the opinion of the Engineer the weight requirement may be waived.

211. Aggregates—Fireproofing

(a) Coarse aggregates for use in fireproofing have been divided into two classifications in recognition of differences in behavior when subjected to high temperatures. In general, Group 1 includes aggregates predominating in materials which change in volume a relatively small amount when exposed to high temperatures, and cinders low in combustible materials; Group 2 includes aggregates containing substantial proportions of particles which change in volume a relatively large amount when exposed to high temperatures, and cinders containing combustible material in excess of the desirable minimum.

(b) The dividing line between the two groups is, necessarily, somewhat arbitrary, but it is believed that it has been drawn as accurately as available data permit. That there is a difference in the ability of concrete made with different aggregates to resist high temperatures is evident from information available; how important these differences are to the protection of life and property is not so readily evaluated. It should be emphasized that adequate fireproofing can be obtained with the materials in either group so long as the differences in their characteristics are taken into account in the design of the concrete.

(c) The classification of the different types of aggregate is consistent with that in the "Recommended Minimum Requirements for Fire Resistance in Buildings" outlined in the Report of the Department of Commerce Building Code Committee, although the limitation on percentage of siliceous particles is more rigid. The committee believes that the recommendations outlined in Sec. 225–S, when considered in connection with those in Sec. 505, offer a conservative basis for the selection of coarse aggregates for fireproofing.

212. Resistance to Abrasion

Typical requirements covering wear resistance of coarse aggregates for use in concrete subject to surface abrasion are included. There are no generally recognized tests for measuring the hardness or abrasive resistance of fine aggregates. The committee recognizes that, under certain circumstances, fine aggregates possessing high resistance to wear are essential and recommends that, in such cases, the general clause covering fine aggregates (Sec. 207–S) be amplified by the Engineer to include a description of the desired characteristics.

Metal Reinforcement

213. General

(a) The principal requirements in the selection of metal reinforcement are the yield point, the bond value, and the ductility.

(b) The advantage of high yield point steel has been recognized for many years, and is self-evident in view of the fact that the yield point of the reinforcement practically determines the ultimate strength of both flexual and compression members.

(c) In ordinary commercial grades of steel, a high yield point is generally accompanied by a decrease in ductility. The balance, therefore, between a high yield point and satisfactory ductility has developed the difference of opinion that exists as to the grade of steel to be used. The relative importance of these qualities depends on the character and service conditions of the structure. The choice of the grade of steel, therefore, becomes a matter of engineering judgment.

214. Bond

The tendency toward increase in unit stresses and the use of high strength concrete emphasizes the need for higher and more dependable bond resistance than that obtained by the use of plain bars. In the absence of standard specifications for acceptable types of deformed bars it has been the practice to permit an increase of 25 percent in bond value of deformed over that of plain bars. This increase in bond resistance to be useful should be developed at very small values of end slip in pull-out tests.

215. Ductility

The necessary ductility in metal reinforcement is that which permits fabrication by cold-bending without indication of fracture or reduction in tensile strength. The practical test for ductility is the cold-bend test in the various specifications. Material that complies fully with the bend test is sufficiently ductile for fabrication purposes.

216. Recommended Sizes

The following standard sizes listed in the U. S. Department of Commerce Simplified Practice Recommendation R26–30, are recommended:

Sizes	Area sq. in.	Weight lb. per ft.
¼" round	.05	.167
⅜" round	.11	.376
½" round	.20	.668
½" square	.25	.850
⅝" round	.31	1.043
¾" round	.44	1.502
⅞" round	.60	2.044
1" round	.79	2.670
1" square	1.00	3.400
1⅛" square	1.27	4.303
1¼" square	1.56	5.313

Chapter III—Proportioning, Mixing, Curing, and Testing Concrete

301. General

The recommendations of this committee, covering proportioning, mixing, curing, and testing concrete, are embodied in the succeeding paragraphs and in the accompanying specifications.

302. Basis for Specification

(a) There are two distinct views with respect to the function of the Contractor which cannot be reconciled in a single specification. Under one of these it is assumed that the function of the Contractor is to contribute his skill as a concrete technician as well as his ability in handling construction equipment and materials. Under the other it is assumed that the Contractor's function is purely that of a builder and that the Engineer, who prepares the plans and specifications, is the concrete technician. Obviously, the manner of specifying the quality of the concrete and how it shall be controlled will not be the same under these two assumptions. The committee, therefore, presents alternate specifications covering the sections on proportioning and concrete quality.

(b) Under Alternate A the Engineer establishes the general limitations of strength and water content within which the Contractor is permitted considerable latitude in the choice of materials and the methods of handling them. The Contractor is required to produce a plastic and workable concrete of the required strength and water content that can be placed without segregation or honeycomb. Under this alternate the Contractor assumes the responsibility for the quality. If the concrete is lacking with respect to any of the above qualities, he must make good the deficiency at his own expense.

(c) Under Alternate B the Engineer designates in detail the quantities of material to be used, the length of mixing time, amount of water, range in slump, etc., and to this extent is responsible for the quality of the concrete. Changes in quantities or types of materials can be made only on the order of the Engineer and then adjustment of compensation will be required under the clauses covering extra compensation or credit in the contract. The Engineer, on behalf of the owner, is responsible for the adequacy of the specification.

(d) In using the accompanying specification, the Engineer must designate which of the alternates is to be used, and fill in the necessary tables with the specific information

required for the project. The recommendations of the committee bearing on the points involved will be found in the succeeding paragraphs.

303. Requirements of Concrete for Various Conditions of Exposure

(a) Since the publication of the 1924 report there has been considerable development in the technology of concrete in which special emphasis has been placed on properties other than compressive strength, particularly durability and watertightness. These properties, it has been shown, are controlled principally by the same factors which control compressive strength; namely (for aggregates and cement of given quality) by the relative proportions of cement and water and the extent to which adequate curing is provided. Studies have also shown that for durability, concrete when finally in place must be free from any honeycomb or other defects which permit the entrance of water. The recommendations of this committee, therefore, are built around the control of the water content and curing and those factors which influence workability of the concrete and the methods of placing and compacting.

(b) In Table 1 are given recommended water contents which are suitable for concrete intended for various conditions of exposure. These are based on the assumption that the concrete will be plastic and workable, and placed and compacted in such manner that a dense, homogeneous mass will be obtained. They also presume that the concrete will be sufficiently protected from loss of moisture and from low temperatures to insure that proper hardening will develop.

304. Specified Strengths and Water Contents—Alternate A

(a) Alternate A is based on a dual control in which both a minimum strength and a maximum allowable water content are specified. It puts on the Contractor full responsibility for the strength, consistency, and water-cement ratio. The strengths to be inserted in Table A, Sec. 301–SA of the specifications, are intended to be those meeting the requirements of the design calculations. As required in the specifications (Sec. 302–SA) the Contractor must submit mixtures which he proposes to use for the different classes of work together with a laboratory report showing that these mixtures will produce the strengths specified and do not exceed the maximum allowable water contents. The method of making the tests and the range of mixtures are covered by the specification.

(b) The maximum allowable water contents to be inserted in Table A, are those meeting the exposure requirements which in the judgment of the Engineer will be required for the several portions of the work. The values to be inserted in Table A can be obtained from Table 1. It may frequently happen that the water content which will meet the particular exposure requirements will correspond to a strength of concrete in excess of that upon which the design calculations were based. Likewise, it may be found that to meet the strength requirements will require a water content even lower than that needed for the exposure.

(c) To avoid a multiplicity of concrete mixes on a given project, a series of mixes, such as shown in Table 2, is recommended. The eight mixes shown provide for the entire range of exposures covered in Table 1. The strengths shown for the different water contents represent those now commonly obtained with normal Portland cement. For important work it is recommended that a similar table be drawn up based on tests of the materials available for the project. Such tests should be carried out as specified in Sec. 321–S to 325–S.

305. Specified Mixtures—Alternate B

(a) Alternate B is a specification based primarily on a designated cement content, but in which there is also specified a maximum water content, a maximum size of aggre-

TABLE 1—WATER CONTENTS SUITABLE FOR VARIOUS CONDITIONS OF EXPOSURE (GAL. PER SACK OF CEMENT)

Type or Location of Structure	*Severe or Moderate Climate, Wide Range of Temperatures, Rain and Long Freezing Spells or Frequent Freezing and Thawing*					*Mild Climate, Rain or Semi-Arid, Rarely Snow or Frost*				
	Thin Sections		*Moderate Sections*		*Heavy and Mass*	*Thin Sections*		*Moderate Sections*		*Heavy and Mass*
	Reinf.	*Plain*	*Reinf.*	*Plain*	*Sections*	*Reinf.*	*Plain*	*Reinf.*	*Plain*	*Sections*
A. At the waterline in hydraulic or waterfront structures of portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged:										
In sea water	5		5½		6	5		5½		6
In fresh water	5½		6		6½	5½		6		6½
B. Portions of hydraulic or waterfront structures some distance from the waterline, but subject to frequent wetting:										
By sea water	5½		6		6	5½		6½		7
By fresh water	6		6½		6½	6		7		7½
C. Ordinary exposed structures, buildings and portions of bridges not coming under above groups	6		6½		7	6		7		7½
D. Complete continuous submergence:										
In sea water	6		6½		7	6		6½		7
In fresh water	6½		7		7½	6½		7		7½
E. Concrete deposited through water	*	*	5½		5½	*	*	5½		5½
F. Pavement slabs directly on ground:										
Wearing slabs	5½	6	*		*	6	6½	*		*
Base slabs	6½	7	*		*	7	7½	*		*

G. Special cases:
(a) For concrete exposed to strong sulfate ground waters, or other corrosive liquids or salts, the maximum water content should not exceed 5-gal. per sack. See Sec. 609.
(b) For concrete not exposed to the weather, such as the interior of buildings and portions of structures entirely below ground, no exposure hazard is involved and the water content should be selected on the basis of the strength and workability requirements.

* These sections not practicable for the purpose indicated.

gate, a range in slump, and a range in percentage of fine aggregate. The other items to be filled in Table B (Sec. 301–SB) are purely informative and not to be confused with specified values. It is strongly recommended that the Engineer, whenever practicable, make preliminary tests of available materials in order to determine the values to be inserted in Table B.

(b) Where it is impracticable to make preliminary tests, and a specification along the lines of Alternate B is to be adopted, the mixes in Table 3 are suggested. The values in Table 3 are for a concrete of a medium consistency (4-in. slump). The quantities of cement indicated will need to be changed if other consistencies are to be entered in Table B. Since the quantities in Table 3 are all approximate, it will be sufficiently accurate to modify the cement content in accordance with the following: For each 1-in. difference in slump, change the cement factor ⅛ sack per cu. yd., increasing this factor for slumps greater than 4 in. and reducing it for slumps less than 4 in.

(c) When tests are being made to determine the quantities and proportions of materials to use in Table B, the weights specified in columns 8 and 9 should be based on the known specific gravities of the aggregates to be used. When these data are supplied from Table 3, it should be recognized that the approximate quantities given in columns 6, 7, and 8 are based on bulk specific gravity of 2.65 in a saturated and surface-dry condition. For aggregates of different specific gravities the approximate weights should be multiplied by the ratio of actual specific gravity to the assumed value of 2.65.

TABLE 2

Class of Concrete	*Maximum Allowable Net Water Content Gal. Per Sack of Cement*	*Probable Minimum Allowable Compressive Strength at 28 Days p. s. i.*
	5	5000
	5½	4500
	6	4000
	6½	3600
	7	3200
	7½	2800
	8	2500
	8½	2000

(d) It should be pointed out further that in the use of Alternate B the various classes of concrete are determined either by tests or by selection from data such as are given in Table 3. Where the tests are to be made the Engineer will arrive at his own values of strengths for various water contents and should select his concrete classes accordingly. Where Table B in the specification is to be filled out from Table 3, it must be understood that the strengths indicated are based on normal Portland cement and aggregates meeting the requirements of these specifications determined in a manner specified in Sec. 321–S to 325–S. If other than normal Portland cement is to be used, these values will not apply.

(e) Particular attention is called to the differences between Table 3 and Table 2. The latter is intended for use where the Contractor has assumed full responsibility for the quality of the concrete and where regular tests will be made to assure that the intended strengths are secured. Table 3, on the other hand, is compiled merely as suggested values to be used when actual data for the materials at hand are lacking. Because of this, the strength values indicated for the different water contents are purposely made conservative.

TABLE 3

Max. Size Coarse Agg. in.	Estimated 28-Day Comp. Str. p. s. i.	Cement Factor, Sacks Cement per cu. yd. Freshly Mixed Concrete	Max. Water per Sack Cement gal.	Fine Agg. % Total Agg. (See Note A Below)	Approx. Wts. Saturated Surface-Dry Agg. per Sack of Cement—lb. (See Note B below) Total	Fine Agg.	Coarse Agg.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	2250	4.9	8	40–46	660	280	380
2	2250	4.5	8	37–43	740	300	440
3	2250	4.1	8	34–40	840	310	530
1	2750	5.6	7	39–45	570	240	330
2	2750	5.1	7	36–42	640	250	390
3	2750	4.7	7	33–39	720	260	460
1	3000	6.0	6½	38–44	520	210	310
2	3000	5.5	6½	36–42	590	230	360
3	3000	5.1	6½	34–40	660	240	420
1	3300	6.5	6	37–43	470	190	280
2	3300	6.0	6	35–41	530	200	330
3	3300	5.5	6	33–39	600	220	380
1	3700	7.2	5½	36–42	420	160	260
2	3700	6.7	5½	34–40	470	170	300
3	3700	6.2	5½	32–38	530	180	350
1	4250	8.0	5	35–41	370	140	230
2	4250	7.4	5	33–39	420	150	270
3	4250	6.8	5	31–37	470	160	310

NOTE A—The limits shown in Col. (5) are approximate and percentages falling outside of the limits shown may frequently be found necessary to produce concrete of the desired workability. When expressed in terms of absolute volume they are applicable to aggregates of different specific gravities; when expressed in terms of weight, differences in specific gravity should be taken into account.

NOTE B—The approximate weights in columns (6), (7), and (8) are based on a bulk specific gravity of 2.65 in a saturated surface-dry condition.

306. Use of High Early Strength Portland Cement

Both Alternates A and B carry provisions for the use of high early strength cement (309–SA and 306–SB). These are based on the assumption that the 3-day and 7-day strengths for the high early strength cement concrete are equivalent, respectively, to the 7 and 28-day strengths for the normal Portland cement concrete. When the materials to be used show other relationships, these of course should be specified.

307. Consistency and Size of Aggregate

(a) The consistency of the concrete and the maximum size of aggregate to be used will be dependent upon the conditions prevailing at each individual job. The factors which will govern are: The available materials, size of the member, quality of concrete to be produced, arrangement of reinforcement, and the manner of transporting and placing the concrete. Decision in respect to these items should be made with the requirements of plasticity and workability clearly in mind. In structures, where the exposure will be severe, it is of utmost importance that the plasticity and workability of the concrete be such that it can be placed and compacted without honeycomb or other defects which will permit the entrance of water.

(b) Table 4 gives suggested aggregate sizes and consistencies suitable for several different classes of work. See Sec. 504–506 and 854 for recommendations regarding embedment and spacing of reinforcement.

Table 4

Portion of Structure	Consistency-Slump Maximum in.	Consistency-Slump Minimum in.	Maximum Size of Coarse Aggregate in.
Reinforced foundation walls and footings	5	2	1½
Plain footings, caissons and substructure walls	4	1	2
Slabs, beams, and reinforced walls	6	3	1
Building columns	6	3	1
Pavements	3	2	2
Heavy mass construction	3	1	3 to 6*

* In making the slump test, all aggregate larger than 2 inches should be screened out of the mixture.

(c) When high frequency mechanical vibration is used for compacting concrete, the limiting consistencies in Table 4 will need to be modified. When properly applied, mechanical vibration permits the use of stiffer consistencies than are possible under hand placing. For a given water content, therefore, leaner mixtures, that is, lower cement factors, can be utilized when this method of placing is employed. Generally, the ratio of fine to coarse aggregate should be reduced where high frequency mechanical vibration is employed. See Sec. 404 for Recommended Practice on Placing Concrete by Vibration.

308. Ready-Mixed Concrete

(a) Sec. 313–S and 315–S require that the maximum size of batch which may be placed in a truck mixer or agitator shall be in accordance with the "specified rating." In general, the manufacturer's rating should be used, since it takes into account the strength and balance of the entire mechanism as well as its efficiency as a mixer or agitator. However, experience with equipment now in general use shows that the rated capacities should not exceed the following percentages of the gross volume of the drum:

1. Truck mixers performing the entire mixing operation (see Sec. 313–S)
   (a) Top-door loading .... 50 percent
   (b) End-door loading ....57½ percent
2. Truck mixers completing the mixing of concrete partially mixed at central plant (see Sec. 314–S) ....66⅔ percent
3. Agitators or truck mixers used for transporting mixed concrete (see Sec. 315–S) .... 80 percent

Frequently, the manufacturer's ratings are less than the limits given above because of factors other than mixing efficiency.

(b) In Sec. 315–S, a period of 1½ hours within which delivery of ready-mixed concrete must normally be made is specified. This is based on the results of research which have shown that a period of 1½ hours between the beginning of mixing and the completion of the discharge of the batch results in no detrimental effects on the concrete. The data indicate that under specially favorable conditions periods up to 2 and 3 hours may be allowed. Experience has shown that with certain soft aggregate greatly prolonged mixing will result in a decrease in size of aggregate particles and a corresponding increase in the proportion of fine material. When air temperatures are unusually high, or the ingredients of the concrete mixture are such that an unusually quick time of set or loss of plasticity may occur, it may be necessary to specify periods shorter than 1½ hours to insure that no damage be done to the concrete. The exact period will depend

upon the materials being used and the prevailing temperatures. It is unlikely, except under the most unusual circumstances, that it will be necessary to specify a period of less than 1 hour.

309. Curing

(a) The protection of concrete against low temperatures and loss of moisture during the period immediately after placing is an important factor in the development of both strength and durability in concrete. Sec. 318–S in the specifications requires that the concrete be protected to prevent loss of moisture from the surface and to prevent temperatures at the surface from going below 50 deg. F. for periods of 7 days where normal Portland cement is used, and 3 days where high early strength Portland cement is used. In fixing these limits it is recognized that under average conditions, curing of concrete does not cease immediately upon removal of the protection against loss of moisture. Where the conditions are severe, as, for example, thin sections in hot dry air or low temperatures, it may be desirable to increase somewhat the protection periods specified.

(b) The committee recognizes that under the specification requirement in Sec. 318–S some doubt may arise as to the methods which will be acceptable. It is not prepared, however, to offer more specific recommendations, but it does suggest the following methods which have been used to achieve the desired end with varying degrees of success:*

(1) Surface remaining in contact with the forms.

(2) The surfaces of slabs protected by ponding.

(3) Covering with burlap or cotton mats kept continuously wet.

(4) Covering with paper of suitable type.

(5) Covering with one-inch layer of thoroughly wet sand, earth, or sawdust.

(6) Covering with six-inch layer (loose) of thoroughly wet straw, hay, or similar material.

(7) Continuous sprinkling of the exposed surfaces.

310. Field Tests

(a) The sections in the specifications referring to field tests (320–S to 325–S) are intended primarily for use with Alternate A under which the Contractor assumes responsibility for the strength of concrete being produced. While the tests are to be made at the expense of the owner and entirely under the supervision of the Engineer, the clauses are included in the specification so that there will be a definite understanding as to the methods by which the quality of the concrete being produced is to be judged.

(b) Where a specification along the lines of Alternate B is used such explicit directions for making the tests are not necessary. However, there seems to be no good reason for omitting these detailed clauses in such case.

311. Field-Cured Specimens

(a) The question may arise as to why the specifications for Field Tests of Concrete (Sec. 320–S to 325–S) call for the curing of specimens in the laboratory, rather than in the field. The committee takes the position that under the conditions prevailing in most structures it is practically impossible to store specimens in the field in such a manner that their strength can be assumed to represent accurately the strength of the

* The committee also calls attention to the specifications for curing Portland cement concrete adopted by the AREA in March, 1936, which carry very definite requirements for protection against low temperatures and loss of moisture. These specifications are reproduced in Appendix 4.

concrete in the structure. An exception is noted in the case of pavement slabs in which a procedure, described in *(d)* below, is used that gives reliable indications as to the strength of the concrete.

(b) Under such a specification as Alternate A, the quality of concrete being placed in the usual type of structure can only be judged on the basis of specimens stored in accordance with standard laboratory procedure.

(c) Field-cured specimens may give information of value as to the curing conditions prevailing on the job, but the results must be interpreted with caution, and under no circumstances should they be used to determine compliance with the requirements of a strength specification of the type covered by Alternate A.

(d) As noted above, it is quite common practice in the construction of concrete pavements to use the results of tests of field-cured beam specimens to determine the age at which it will be safe to open the road to traffic. The usual practice is as follows: After removal from the molds at the end of 24 hours the specimens are bedded on the subgrade alongside the pavement and the sides banked with earth, leaving only the surfaces exposed. Every care is taken to give the surfaces of these beams exactly the same curing treatment as the pavement. A sufficient number of specimens is made each day to permit testing at various ages until the results show that the concrete has attained the required flexural strength. The tests are ordinarily made on the job, using one of the several types of portable beam testing machines on the market.

312. Enforcement of Strength Requirements

Any contract in which concrete of a definite strength is specified should contain some provision outlining the procedure to be followed in case it is discovered after portions of the structure are completed that the concrete fails to comply with the requirements. The objection to a strength specification has largely been based on the absence of such provisions. Sec. 326–SA to 328–SA in the specifications are intended to cover this contingency. These sections should be stricken out if Alternate B Specification is adopted.

Chapter IV—Forms and Placing

401. General

Except for the following special cases the recommendations of the committee are embodied in the specifications.

402. Pneumatic Placing of Concrete

(a) In order to obtain the best results with equipment now available the following general rules should be observed:

(1) The placing equipment should be located as close to the point of deposit as practicable, and the concrete should be conveyed from the mixer with as little segregation as conditions will permit.

(2) The volume of concrete at each discharge of the gun, in general, should not exceed 7 cu. ft. Distances from gun to nozzle greater than 1,000 ft. should be avoided. The general slope of the discharge line may vary from a horizontal to a vertical direction, but in no case should it be inclined downward.

(3) The position of the nozzle should be such that the concrete is directed to the point of deposit without impinging directly on the reinforcement, and without excessive rebound of material.

(4) Concrete of a medium consistency gives the best results. Sloppy mixes are unsatisfactory.

(b) When this method is being used cores should be drilled at appropriate intervals for tests to determine whether the concrete being placed is of the desired quality.

403. Pumping Concrete

(a) The pumping equipment, the charging hopper, and the devices used at the outlet of the pipe should be such that concrete of the specified quality and consistency can be transported and delivered in the forms without segregation. The devices used at the outlet of the pipe—deflectors, spouts, hose connections, swivel-mounted elbows, elephant trunks, etc.,—should be selected to meet the particular requirements of the job.

(b) The pump should be able to produce a working pressure of at least 300 lb. per sq. in., and the pipe line and fittings should be designed to resist approximately double this pressure.

(c) The pipe line should be laid with as few bends as possible, and changes in direction should be accomplished preferably with bends 45 deg. or less. Ninety-degree bends should be used only where they are unavoidable.

(d) Where it is necessary to lay the pipe with a downhill grade, a choke should be used at the discharge end to keep a continuous flow of concrete in the line. For vertical pumping, a shut-off valve should be placed in the lower line to prevent backflow when pumping is stopped, or when making pipe changes or cleaning at the end of a run.

(e) Concrete having a slump of two inches or more can be handled easily by pumping—irrespective of the character and type of coarse aggregate, that is, whether round or angular. For workable mixes of less than two-inch slump, gravel concrete pumps more easily than crushed stone concrete. With concrete having 4.5 sacks or less cement per cubic yard the quality and grading of sand is important for successful pumping. For such concrete, sand with a relatively high percent of fines that will hold water and prevent "bleeding" is desirable.

(f) A shut-down of half an hour usually will not prevent the starting of the pump and the delivery of the concrete in good condition. The permissible limit of a shut-down with a full charge of concrete in the line will depend on temperature conditions and the rate of stiffening or hardening of the concrete.

(g) Immediately before concreting is begun the empty pipe line should be flushed with water and a charge of thin grout placed ahead of the concrete to properly lubricate the line. About one cubic foot of grout should be used for each 1,000 sq. ft. of inside surface area of pipe line and a plug or "go-devil" should be used just ahead of the grout to force out any free water.

(h) At the end of a run a "go-devil" should be forced through the pipe line to clean out the concrete.

(i) Job experience with pumping equipment suggests the use of the following sizes of pipe, maximum sizes of coarse aggregate, and slump of concrete for maximum pumping distances.

Pipe Size in.	*Slump of Concrete in.*	*Maximum Pumping Distance—ft.*		*Maximum Size Material (Passing Screen Size—in.)*
		*Horizontal**	*Vertical* **	
8	Not less than 1	1000	100	3
7	Not less than 1	800	100	2½
6	Not less than 3	600	100	2

* A 90-deg. elbow is estimated to be equivalent to 40 ft. of horizontal piping.
** Not over 200 ft. of pipe, actual.

404. Placing by Vibration

(a) The use of vibration for compacting and placing concrete is comparatively new, and differences of opinion exist as to the best methods, particularly as to frequency,* methods and position of application, amplitude,* length of time of vibration, force of blow (related to the size of vibrator), and the area or volume of concrete over and through which vibration is effective. It is desirable, therefore, that the supervising personnel, as well as the operators of the vibrating equipment, be experienced.

(b) Vibration imparts no new properties to concrete. However, its use permits economies or improvement in the quality of the concrete through the use of stiffer and harsher mixtures with lower water content than is possible with the usual methods of placement. The consistency of the concrete should be adjudged to the particular conditions of placement and equipment in use. The concrete should not be so dry as to make placement difficult, nor so wet as to produce a fluid condition on the surface of the concrete. In general, vibration should not be used when the slump of concrete exceeds three inches except as an aid in placing under difficult conditions.

(c) All jobs on which the use of vibration is new should start with a mixture which can be placed readily by the usual methods. The quantity of cement, water, and proportion of fine to coarse aggregate should then be adjusted gradually until the mixture has the desired placeability. This will generally require a readjustment in the ratio of fine to coarse aggregate, usually an increase in the percentage of coarse aggregate. Where economy is desired the total volume of the aggregates should be increased. Where improved quality is desired, the water-cement ratio should be reduced.

(d) Where excessive bleeding occurs which cannot be readily corrected by adjusting the mixture, the percentage of sand finer than the No. 50 sieve should be increased.

(e) Vibration should not be applied directly or through the reinforcement to sections or layers of concrete which have hardened to the degree that the concrete ceases to become plastic under vibration. Vibration should not be continued at any one point to the extent that localized areas of grout are formed.

(f) One of the evidences of sufficient vibration is the appearance of a line of cement paste at the junction of the concrete and the forms, or the concrete and surface of the steel reinforcement. When the decrease in volume of the concrete is no longer apparent the vibration has been sufficient.

(g) Vibration should not be used to make concrete flow in the forms over distances so great as to cause segregation.

(h) Vibration is applied to the concrete in various ways, depending upon the type and size of member being cast and whether applied in the field or in the shop. It is applied to the forms generally for sections of walls, columns, floor slabs, and precast units too small for operating vibrators of the internal type. Both internal vibrators and platform vibrators are used for compacting concrete in massive structures. A table vibrator is used for making cast stone or concrete products. For pavement work a vibrating screed is used.

(i) Vibration increases pressure on the forms which should therefore be designed for the higher pressures and greater strains on ties and supports. Proper precautions should be taken to prevent leakage of mortar through joints in the form work during vibration.

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* Frequency—The number of complete oscillations per minute.

Amplitude—The maximum displacement of a vibrating body from its mean position; that is, half of an oscillation.

Oscillation—A complete cycle of movement of a vibrating body.

405. Number and Size of Vibrators Required

(a) The factors which govern the selection of type, number, and size of vibrators are the following:

Depth and area of section.
Size of batch.
Number of batches per hour.
Size of aggregate.
Amount and spacing of reinforcement.
Proportions, particularly the respective amounts of fine and coarse aggregate and the consistencies of the mixtures.

(b) The number and size of vibrators of whatever type used should be such as to insure vibration throughout the entire volume of concrete to be vibrated. Application of vibrators should be at points uniformly spaced and not farther apart than the radius over which vibration is visibly effective. The vibration should be such that the concrete becomes uniformly plastic.

406. Pneumatically Applied Mortar

(a) Construction utilizing pneumatically applied mortar has been in the hands of a few organizations specializing in this field and utilizing equipment produced by a very limited number of manufacturers. The type of construction has been in use for many years and considerable advance in technique and equipment has been made during that period, but there is still considerable divergence in procedure between the different users. The purpose of this section is to provide a resumé of accepted practice as supplementary to the general specifications.

(b) The results obtained in pneumatically applying mortar depend to a large extent on the skill of the operator and the work should be done only by experienced men.

(c) Two types of equipment are available, single or double chamber. The single chamber type is operated intermittently, and is adaptable to small jobs only. The double chamber type which can be operated continuously is the most common type in use.

(d) The grading of the sand is important in obtaining high strength and density. The sand should be passed through a ⅜-in. sieve and have a fineness modulus of 3.0 or less. Stone sand subject to the same grading limitations as natural sand gives satisfactory results.

(e) The proportions of cement to sand for various purposes should range from 1 part cement to 3 parts sand to 1 part cement to 4½ parts sand, in terms of dry and loose volumes. The mortar in place will have a somewhat lower proportion of sand because of the loss due to rebound.

(f) Control of the water content is important for pneumatically placed mortar in order to obtain proper placement. The water content should be such that a very slight film of water will form on the surface of the applied material. Insufficient water results in dry porous spots and excess water causes low strength and slipping of the mortar.

(g) The air and water pressure should be maintained uniform. The water pressure should be at least 15 lb. per sq. in. higher than the air pressure which should be sufficient to give proper velocity to the material leaving the nozzle. To avoid excessive impact the air pressure should not exceed 75 lb. per sq. in.

(h) The sand should be neither excessively dry nor wet—about four percent moisture by weight is desirable. Sand and cement should be thoroughly premixed by machine as very little mixing takes place during the application.

(i) The velocity of the material that leaves the nozzle should be maintained uniform and should be such as to produce a minimum of rebound of the sand. The nozzle should be held between three and four feet from the surface being covered and should be kept moving to obtain a uniform coating.

(j) Special care should be taken in the removal of forms and in the curing to avoid cracking of the thin sections. Placing at temperatures below 50 deg. F. should not be attempted unless adequate facilities are available for keeping the mortar above 50 deg. during and after placing. The surface to which mortar is applied should be free from frost.

(k) Shooting strips should be used at corners, edges, and on surfaces where necessary to obtain true lines and proper thickness. The surface of the mortar may be "steel floated" when a very smooth finish is desired.

(l) The placement equipment should be thoroughly cleaned whenever work is to be stopped for a period in excess of 30 min.

(m) The position and size of reinforcement where required and the thickness of coating varies with the use of the pneumatically applied mortar and should be within the limitations given below. Square reinforcement bars should not be used.

Use	*Reinforcement*	*Thickness*
Encasement of Steel	Galvanized welded fabric 2 x 2—No. 12 and No. 12 or 3 x 3—No. 10 and No. 10 bent to templet, and securely fastened to the steel at ¾ in. from steel.	1½ to 2 in. placed in two layers, second is ⅛ in. thick.
Floor, Wall and Roof Slabs	Rods and galvanized welded fabric not larger than ⅜ in. diameter sufficient for load requirements. Reinforcement not closer than ¾ in. to exposed surface.	As determined by load requirements. Placed in two or more layers. Final coat ⅛ in. thick.
Stucco or Facing on Tile, Terra Cotta, Brick, and Concrete.	Not necessary except for badly disintegrated surfaces in which case use galvanized welded fabric equal to 0.2% of cross-sectional area of the mortar securely attached to the structure and located at middle of coating.	⅝ in. to 1 in. placed in two layers, second ⅛ in. thick. Screed to proper surface before applying second layer.
Concrete Restoration	Galvanized welded fabric 2 x 2—No. 12 and No. 12 or 3 x 3—No. 10 and No. 10 securely attached to old structure at middle of coating. Two layers of mesh for thickness of 3 in. and greater.	Not less than 1 in. placed in two or more layers. Screed to proper surface before applying final ¼ in. layer.
Linings for Reservoirs	Galvanized welded fabric 4 x 4—No. 8 and No. 8 or greater at middle of coating.	Not less than 2 in., in two or more layers.
Linings for Canals and Ditches	Galvanized welded fabric not less than 0.2% of cross-sectional area of mortar middle of slab.	1 to 2 in. two or more layers.

Chapter V—Details of Design and Construction

501. General

(a) The monolithic character of reinforced concrete construction creates problems in details of design as well as in construction that require adequate treatment if the structure is to be durable, structurally sound, and acceptable in appearance.

(b) To insure durability where the structure is exposed to the weather, the reinforcement should be protected by an adequate covering of concrete. For exposure to sea water, corrosive fluids, or high temperatures, extra precautions are necessary. In order to maintain a proper amount of covering the metal reinforcement should be accurately and firmly held in position.

(c) Only comparatively small structures can be cast without interruption. Consequently, construction joints in the concrete and splices in the metal reinforcement are required.

(d) In addition to construction joints it is frequently necessary to articulate a structure to provide for length changes due to temperature variation and shrinkage. Also in some cases joints are introduced for structural or design purposes, as in open spandrel or hinged arches and some types of framed structures. Joints of this character need special attention on the part of the designer and the construction organization if they are to function properly. Where concrete structures are exposed to water pressure, there is added to these requirements the necessity of maintaining watertightness.

(e) The use of reinforcement in distributing and minimizing the formation of cracks should be given careful attention.

(f) The following recommendations cover some of the more important construction details, and are intended to guide in the design as well as in the construction. These should be considered in connection with Sec. 501–S to 511–S of the specifications.

Details of Reinforcement

502. Splicing of Reinforcement

When it is necessary to splice reinforcement, the splice should develop the strength of the bar by bond resistance over the surface limited by the length of splice. In lapped splices the bars should be placed in contact and wired together. The minimum distance recommended in Sec. 504 should be considered to apply to the space remaining between a pair of bars so spliced and adjacent bars or splices. Wherever possible, splices of adjacent bars should be staggered. A welded or mechanical connection should develop the full strength of the bars.

503. Offsets in Column Reinforcement

When changes in the cross section of a compression member occur, the longitudinal reinforcement should be sloped the full length of the member or offset in a region where lateral support is provided sufficient to resist the transverse component of the thrust in the inclined portion of the offset. Where offsets are used, the slope of the inclined portion of the bars should be not more than 1 to 6 with respect to the axis of the members (see Sec. 854 (*c*)).

504. Clearance and Embedment

Reinforcement bars should be located a sufficient distance from the surfaces of members and from each other to afford adequate embedment for bond resistance and for satisfactory placing. The minimum spacing between parallel bars should be 2½ times the diameter of round or 3 times the side dimension of square bars, but in no case should the clear distance between bars be less than 1½ times the maximum size of the coarse aggregate nor less than 1 in. in beams and girders, nor 1½ in. in columns. See Sec. 854 for recommendations concerning column reinforcement.

505. Fire Protection

(a) Metal reinforcement should be protected against fire by the minimum thicknesses of concrete shown in the following table for the various classes of structural members and types of aggregates (designated as Group 1 and Group 2, and defined in Specifications Sec. 225–S).

Fire Resistance	*Minimum Thickness of Concrete—in.*			
	4 hr.	*3 hr.*	*2 hr.*	*1 hr.*
For columns, beams, girders, and unprotected ribbed slabs				
Group 1, Aggregate	1½	1½	1½	1
Group 2, Aggregate	2	1½	1½	1
For solid slabs				
Group 1, Aggregate	¾	¾	¾	¾
Group 2, Aggregate	1	¾	¾	¾

(b) In ribbed floor construction where ribs are spaced not more than 30 in. in the clear, and formed between permanent masonry filler blocks, or between permanent or removable forms, and having the additional protection of ¾ in. of Portland cement or gypsum plaster applied directly to the ribs and masonry fillers, or to metal lath attached to or suspended below the ribbed construction, the fire protection requirements for the ribs should be those indicated in the table for solid slabs.

506. Moisture Protection

(a) At those surfaces of footings and other principal structural members in which the concrete is deposited directly against the ground, metal reinforcement should have a minimum covering of three inches of concrete. At other surfaces of concrete exposed to the ground or to severe weathering conditions, metal reinforcement should be protected by not less than two inches of concrete. At undersides of slabs exposed to weather one inch should be provided.

(b) Where metal fabric in the form of wire mesh or expanded metal is used as reinforcement for protective coatings on columns, beams, or girders, it should have a minimum covering of 1½ in. for structures exposed to water, ground, or weather, and a minimum of ¾ in. for structures not so exposed.

(c) Where pneumatically applied mortar is used for moisture protection, it should not be less than 1½ in. in thickness and reinforced with metal fabric as provided in Sec. 406 *(m)*. The mesh should be securely fastened to the surface to be protected.

(d) In large and monumental structures such as large bridges, locks, and dams, it is recommended that the minimums enumerated above be increased.

(e) Structures or structural elements exposed to the injurious action of corrosive liquids and vapors require special designs of protective coverings.

507. Concrete in Sea Water

(a) For the protection of the reinforcement where concrete is exposed to sea water both the quality of the concrete and the thickness of the protection should fulfill more than ordinary requirements. The minimum water contents shown in Table 1, Section 303, are recommended. The placing should be in accordance with the specification paragraphs, 420–S and 421–S.

(b) The depth of protection for all metal reinforcement, including supports, ties and stirrups, should be a minimum of three inches at all plane or curved surfaces and four inches near the corners of exposed members.

508. Future Bonding

Where reinforcing bars are to be left protruding from a structure for the purpose of bonding with future additions, special care should be taken to protect them against injury or corrosion.

Expansion and Contraction Joints

509. Purpose and Location

(a) If a reinforced concrete structure is free to expand and contract with variations in temperature or moisture conditions (uniform over the section), no stresses of any importance will be developed. When the movement of the structure is restrained, however, or when temperature or moisture variations are not uniform over the section, stresses are introduced which should be provided for in the design.

(b) Points requiring special consideration are located where large changes in cross section occur or at corners in long members where expansions or contractions may result in rupture of the side members. No amount of reinforcement will prevent the formation of cracks in a restrained structure in which the required change in length exceeds the extensibility of the concrete, but reinforcement properly designed will serve to distribute the cracks.

(c) Joints providing a complete separation in the structure, when properly located, can relieve the restraint and prevent or greatly minimize the development of cracks. Such joints should be carefully designed with respect to the type of structure and should provide for the full expected movements without introducing local stresses severe enough to rupture the concrete. They should be located at predetermined points and fully detailed on the drawings. They may or may not be designed to carry load or distribute stress across the joint. Frequently this type of joint requires some form of protection to keep out extraneous material.

510. Expansion Joints in Long Buildings

(a) Expansion joints are expensive and in some cases difficult to maintain. They are, therefore, to be avoided if possible. In relatively short buildings, expansion and contraction can be provided for by additional reinforcement. No arbitrary spacing for joints in long buildings can be generally applicable. In heated buildings joints can be spaced farther apart than in unheated buildings. Also, where the outside walls are of brick or of stone ashlar backed with brick, or where otherwise insulated, the joints can be farther apart than with exterior walls of lower insulating value.

(b) In localities with large temperature ranges, the spacing of joints for the most severe conditions of exposure (uninsulated walls and unheated buildings) should not exceed 200 ft. Under favorable conditions buildings 400 to 500 ft. long have been built without joints even in localities with large temperature ranges.

(c) In localities with small temperature ranges, the spacing of joints for unheated buildings or with uninsulated walls should not exceed 300 ft. In such localities buildings up to 700 ft. long have been successfully built without joints where other conditions were favorable.

(d) In roof construction, provision for expansion is an important factor. The joints in the roof may be required at more frequent intervals than in the other portions of the

building because of more severe exposure. In some cases expansion joints spaced 100 ft. apart have been provided in roofs and not in walls or floors.

(e) Joints should be located at junctions in L-, T-, or U-shaped buildings and at points where the building is weakened by large openings in the floor construction, such as at light wells, stairs, or elevators. Joints should provide for a complete separation from the top of the footings to the roof, preferably by separate columns and girders.

511. Retaining Walls

For retaining walls and similar structures subject to large temperature and moisture changes, the details suggested in Sec. 877 are recommended.

512. Concrete Trestles

For concrete trestles and similar structures the spacing of joints will depend upon the temperature range, flexibility of the supports, and other structural requirements. In general, for structures of this type it is desirable to place the joints not farther apart than 125 ft. For this type of construction joints, where heavy loads are being transmitted, sliding joints should not be used.

Construction Joints

513. Location of Joints

Wherever it is necessary to interrupt the placing of the concrete, an effort should be made to form a joint that will least impair the appearance or serviceability of the member or structure. Where such joints are objectionable, the drawings should clearly indicate the limits of the various sections to be placed at one operation and the joints desired should be fully detailed. When construction joints cannot be avoided the method of procedure given in Sec. 508–S to 511–S of the specifications should be followed.

514. Watertight Joints

Where construction joints are necessary in structures exposed to water pressure, or where for other reasons the joints must be watertight, non-corrosive metal water stops should be installed.

Chapter VI—Waterproofing and Protective Treatments

601. General

The questions of when to waterproof and what method to use are so largely matters of individual cases that it is not possible to offer specific recommendations that will be generally applicable. In the following paragraphs some comment is offered on the general aspects of the problem. It is realized that experienced engineers are likely to be well informed on these subjects, but this brief statement of the factors involved is intended to serve as a background for the satisfactory solution in any individual case.

602. Watertightness of Concrete

(a) Many studies of permeability have shown that concrete of proportions suitable for structural or hydraulic work, if properly placed and adequately cured, is watertight for all practical purposes even under very high pressures. Failure to obtain watertight structures therefore is due either to improper concrete practice or to such structural features as cracks, joints, etc., which permit the passage of water.

(b) Observations on structures in service have shown that where water finds its way through the concrete itself, it is almost invariably through defective spots resulting

from improper placement or mix proportions. By far the most common source of leakage observed is at the planes of contact between successive lifts. This usually results from improper bond or from porous concrete at the top of the lift due to watergain. Another common source of leakage is found in defective areas resulting from honeycomb or segregation during placing. Obviously, the prevention of such defects is a first requirement of watertight construction.

603. Presence of Cracks and Joints

(a) No matter how impervious the concrete may be, or how perfectly placed, there is always the possibility of leakage through expansion joints, construction joints, or cracks. In Sec. 514, the use of non-corrosive water stops at joints is recommended where watertightness is required.

(b) Cracks, such as might result from load, settlement, temperature changes, or shrinkage of the concrete may be the source of considerable and annoying leakage in a structure exposed to direct water pressure. Provision against the formation of such cracks can be made by careful attention to all features of design. Spacing and arrangement of contraction joints and proper distribution of reinforcement can accomplish much in the prevention of cracks which will permit the entrance of water.

604. Importance of Drainage

Too much emphasis cannot be placed on the need for drainage around the structure where unsightliness or damage will result from the penetration of water. In many cases, proper drainage would be all that is needed to preserve the structure or to protect the interior. In the opinion of this committee, drainage should be considered not as an adjunct to waterproofing, but rather as a first requirement to which waterproofing is added as a further protection.

605. Need for Some Type of Protection

In many types of structures exposed on one side to direct water pressure, it is important that the other side be absolutely dry. In the case of such structures, some method of waterproofing may be necessary which takes into account the possibility of the occurrence of structural cracks or the presence of defective spots in the concrete. Some of the methods mentioned below for waterproofing the concrete without a membrane may be effective in such cases, or an outside waterproof membrane may be needed. Where a membrane is necessary, the materials to be used and the methods of applying them should be those best adapted to the particular location or structure. The problems of this type of waterproofing are not peculiar to concrete construction and are therefore outside the scope of these recommendations.

606. Protection Against Weathering

(a) Although concrete of normal proportions, properly placed and cured, is impervious to the actual passage of water under pressure, it is not immune to the passage of water due to capillary forces. As indicated in Table 1 of Sec. 303 *(b)*, concrete even though properly made and cured, is affected by weathering in proportion to the severity of exposure and to the water-cement ratio of the paste. The greater the water-cement ratio, the greater the amount of free water that may be present and the more destructive the effect of the repeated freezing and thawing and wetting and drying. Laboratory tests, as well as field experience, have shown that a high degree of resistance can be obtained with properly placed and well-cured concrete by the use of low water-cement ratios. Low water-cement ratios require the use of rich mixes or some method of placing which permits concrete of stiffer consistencies to be properly consolidated.

(b) There is also evidence from both experiment and experience to show that certain protective coatings which are effective in sealing the concrete to the penetration of moisture are effective in increasing the resistance to the destructive action of alternate freezing and thawing. Such protective coatings or a membrane waterproofing, therefore, may frequently be necessary as a protection against weathering.

607. Dampproofing

(a) Water which enters the concrete wall by absorption will be distributed by the capillary forces throughout the concrete until a condition of saturation is reached or until evaporation balances the inflow. If there is a continuing supply of free water available on one surface and evaporation can take place from another, there will be a continuing passage of water. If the air becomes saturated or the temperature drops sufficiently, moisture will condense on the wall. When this occurs, or if a seal coat is applied to the face away from the source of the moisture, the outflow of water ceases and saturation of the concrete is encouraged. The prevention of moisture penetration by capillarity is commonly referred to as "dampproofing" as contrasted with "waterproofing," which implies the prevention of an actual flow of water through the structure.

(b) The appearance of moisture on a wall does not always indicate, of course, that the water vapor in the air is entirely due to passage of water through the wall. Oftentimes, dampness on the inside of a wall is mistakenly ascribed to moisture penetration, when in fact it is merely the result of condensation, on the cold wall, of moisture which originated elsewhere.

(c) Dampness due to absorbed water or condensed water vapor can develop on and within concretes through which water will not "flow" even under great pressure. The remedy is to seal the pores on the side exposed to the moisture. Most of the methods mentioned below for waterproofing should be effective in preventing the entry of water into concrete. Other and more simple methods might also be effective. The use of a seal coat on the side away from the water may be effective for some time, but if the wall is subject to freezing temperatures the use of such seal coat may in the long run result in greater damage than leaving the wall unprotected.

608. Protection of Reinforcement

Spalling of concrete due to corrosion of the reinforcement is frequently the cause of damage to structures. In structures exposed alternately to wetting and drying, this is probably the most common cause of deterioration. Where the concrete protection is in accordance with Sec. 506, the only special requirement for protection of the reinforcement will be that necessary to prevent the moisture reaching the reinforcement through cracks or defective areas.

609. Protection Against Corrosive Substances

Research and experience have developed various types of treatments for protecting concrete against the effect of exposure to various types of substances. The committee has assembled in Appendix 1 the best available information on the effect of some of the more common types of substances and the treatments which have been found helpful in retarding or preventing corrosion.

610. Coatings on the Side Away from the Water Pressure

The desirable procedure in waterproofing a structure is to apply protection on the side exposed to water pressure. Frequently, however, this is impossible and it is necessary to apply waterproofing on the opposite side. Where the waterproofed surface is protected from freezing temperatures, this procedure has some advantage in that in the case of failure of the waterproofing it is easier to locate the source of weakness and make the necessary repair. Where the waterproofed surface is to be exposed to freezing temperatures, however, the method is not to be recommended. The freezing of water in the concrete immediately underneath the protective coating will not only damage the coating, but injure the concrete itself. The concrete may be affected more rapidly with the coating than it would if the coating were absent, when there would be less opportunity for the concrete to become saturated at the surface.

611. Waterproofing with Portland Cement Mortar

(a) A plaster coat of Portland cement mortar on the side of a wall exposed to water pressure, when properly applied and cured, will effectively protect porous concrete against the penetration of water under pressure. However, any structural movement resulting from load, settlement, shrinkage, etc., which will crack the structure, will crack the plaster, thereby destroying its waterproofing value at these points. The use of this type of waterproofing, of course, would require that any cracks existing in the concrete be chipped out and filled with mortar before applying the plaster coat.

(b) Portland cement plaster applied on the side of the structure away from the water pressure has been successfully used against considerable heads. Cracks and defective spots are readily filled by mortar applied from the inside. When skillfully done, this method can be used to shut off actual flowing leaks. When the quantity of water flow is considerable, some accelerating agent, which will reduce the setting time to a few minutes, may be necessary.

(c) This method of waterproofing has the advantage that cracks occurring after the plaster is in place can be readily located and repaired. It does not, of course, prevent possible damage to the structure from corrosion or weathering even though the interior may be kept dry. It should not be used where the surface is to be exposed to freezing temperatures. The method, however, has its uses and in some instances may be the only possible one.

(d) Good plastering technique is required for successful waterproofing with Portland cement plaster, whether applied on the inside or the outside. This includes such details as clean surfaces, proper suction at the time of application, plastic consistency, and the proper curing of each coat. The mortar should be about a 1 : 2 mix applied in at least two coats, each coat about ⅜ in. thick. Powdered iron preparations (Sec. 613 (*e*)) are sometimes added to the mortar.

612. Integral Waterproofing

(a) Powdered Admixtures.—Misconception of the function of admixtures and frequent overstatement of their properties have led to much misunderstanding regarding their use. In very lean mixtures almost any fine, inert material will improve the watertightness of concrete. This improvement comes about in two ways. First, with the extra fines the paste will have a more plastic consistency which will segregate less and be more watertight. Second, the more plastic paste will improve the workability of the concrete and thereby guard against those defects in placing which leave open channels for water to pass through the member.

In rich mixes, on the other hand, where the cement-water paste is already of plastic consistency, and of sufficient quantity to give the needed workability, powdered admixtures serve no useful purpose so far as watertightness is concerned. For mixtures in this range most of the powdered admixtures require increased water content, as compared with the plain mix, which reduces the quality of the paste and detracts from its watertightness.

The field of powdered admixtures, therefore, for waterproofing concrete will depend upon the character of the concrete mix just as much as upon the characteristics of the admixtures. Lean mixtures or normal mixtures deficient in fines in the aggregate can be improved by some of the admixtures. On the other hand, rich mixes, and normal mixes in which adequate fines are present, may be reduced in watertightness by the presence of these added fines.

(b) Water-Repellent Admixtures.—Stearates or other water-repellent materials have found considerable use as admixtures for concrete where the penetration of moisture is to be retarded. These materials reduce the absorption and retard penetration of moisture by capillary action. They do not seem to be effective as waterproofing when the concrete is exposed to direct water pressure. Some of these water-repellent admixtures improve the workability of concrete and thereby may improve the watertightness of a wall exposed to direct water pressure.

613. Waterproofing with Surface Treatments

(a) There are a number of surface materials which can be applied to concrete for protection of the surface against weathering or other attack. Those referred to in Sec. 609 and listed in detail in Appendix 1 are materials which have been found especially effective for certain uses. Some of these may be sufficiently permanent to serve as a waterproofing or dampproofing coating. In the following paragraphs are listed some of those which have been found particularly adaptable.

As in the case of cement mortar plaster, any structural movement which produces a crack will break these applied coatings and destroy their waterproofing value at these points. Likewise, none of these surface treatments is of sufficient body or strength to span cracks already in the structure and prevent the entrance of water. As pointed out in Sec. 610, these materials, when used on the side away from the pressure, may accelerate deterioration of a wall if exposed to freezing temperature.

(b) Bituminous Coatings.—There are a number of asphaltic and tar coatings which are available for application to concrete. Some of these are to be applied hot; others, which depend for their hardening on the evaporation of a liquefier, are to be applied cold. The extent to which these materials can waterproof concrete and the period over which the protection will remain effective, depend not only upon the materials themselves, but on the condition of the concrete to which they are applied and the type of exposure to which the surfaces will be subjected. This same comment might with equal propriety be applied to the other materials mentioned below.

(c) Oil, Oil Paints, or Resin Combinations.—Linseed oil by itself, or in combination with resinous varnishes, makes a very satisfactory coating material for ordinary weathering and many other types of exposure. Oil paints based on linseed or other weather-resisting oil also have value. The preparation of the surface and the application of the materials should be done in accordance with the best painting technique with particular reference to the type of materials being used.

(d) Portland Cement Paints.—Mixtures of Portland cement and water or specially prepared combinations consisting mainly of Portland cement are shown to have considerable value in resisting the penetration of water into concrete surfaces under conditions of moderate exposure. The use of these materials requires that special attention be given to curing methods to develop their greatest effectiveness.

(e) Powdered Iron Preparations.—Mixtures of pulverized iron and cement, usually with some agent designed to hasten the oxidation of the iron, have been used for waterproofing concrete surfaces. These are usually applied with a brush, either in a thin coating like a paint, or in a stiffer consistency to a measurable thickness. The water-

proofing effect is considered to result from the formation of the oxide of iron within the pores of the concrete. The agent most commonly used to accelerate the oxidation of the iron is ammonium chloride. These materials are also sometimes mixed with cement mortar for use in waterproofing (see Sec. 611).

(f) Proprietary Surface Treatments.—Many surface treatments of a proprietary nature are available for painting concrete which are based on some of the foregoing or similar materials. The use of such proprietary compounds should be restricted to those which have been proven by service test and which are susceptible to tests that will insure uniformity. They should always be limited to the type of service for which they are intended and the method of application should be strictly in accordance with the directions of the manufacturer.

614. Bituminous Membrane Waterproofing

(a) This method is particularly adaptable to large areas where there is some uncertainty as to the possibility of further cracking in the structure which would render other forms of waterproofing ineffective. It involves the use of a membrane consisting of one or more layers of bitumen-saturated cotton fabric or felt, or combinations of both materials cemented together (and to the surface waterproofed if a priming coat is used) by means of bituminous coatings. The bitumen to be used for the saturant and coating should be either asphalt or tar. The technique of applying this type of waterproofing is well established and organizations and workmen experienced in its use are generally available.

(b) Where there is any possibility that the membrane will be punctured by the backfilling material, it should be protected by an additional layer of masonry or by some such method as Portland cement mortar or bituminous mastic, or by an asphalt blanket or bituminous mastic blocks.

Chapter VII—Surface Finishes

701. General

(a) Surface finish is a term used to denote the process or method of mixing, placing, and treating concrete to produce a desired appearance and texture of the surface.

(b) The requirements of the sections of this Report relating to materials, forms, mixing, curing, conveying, depositing, and protection of concrete should apply except as they may be modified by these special requirements.

(c) Concrete should be placed in one continuous operation between prescribed expansion or construction joints, unless the drawings indicate other points where the placing of concrete can be discontinued.

(d) The same brand of cement, the same kind and size of aggregates, the same proportions and type of finish should be used where it is desired to duplicate texture and appearance on any showing surface.

702. Forms

(a) Forms for finished surfaces should be smooth and mortar tight. If wood forms are used, the boards must be uniform in thickness, tongued and grooved, smoothly finished on the surface next to the concrete, evenly matched and tightly placed, except where the desired surface or appearance requires special treatment.

(b) The forms should be so constructed as to be removable in sections without marring or damaging the surface of the concrete. Forms should be removed as soon as possible in order to make necessary repairs and finish the surface. As soon as forms are

removed any undesired fins or other projections on the surface should be carefully removed, offsets leveled, and voids or damaged places immediately saturated with water and repaired by filling with a concrete or mortar of the same composition as was used in the surface. After making the necessary repairs the surface should be finished with a wood float so as to be free from streaks, discolorations or other imperfections. Plastering should not be permitted and a steel trowel should not be used to finish surfaces.

703. Preparation for Surface Finish

(a) Where a surface mortar is to be the basis of the finish, the coarse aggregate should be worked back from the forms with a suitable tool so as to bring a full surface of mortar against the forms, care being taken to prevent the formation of voids and aggregate pockets.

(b) Where a special surface finish is called for on the drawings or in the specifications, the work of preparation should be carried out as specified.

Decorative Finishes

704. General

(a) Modern materials and methods may be used in the decorative treatment of architectural concrete to express the designer's ideas and taste in a wide variety of motifs, color, and texture.

(b) Decorative finishes on exposed concrete surfaces may be classified as:

1. Precast ornament
2. Monolithic ornament
3. Surface treatment after removal of forms
4. Applied finish

705. Precast Ornament

Precast ornamental units should be applied to the inside face of forms or set in framed openings in the structural form work. Such units are ordinarily made of cast stone from approved models. Positive anchorage into concrete should be made by means of rabbets, lugs, non-corrodible metal anchors, or other approved means of anchorage.

706. Monolithic Ornament

(a) Ornament is produced monolithically by forming concrete with negative models or molds. The precast models or stamped forms should be accurately and securely set in the structural forms. Special treatment of absorptive molds should be provided to prevent the absorption of moisture. Particular care is required in the design of the mixtures and in placing ornamental concrete to assure structural soundness and the desired finish.

(b) Finished samples of positive models should be submitted and approved as to craftsmanship, form, texture, and appearance.

(c) Construction joints in monolithic ornament, when necessary, should be located and constructed in such a manner as to be unobjectionable in the finished work. When molds are removed in less than seven days, the surface should be immediately sprinkled with water and kept wet until the concrete is at least seven days old. All ornamental work should be protected from damage until it is accepted.

707. Surface Treatment after Removal of Forms

(a) The desired appearance, texture, and finish for the surface should be determined from sample surfaces. Form linings, such as sheet metal, fiber, or manufactured board, may be used to produce concrete surfaces with specified markings or patterns.

(b) Where a special facing mix with selected aggregates is to be used, it should be placed to the required thickness and in such a manner as to bond securely with the backup concrete.

(c) The time of removal of face forms will depend upon the type of surface finish desired. For scrubbed finish the face forms should be removed as soon as safety permits and before the surface becomes too hard. For rubbed, sand-blasted, or tooled finishes, the surface must be thoroughly cured and hard before finishing.

708. Type of Finish

(a) Rubbed Finish.—The surface should be thoroughly wetted, and rubbed or ground with carborundum or other abrasive until it presents a uniform and smooth appearance. Cement mortar may be used in the rubbing, but the surface should not be brush coated with cement or grout after rubbing.

(b) Scrubbed Finish.—The surface should be thoroughly wetted and scrubbed with stiff fiber or wire brushes using water freely until the surface film of mortar is removed and the aggregate uniformly exposed. The surface should then be rinsed with clean water. If portions of the surface have become too hard to scrub in equal relief, dilute hydrochloric acid (commercial acid diluted with 4 to 10 parts water) may be used to facilitate the scrubbing, the acid being removed from the finished surface with clean water.

(c) Sand-Blasted Finish.—The thoroughly cured concrete surface should be sand-blasted with hard, sharp sand until the aggregate is in uniform relief.

(d) Tooled Finish.—The thoroughly cured concrete surface should be dressed with tools to a uniform texture and even face. The tools ordinarily used are electric or air or hand tools, giving various textured surfaces such as hand-tooled, rough or fine pointed, crandalled, or bush-hammered, as specified and as selected from sample surfaces.

(e) Sand-Floated Finish.—The forms should be removed before the surface has fully hardened; the surface wetted and rubbed with a wood float by a uniform circular motion, fine sand being rubbed into the surface until the resulting finish is even and uniform.

709. Applied Finish

(a) With applied stucco or plaster finishes the surface of the concrete should be removed to a depth of at least $\frac{1}{16}$ in., exposing the aggregate and leaving a clean, firm, granular surface for the permanent adhesion of the finish. A chemical compound may be used on the inside of forms to retard the setting of the surface concrete, in which case all loose material should be removed and surface thoroughly cleaned before finishing. If mechanical treatment, such as hacking or chipping or grinding is used, care should be taken to leave no untreated surfaces. A mechanical bonding surface may be formed by using a suitable form material or form lining.

(b) When applying the first coat of stucco or plaster, the concrete should be thoroughly wetted but should have no free water on the surface.

Wearing Surfaces

710. One-Course Work

In one-course work the slabs should be placed continuously for the full thickness without change of proportions. The least quantity of mixing water should be used to meet placing conditions. The proportions should be such that not over 5 gal. of mixing water, including that carried by the aggregate, is used per 94-lb. sack of cement.

711. Two-Course Work

(a) In two-course work the wearing surface or topping may be applied either before or after the base has hardened. For pavements and driveways the top coat should have a minimum thickness of 2 in. Floors subject to heavy wear should have a minimum thickness of 1 in. For walks and ordinary floors ¾ in. may be used.

(b) On an unhardened base the concrete topping should be applied within 45 min. after the concrete base is in place. The unhardened base course should be free from water, laitance, foreign matter and loose particles.

(c) For a hardened base the surface should be roughened to improve bonding, should be thoroughly wetted just prior to placing the finish, and a thin coat of neat cement paste should be broomed into the surface for a short distance ahead of the topping. The wearing course should be immediately applied.

712. Aggregates

Aggregates should meet the requirements of specification Sec. 207–S to 219–S. Coarse aggregates should be graded from No. 4 to ⅜ in. or from No. 4 to ½ in.

713. Proportions

For surfaces not subjected to severe wear or heavy abrasion the proportion should be one part cement to not more than two parts fine aggregate by volume. For surfaces subjected to severe wear or heavy abrasion the proportions should be one part cement, not more than one part fine aggregate, and not more than two parts coarse aggregate of the specified grading.

714. Finishing

(a) Topping applied to an unhardened base should be struck off to a true and even surface and finished to the desired smoothness with a wood float and steel trowel, or with a mechanical float machine and steel trowel. Cement or a mixture of cement and aggregate should not be sprinkled on the surface to absorb moisture or to stiffen the mix.

(b) Topping applied to a hardened base should be struck off and compacted by rolling or with tampers or vibrators. The surface should be finished to the desired smoothness with a wood float and steel trowel, or with a mechanical float machine and steel trowel.

715. Curing

As soon as the finished wearing course has hardened sufficiently to prevent marring it should be sprinkled with water or covered with sand or other approved coverings and kept continuously wet for at least 10 days where normal Portland cement is used, or three days where high early strength Portland cement is used.

Terrazzo

716. Methods of Bonding

Terrazzo finish should be bonded to the structural concrete base following Method 1, or separated from the concrete base or supporting surface following Method 2.

Terrazzo Method 1

717. Treatment of Base

The surface of the structural concrete base or fill course upon which terrazzo is to be placed should be at least two inches below the finished floor level. The base course should be cleaned of all loose and foreign materials, thoroughly wetted and a thin coat of neat cement broomed into the surface for a short distance ahead of the placing of the mortar base.

718. Mortar Base Course

Upon the concrete base should be placed a mortar base course at least 1¼ in. thick, with the surface struck off at least ¾ in. below the finished floor level. The mortar base should be composed of one part Portland cement to not more than four parts sand and sufficient water to produce a mortar of the stiffest consistency that can be struck off cleanly with a straight edge.

719. Metal Strips

Metal dividing strips of the type and width desired and at least 20 gage in thickness should be inserted in the mortar base before it hardens and should be so positioned as to control the location of cracks and conform to the design or pattern required. The tops of the metal dividing strips should extend at least $\frac{1}{32}$ of an inch above the finished level of the floor.

720. Terrazzo Mix

The terrazzo mixture should consist of one part gray, white, or colored Portland cement, as desired, to not more than two parts by weight of marble chips, stone chips, or abrasive aggregate, or a mixture of these of the required grading, quality and color. The consistency of the terrazzo mixture should be plastic and workable; wet or fluid mixes should be avoided. Coloring agents other than aggregates should be mineral pigments.

721. Placing

When the mortar base has hardened sufficiently to withstand rolling, the terrazzo mixture should be placed to the level of the tops of the metal dividing strips. After being struck off the surface should be rolled lengthwise and crosswise to secure a thorough compacting. Additional aggregates of the quality, grading, and color required should be spread over the surface during the rolling until at least 70 percent of the finished surface is composed of aggregate. Immediately after rolling the surface should be floated and troweled once without attempting to remove trowel marks.

722. Grinding and Finishing

After the terrazzo concrete has hardened sufficiently to prevent dislodgment of the aggregate it should be ground down by hand or with an approved type of grinding machine shod with rapid cutting carborundum stone or other abrasive. The floor should be kept wet during the grinding process. All material ground off should be removed by squeegee and by flushing with water. Air holes and other blemishes and imperfections should be filled with a thin grout composed of neat Portland cement paste spread over and worked into the surface. After the cement paste has hardened for at least 72 hours the floor surface should receive a second or final grinding sufficient to remove the film of cement paste.

723. Curing

See Sec. 715.

724. Cleaning

After removing all loose material the finished floor should be scrubbed clean with warm water and soft soap and mopped dry.

TERRAZZO METHOD 2

725. Sand and Paper Course

The surface of the structural base or fill course upon which the terrazzo is to be placed should be 2¼ in. below the finished level of the floor. Over this surface should be placed a layer of fine, dry sand about ¼ in. in thickness. The sand should be struck off with a straight edge to a smooth surface not less than 2 in. below the finished floor level. The surface of the sand should be covered with waterproofed paper. The paper should be so placed that all side and end laps are at least 1 in. wide.

726. Construction

The mortar base course should be placed upon the paper and terrazzo finish laid as described for Method 1 (Sec. 717 to 724).

Use of Color

727. Pigments

(a) Quality of Colors.—Only those pigments should be used which are insoluble in water and free from acids and soluble salts, and which are definitely known not to react with the calcium hydroxide set free during the hardening of the concrete, and which are further known through service not to be fugitive. Inorganic pigments are to be preferred; organic coloring agents should be used only when known to have the above characteristics.

(b) Limiting Amounts.—Pigments having a specific gravity of 3.0 or higher should be used in amounts not greater than 10 percent of the weight of the cement. The lighter weight pigments should be used in lesser amounts. When in doubt as to the permissible amount that should be used for any particular job, tests should be made using all the materials and in the proportions indicated for the job, and noting the appearance and effect on the physical properties, particularly strength and volume change of the concrete.

(c) Mixing.—Preferably, the pigment should be ground with the cement; otherwise, it should be thoroughly mixed dry with the cement and fine aggregate until a uniform color is secured throughout.

728. Colored Aggregates

Colored aggregates may be used when tests have shown that they will produce a concrete having the desired properties and that the colors are not fugitive and will not react with the calcium hydroxide set free during the hardening of the cement. Naturally occurring aggregates and those produced from crushing and sizing vitrified ceramic products and colored glasses have generally proved satisfactory. These aggregates should be used as normal aggregates.

Paints

729. Classification

(a) Paints commonly used for concrete may be of three classes:

Lead and oil paints.
Cement and oil paints.
Portland cement paints.

(b) "Lead and Oil Paints" is the general term used for paints based upon the principle of grinding a pigment, such as white lead, in a vehicle such as linseed oil with the addition of driers and thinners. Modern paints of this type may be composed of many other pigments besides white lead, and other vehicles besides linseed oil.

(c) "Cement and Oil Paints" is the general term used for paints made by grinding Portland cement and pigment in an oil or synthetic resin vehicle.

(d) "Portland Cement Paints" is the general term for mixtures of Portland cement and pigment prepared for application by mixing with water.

730. Application of Lead and Oil Paints, Cement and Oil Paints

(a) Seasoning of Concrete.—A period of eight to ten weeks following the curing period should be allowed for concrete to season before painting. The alkalinity of the surface should then be reduced by applying a solution consisting of two to three pounds of zinc sulfate per gal. of water. When thoroughly dry, all crystals should be brushed from the surface. This treatment is not necessary on old concrete or stucco.

(b) Condition of Surface.—The surface should be clean and free from dirt, oil, grease, and efflorescence, and should be thoroughly dry at the time of painting. If water dashed on the surface from a brush is rapidly absorbed, the surface may be assumed to be dry enough for painting.

(c) Number of Coats.—The number of coats necessary will depend on the porosity of the surface and in general should be not less than three on surfaces previously unpainted. The first coat should be well thinned for penetration. The second coat should contain more pigment, the amount depending on the suction remaining. The number of undercoats should be sufficient so that oil will not be drawn from the finish coat and it will dry to a uniform gloss and color.

731. Application of Portland Cement Paints

(a) Condition of Surface.—The surface should be clean and free from dirt, oil, grease, and efflorescence, and should be uniformly damp at the time of painting. The surface should be dampened sufficiently in advance so that free water has drained from the surface.

(b) Application and Curing.—After the first coat of paint has hardened sufficiently to prevent damage to the surface, it should be moistened with water applied with a fine spray and a second coat of paint applied. As soon as it is possible to do so without marring the surface, the second coat of paint should be sprayed with water and the surface kept wet for at least three days to insure proper curing and hardening of the paint.

Chapter VIII—Design

801. General

(a) In presenting recommendations for the design of reinforced concrete structures the committee has given consideration to such recent developments as plastic flow, or time yield, in concrete, and the application of the elastic frame theory in design. Concerning plastic flow, the committee adopts the prevailing opinion that in flexural members there is an adjustment in the concrete and steel stresses of moderate amounts, but that the load carrying capacity of the member is not materially affected. In fact, according to this opinion plastic flow may aid the structure in producing a more uniform stress distribution by yielding at heavily stressed sections.

(b) In regard to the elastic frame theory the committee takes the position that the design of a monolithic frame as an aggregation of isolated members is not tenable. Frames of buildings and other types of structures are generally built with the various members rigidly connected with one another. This feature of continuity of construction

complicates the problem of determining the character and amount of bending at critical sections of the frame.

(c) In the design of buildings it has been for many years common practice to design columns and beams as isolated members, the columns as compression members axially loaded, and the floor system by prescribed coefficients for moments at the ends and in the center of the span. In some cases prescribed moment coefficients have also been used to evacuate the bending in columns induced by unbalanced loadings from the floor system.

(d) Although such practice has apparently resulted in safe design in the case of buildings with uniform column spacings, it has become increasingly clear with the advent of newer methods of analysis that the degree of safety was neither uniform throughout the structure nor in some cases equal to that intended in the design. In the rather frequent cases of unequal spacing of columns or story heights, the design based on the usual moment coefficients often leads to improper design, and quite generally to wide departure from uniformity of factor of safety in the various members of the structure.

(e) The committee recognizes that more exact methods of analysis are now available for general use in the design of buildings and other framed structures, also that they may be simplified without undue sacrifice of accuracy. These methods will result in better provision for the effects due to continuity and should thereby secure a more uniform degree of safety. The need for such improvement in design becomes more important with the introduction of higher strengths and lighter weights of concrete and the accompanying higher working stresses. The consideration of continuity is especially important in cases of unequal spans alternately loaded where the ratio of live to dead load is large.

802. Assumptions

The design of reinforced concrete frames, beams, and slabs, is based on the following assumptions:

1. Plane sections normal to the axis remain plane after bending.
2. Tensile strength of concrete is negligible in resisting bending.
3. The ratio of the modulus of elasticity of steel to that of concrete, for concrete of a given strength, is constant in flexural members within the range of working stresses. The ratio, however, is not considered as fixed in the case of columns or in the case of compression reinforcement in flexure where, due to plastic flow, the reinforcement will be more highly stressed than indicated by a constant value of the modular ratio.
4. The moment of inertia of flexural members, for purposes of computing the relative stiffness, may be that of the gross cross-sectional area of the member, making reasonable allowance for the effect of flange width in T-beams permitted in 804*(d)*. For columns or other compression members the transformed area of the steel reinforcement should be included.
5. Temperature changes and shrinkage are neglected in the computation of stresses for buildings of ordinary size. (See Sec. 510 for recommendations regarding expansion joints and temperature reinforcement.)
6. In engineering structures such as arches, elastic frame bridges, and similar types where temperature change is an important factor in the resultant stresses, it is assumed that the temperature change is uniformly distributed throughout the member affected. For design purposes the coefficient for temperature change may be taken as 0.000006 per degree F.

7. Where shrinkage is considered a factor in design it may be assumed to range from 0.00015 to 0.00045, depending upon the size of the member and the moisture conditions.

803. Superimposed Loads

(a) Uniform Loads.—It is generally recognized that the conventional assumption of uniform load is a device employed for convenience of design and is only an approximation to floor loadings found in service. Uniform load, however, has been found to cover adequately the usual varieties of partial loadings in buildings and may be accepted unless the loads are permanently fixed in position. For the usual building, the following arrangement of loaded spans for computing maximum positive and negative bending moments, respectively, is recommended, unless conditions indicate a need for more careful analysis:

1. Alternate spans loaded, with a maximum of three loaded spans.
2. Two adjacent spans loaded, other spans unloaded.

(b) Moving Loads.—In structures subject to moving loads the bending moments and shears to be used in design should be the maximum values which may result from any probable position of the conventional or actual system of loads to be provided for.

(c) Impact.—For moving or other impact-producing loads suitable allowance should be made in the various portions of the structure for these effects. Such allowance should take into account the ratio of the live to dead load.

(d) Structures in Earthquake Regions.—In structures subject to earthquake shocks special analysis should be made to determine the probable stresses which should be added to those resulting from static or moving loads.

Design of Frames, Beams, and One-Way Slabs

804. General

(a) Effective Span for Determining Bending Moments.—

1. In continuous beams and slabs or elastic frames the effective span should be taken as the center-to-center distance between supports.

2. In beams or slabs of one span freely supported, the effective span length should be taken as the center-to-center distance between supports, but need not exceed the clear span plus the distances to centers of the required bearing areas.

3. In slabs built integrally with supports capable of fully restraining the slab the effective span length may be taken as the clear distance between supports.

(b) Lateral Support.—If the distance between lateral supports of beams exceeds 24 times the least width of the compression face, the allowable unit stress should be reduced. In no case should the distance between supports be more than 36 times the least width, at which limit the reduction in stress should be 50 percent. Proportionate reduction for intermediate ratios of span to width should be made.

(c) Compression Reinforcement in Beams.—Compression reinforcement in girders or beams should be secured against buckling by ties or stirrups adequately anchored in the concrete and spaced not more than 16 bar diameters apart. Where compression reinforcement is used its effectiveness in resisting bending may be taken at twice the value indicated from the calculations, assuming a straight-line relation between stress and strain and the modular ratio given in Table 7, Sec. 878. However, in no case should a stress in compressive reinforcement greater than 16,000 p.s.i. be allowed.

(d) T- and L-Beams, Limitations.—

1. In T- and L-beam construction the slab and beam should be built integrally or otherwise effectively bound together.

2. The effective flange width used in the design of T-beams should not exceed one-fourth of the span length of the beam, nor should the overhanging width on either side of the web exceed eight times the thickness of the slab or one-half the clear distance to the next beam.

3. For beams having a flange on one side only, the effective overhanging flange width should not exceed one-twelfth of the span length of the beam, nor six times the thickness of the slab, nor one-half the clear distance to the next beam.

(e) Transverse Reinforcement in Flange of T- and L-Beams.—Where the principal slab reinforcement is parallel to the beam, transverse reinforcement should be provided in the top of the slab. This reinforcement may be designed to carry the load on that portion of the slab which is assumed to act as the flange of the T-beam.

805. Bending Moments in Frames

(a) In monolithic frames or continuous construction the members should be designed to resist the bending moments and shears produced by the dead, live, and wind loads in accordance with methods of elastic frame analysis. For special conditions, such as centrifugal force, impact, braking and tractive forces in railway loadings, and for earthquakes or unequal settlement of the foundations, etc., the analysis should include the effect of these additional forces.

(b) For unusual building frames, continuous girder bridges, arches, or other types of statically indeterminate structures, rigorous methods of analysis are recommended.

(c) For ordinary building construction approximate methods of frame analysis are satisfactory.

(d) Regardless of the method of computing bending moments, all horizontal members of the frame should be designed to resist a positive moment near the center of the span not less than $0.04wl^2$.

806. Bending Moments in One-Way Slabs (Solid or Ribbed), Spans of Any Length or Loading

(a) Floor slabs over a series of spans should be designed as restrained by their continuity with each other. Restraint afforded by the supports themselves, unless approaching fixity, and except as specially provided in *(c)* below, may be disregarded. However, a negative moment of at least $0.04wl^2$ per foot of width should be provided for in the slab at the discontinuous end.

(b) It is recommended that bending moments be computed for the following arrangement of live load:

1. The maximum negative moment at the support for two adjacent spans loaded.

2. The maximum positive moment near the middle of a loaded span when adjacent spans are not loaded.

3. The resultant moment (positive or negative) near the middle of an unloaded span when adjacent spans are loaded.

(c) In computing the bending moment near the middle of unloaded spans, in accordance with *(b)* 3 above, the torsional resistance of the supporting beam may be considered to restrain the rotation of the support to the extent that adjacent spans may be assumed loaded with only one-half their specified live load.

(d) For proportioning the sections of slabs or ribs the negative bending moments may be computed at the face of the supports.

(e) In Appendix 2 is given a general method for computing moments at the center of the supports which can be applied to the assumptions of this section. The positive moments at mid-span can be obtained by the ordinary methods of statics, but the resisting moment provided should not be less than required by 805*(d)*.

807. Bending Moments in One-Way Slabs (Solid or Ribbed) of Equal Spans

(a) For the special case of equal span lengths, equal stiffness, and uniform loading, the requirements in Sec. 806*(a)*,*(b)*, and *(c)* are substantially fulfilled by the coefficients given in Appendix 3.

808. Bending Moments in Beams and Girders

(a) The positive and negative bending moments in beams and girders designed to be built monolithically with columns, beams, or walls, should be computed in accordance with the theory of elastic frames.

(b) In building construction, horizontal members of the frame should be designed as being restrained by their continuity with each other and by supporting and other members connecting at the joints. Where no great irregularities of span, story-height, or loading are involved the general method given in Appendix 2 may be used for computing the moment at the centerline of supports. In the case of beams framing into a girder, the restraint due to the torsional resistance afforded by the girder may be assumed as equal to that which would be furnished by a column having a stiffness factor equal to one-half the average stiffness factor of the beams framing into the girder.

(c) Bending moments should be computed for the arrangement of live load recommended in Sec. 803*(a)*.

(d) The moment at the face of a support may be used for proportioning the member. This moment may be obtained approximately from the moment at the centerline by subtracting a quantity $Va/3$, where V is the shear at the face of the support and a is the width of the support.

(e) Positive moments may be computed by the ordinary methods of statics, but the resisting moment provided should not be less than $0.04wl^2$.

Two-Way Slabs with Supports on Four Sides

809. General

(a) These recommendations are intended to apply to slabs (solid or ribbed), isolated or continuous, supported on all four sides by walls or beams, in either case built monolithically with the slabs. The recommended coefficients, as in the case of the design provisions for flat slabs, are based partly on analysis and partly on test data.* The analysis indicates that for square panels the moments may be substantially less than those determined on the basis of independent prismatic beam elements. Similar decrease is considered to hold for other than square panels but at reducing percentages until a ratio of short to long span of 0.5 is reached. For this and all lesser ratios the entire distributed load (except that in the column strips) is assumed to be carried in the short direction of the panel. Available test data indicate that these assumptions are justified.

(b) Available data also indicate that when two-way slabs are cast monolithically with supporting beams, the distribution and the numerical values for bending moments in slabs with one or more discontinuous edges do not differ widely from those of in-

* In general, the coefficients and methods given in these recommendations are based upon the coefficients proposed by Dr. H. M. Westergaard (Formulas for the design of rectangular floor slabs and supporting girders, p. 26, Proceedings of the American Concrete Institute for 1926). Some modifications of these coefficients have been made and the series extended to include cases not covered by Dr. Westergaard. In making these modifications and extensions full consideration has been given to the results of available test data.

terior panels. However, these data are rather limited, but the moment coefficients recommended in Table 5 for the slabs with discontinuous edges are conservative and in general agreement with accepted theoretical considerations and general practice.

(c) In the special case of slabs discontinuous at four edges (isolated panels, case 5, Table 5), the coefficients may be assumed to apply also to slabs which are built into masonry walls, provided the weight of masonry above the slab is sufficient to restrain the slab properly at the edges. The average parapet wall is probably lacking in this respect.

810. Limitations and Notations

(a) The recommended moment coefficients in Table 5, Sec. 811, are intended to apply to panels fully loaded with a uniformly distributed load. For values of m intermediate between those shown in Table 5, interpolated values of the moment coefficients may be used. For values of m less than 0.5 the coefficients given for this ratio should be used.

(b) Panels are considered as being divided into middle strips and column strips as in flat slabs. (See Sec. 834*(a)*). For panels in which the ratio m is less than 0.5 the middle strip in the short direction of the panel should have a width equal to the difference between the long and short spans, the remaining area representing the two column strips.

(c) Notation.—Span lengths of panels should be taken as the center-to-center distance between supports or as the clear span plus twice the thickness of the slabs, whichever value is the smaller.

$S =$ short span as defined above

$m =$ ratio $\frac{\text{short span}}{\text{long span}}$

$w =$ load per unit area

(d) Principal Design Sections.—The critical sections for moment calculations are referred to as principal design sections and are located as follows:

For negative moment, along the edges of the panel at the faces of the supporting beams.

For positive moment, along the center lines of the panels.

811. Bending Moment Coefficients

(a) Middle Strips.—In Table 5 are given the bending moment coefficients for the middle strips for both short and long spans for varying values of the ratio m of short to long span. These coefficients, when multiplied by wS^2 give the bending moment per unit width of slab. The basis of this table is a maximum negative moment of 0.033 wS^2 per unit width in the middle strip for square interior panels. The coefficients for other than square panels and for panels with one or more edges discontinuous are based on the following modifications of this basic moment for the square interior panel:

1. Bending moments in the short span increase as the ratio m decreases.
2. Bending moments in the short span increase successively with the introduction of one or more discontinuous edges, the increase being independent of the position of the discontinuous edges.
3. Bending moments for the long span for all values of m are equal to the bending moments in a square panel having sides equal to the short span.
4. Negative moments at discontinuous edges are taken as equal to one-half of the corresponding moment at the continuous edge.
5. Positive moments at the center are taken as three-quarters of the negative moment at the continuous edge.

(b) Column Strips.—For moments in the column strips, coefficients two-thirds of those given in Table 5 for the corresponding moments in the middle strip should be used. In determining the spacing of the reinforcement for the column strip, the moment at any section may be assumed to vary from a maximum at the edge of the middle strip to a minimum at the edge of the panel, but the average should be that computed from the coefficient as given herein.

TABLE 5—BENDING MOMENT COEFFICIENTS FOR RECTANGULAR PANELS SUPPORTED ON FOUR SIDES AND BUILT MONOLITHICALLY WITH SUPPORTS

Coefficients are for moments in middle strips.

Moments	*Short Span*						*Long Span All Values of m*
	Values of m						
	1.0	*0.9*	*0.8*	*0.7*	*0.6*	*0.5 and less*	
Case 1—Interior Panels							
Negative Moment at							
Continuous edge	.033	.040	.048	.055	.063	.083	.033
Discontinuous edge	----	----	----	----	----	----	----
Positive Moment at Midspan	.025	.030	.036	.041	.047	.062	.025
Case 2—One Edge Discontinuous							
Negative Moment at							
Continuous edge	.041	.048	.055	.062	.069	.085	.041
Discontinuous edge	.021	.024	.027	.031	.035	.042	.021
Positive Moment at Midspan	.031	.036	.041	.047	.052	.064	.031
Case 3—Two Edges Discontinuous							
Negative Moment at							
Continuous edge	.049	.057	.064	.071	.078	.090	.049
Discontinuous edge	.025	.028	.032	.036	.039	.045	.025
Positive Moment at Midspan	.037	.043	.048	.054	.059	.068	.037
Case 4—Three Edges Discontinuous							
Negative Moment at							
Continuous edge	.058	.066	.074	.082	.090	.098	.058
Discontinuous edge	.029	.033	.037	.041	.045	.049	.029
Positive Moment at Midspan	.044	.050	.056	.062	.068	.074	.044
Case 5—Four Edges Discontinuous							
Negative Moment at							
Continuous edge	----	----	----	----	----	----	----
Discontinuous edge	.033	.038	.043	.047	.053	.055	.033
Positive Moment at Midspan	.050	.057	.064	.072	.080	.083	.050

These coefficients, when multiplied by wS^2, give the moment per foot of width. w = load per sq. ft.; S = short span as defined in Sec. 810*(c)*.
Note that wS^2 is the multiplier for both short and long span moments.

(c) Corner Reinforcement.—Experience and theoretical considerations have shown the need for reinforcement at exterior corners to prevent cracks in diagonal directions. The effective amount of such reinforcement per foot of width should be equal to that for the positive moment in the middle strip. This is required in both the top and bottom face of the slab. By the effective amount of the steel is meant the normal area multiplied by the sine of the angle which the bar makes with the critical section. In the top of the

slab the critical section is perpendicular to the diagonal; in the bottom of the slab it is parallel to the diagonal.

812. Distribution of Unequal Negative Moments at Supports

(a) In applying the moment coefficients of Table 5 to adjacent panels of varying dimensions and unequal loading, the negative moments on either side of a supporting beam may differ materially. Under these conditions some modification of the moments should be made, based on the relative rigidity of the slabs and the resistance offered by the support. For this purpose the assumption that the supporting beams offer a restraint equivalent to the average of the stiffness factors of the adjacent slabs may be used in a manner similar to that given in Sec. 808*(b)* for beams framing into girders. On this basis two-thirds of the unbalanced negative moment should be distributed to the two spans in proportion to their respective stiffness factors.

(b) Where conditions are such as to require modification of the support moments, as given in *(a)* above, the corresponding midspan moments may be obtained by the procedure ordinarily followed for continuous beams. For this purpose, the unadjusted negative moments obtained from Table 5, considered as equivalent to fixed end moments, may be multiplied by 1½ to obtain the simple span moments. The midspan moment then would be equal to the average adjusted end moments less 1½ times the unadjusted end moments. The coefficients in Table 5 for positive moments at midspan are sufficiently conservative to cover ordinary cases. However, where large adjustment of the support moments is required, the midspan moments should be investigated.

813. Shear in Slabs

The shearing stresses in the slab should be computed on the assumption that the load is distributed to the supporting beams in accordance with Sec. 815.

814. Minimum Slab Thickness

The slab thickness should not be less than 4 inches, nor less than the value computed by the following formula:

$$t = \left[S + \frac{S}{m} - \frac{N}{10} \right] \frac{1}{72} \sqrt[3]{\frac{2500}{f'_c}}$$

Where t = Slab thickness in inches
S (in inches) and m as in Sec. 810*(c)*
N = Total length in inches of slab periphery which is continuous with adjacent slabs.

815. Loads and Bending Moments in Supporting Beams

(a) Distribution of Load.—The loads on the supporting beams for a two-way rectangular panel may be assumed as the uniformly distributed load within the tributary areas of the panel bounded by the intersection of 45 deg. lines from the corners with the median line of the panel parallel to the long side.

(b) Total Load and Shear.—On the basis of the load distribution in *(a)* above, the total loads on the short and long span beams due to one loaded panel are given by the following formulas, respectively.

$$W_S = \frac{wS^2}{4}$$

$$W_L = \frac{wS^2}{4} \left[\frac{2 - m}{m} \right]$$

The end shears may be obtained from the above loads by the usual modifications of the reactions for any difference in end moments.

(c) Bending Moments.—The bending moments may be obtained for the load distribution assumed by the methods of mechanics appropriate to the conditions of support, or they may be determined approximately by transforming the load on the beams to equivalent uniform load per lineal foot of beam as follows:

For the short span, $= \frac{wS}{3}$

For the long span, $= \frac{wS}{3}\left[\frac{2 - m^2}{2}\right]$

Diagonal Tension and Shear

816. General

(a) For homogeneous beams the diagonal tensile stress is given by well-known formulas as a combined stress. This stress is a function of the shearing and the flexural stress at any point in the beam. Where the flexural stress is zero, as for example, at the neutral surface, at points of inflection, or at the supports of simple beams, the diagonal tensile stress is equal to the shearing stress and is inclined at an angle of 45 deg. with the neutral surface.

(b) Because of the composite character of reinforced concrete beams the action of reinforcement in resisting diagonal tension is not susceptible of exact analysis. The design of web reinforcement is therefore based on empirical or modified rational methods. These methods were developed by observation of existing structures and from test results that do not apply with certainty to new and untested arrangements of reinforcement.

(c) However, when ordinary web reinforcement is used, such as vertical stirrups, bent-up longitudinal bars, or the combination of these, the resistance to diagonal tension or shear is greatly increased. This is especially true if adequate bond resistance is provided, either in the form of low bond stress or effective anchorage of the reinforcement. The importance of bond resistance is such that high working stresses in shear are only permitted when all the reinforcement is properly anchored.

(d) In view of available data the following assumptions are recommended as a proper basis for design.

1. The vertical shear is a measure of diagonal tension in the web of beams.
2. The effectiveness of web reinforcement is measured by its projection on a plane inclined at 45 deg. with the neutral surface.
3. Web reinforcement provides for the shear in excess of that permitted in beams with longitudinal reinforcement only.

817. Shear and Diagonal Tension in Beams

(a) Beams (including ribs and other members subject to bending) should be designed to resist the diagonal tension in their webs without exceeding the stresses prescribed in Sec. 878. The critical section for diagonal tension should be taken at the face of the supports.

(b) For purposes of design, diagonal tension is assumed to be directed at an angle of 45 deg. with the axis of the beam, and its intensity is measured by the unit shear as computed by the formula:

$$v = \frac{V}{bjd} \quad \cdots\cdots (1)$$

Where V = total external vertical shear at the section
jd = moment arm of the internal force couple
b = width of the beam

For beams of I- or T-section, b is the width of the concrete web or stem. In case the sides of the web are not parallel the average width may be used, provided it does not exceed the minimum width by more than 20 percent.

(c) In ribbed tile construction where fillers are used consisting of burned clay or concrete tile having a net compressive strength in the shells at least equal to that of the concrete in the ribs, and so placed that the joints in alternate rows are staggered, the shells of the fillers in contact with the ribs may be used in computing the shearing stress at any section of the rib.

(d) Where the shearing stress as computed by Formula (1) exceeds the stress (v_c) permitted for an unreinforced web (Sec. 878), web reinforcement should be provided at all sections for the amount of shear exceeding that allowed for webs without reinforcement.

(e) Where the shearing stress exceeds $0.06f'_c$ the web reinforcement should be designed to carry the entire shear.

818. Types of Web Reinforcement in Beams

Web reinforcement may consist of vertical or inclined stirrups and bent-up longitudinal reinforcement or combinations thereof. Bars inclined at an angle less than 15 deg. with the axis of the beam shall not be considered as web reinforcement. When v exceeds $0.06f'_c$ bent-up bars or inclined stirrups should be provided in addition to vertical stirrups.

819. Design of Web Reinforcement in Beams

(a) Web reinforcement is considered effective only when anchored at both ends according to Sec. 828 and 830.

(b) Web reinforcement, whether vertical or inclined, is assumed to contribute to diagonal tensile resistance only the component of its total resistance that lies in a direction of 45 deg. with the axis of the beam.

The stirrup spacing (or length of beam over which the bar is effective) is given by the formula:

$$s = \frac{A_v f_s jd\ (\cos x + \sin x)}{V'} \quad \text{.......... (2)}$$

wherein: s = the horizontal distance along the axis of the beam between bars;
x = the angle the bars make with the axis of the beam;
A_v = the total normal cross-sectional area of web reinforcement in any plane;
V' = the total external vertical shear in excess of that allocated to the unreinforced web according to Sec. 817*(d)* and *(e)*.

For vertical stirrups this becomes:

$$s = \frac{A_v f_s jd}{V'} \quad \text{.......... (3)}$$

and for stirrups or bars inclined at 45 deg.:

$$s = \frac{A_v f_s jd}{0.7\ V'} \quad \text{.......... (4)}$$

wherein f_s = 16,000 p.s.i. or less, regardless of the grade of steel used. Where bars are bent up in a single plane the effective length *(s)* as given by Formula (2) is to be measured, one-half each way from the bar at the mid-depth of the beam and should not exceed $\frac{3}{4}d$.

(c) Web reinforcement should be so spaced that every 45 deg. line extending from the mid-depth of the beam (downward and towards the nearest support) to the longi-

tudinal tension bars should be intersected by at least one line of web reinforcement. If the shearing stress exceeds $0.06f'_c$, every such line should be intersected by at least two such lines of web reinforcement.

(d) Where more than one type of reinforcement is used to reinforce the same portion of the web, the total shearing resistance of this portion of the web is assumed to be the sum of the shearing resistances computed for the various types separately.

820. Shear and Diagonal Tension in Flat Slabs

(a) The shearing stress on a vertical section which lies at a distance equal to the effective depth of the slab beyond the edge of the column capital (or bracket) and parallel or concentric with it, should not exceed the following values when computed by Formula (1):

1. $0.03f'_c$ when at least 50 percent of the total negative reinforcement of the column strip passes through the section,
2. $0.025f'_c$ when 25 percent of the total negative reinforcement of the column strip passes through the section,
3. For intermediate percentages, proportional values of the shearing stress may be used.

(b) The shearing stress on a vertical section which lies at a distance equal to the effective depth of the slab beyond the edge of the drop panel and parallel with it should not exceed $0.03f'_c$ when computed by Formula (1). At least 50 percent of the cross-sectional area of the negative reinforcement in the column strip should be placed within the strip directly above the drop panel. (See Sec. 843.)

821. Shear and Diagonal Tension in Footings

(a) The shearing stress as computed by Formula (1) on the critical sections (as defined in Sec. 866*(c)* and *(d)*) should not exceed $0.02f'_c$ for footings reinforced with straight bars only, nor $0.03f'_c$ where the reinforcement is adequately anchored by hooks or otherwise as described in Sec. 827 and 828.

(b) For combined footings and raft foundations the shearing stresses and web reinforcement for beam elements may be treated the same as for flexural members described in Sec. 818 and 819 except that the shearing stress should not exceed $0.06f'_c$.

822. Wedge-Shaped Beams

In beams of variable depth the resultant internal shear at any section is increased or decreased by the vertical components of the inclined stresses (tension or compression) as described in Sec. 825.

Bond and Anchorage

823. General

(a) The theory of reinforced concrete is based on the assumption that stress is transmitted from one material to the other by bond. Consequently, all members of the structure should be so designed that stress transfer is accomplished without exceeding recommended allowable bond values.

(b) In members subject to direct stress, also in end anchorage of flexural reinforcement, the bond stress is assumed to be uniformly distributed over the embedded surface of the bar.

(c) In members subject to bending, the bond stress varies in proportion to the amount of external shear and is generally a maximum in the region near the supports.

In order to maintain normal beam action and structural integrity of the member, slipping or appreciable movement of the reinforcement must be prevented. End anchorage is effective in increasing resistance to slipping and therefore serves as an added factor of safety against failure by diagonal tension.

824. Bond Stresses in Beams of Uniform Depth

(a) In beams in which tensile reinforcement is parallel to the compressive face, that is, excluding wedge-shaped beams, the bond stress, u, is given by the formula*:

$$u = \frac{V}{\Sigma o j d} \qquad (5)$$

Wherein Σ_o = the sum of the perimeters of all the bars at the section, and
V and jd are as in Sec. 817*(b)*.

(b) In applying Formula (5) to any section of a beam in which the reinforcement includes bent bars, those portions of bars which are within a distance of one-third the effective depth of the beam from the main longitudinal reinforcement may be counted as contributing to bond resistance.

825. Wedge-Shaped Beams

(a) In beams of variable depth the resultant internal shear at any section is increased or decreased by the vertical components of the inclined stresses (tension or compression) depending on whether they agree or are opposite in sign to the direction of the external shear. The bond stress is obtained by substituting for V in Formula (5) the value V_1, given by the following formula:

$$V_1 = V \pm \frac{M}{d}(\tan c + \tan t) \qquad (5a)$$

The negative sign to be used when the depth of the beam increases in the direction of increasing bending moment and the positive sign when the depth decreases as the moment increases.

Wherein M = bending moment;
d = depth of beam at the section; and
c and t = the angles, respectively, that beam faces make with a direction normal to the direction of the external shear.

(b) In beams of this type including sloped footings, tapered brackets, and cantilever beams, bond stresses may be excessive. This is particularly true of tapered cantilever beams loaded at the unsupported end. These and similar cases may require end anchorage.

826. End Anchorage of Reinforcement

(a) In beams where the bond stress as computed by Formula (5) exceeds the allowable normal working stress, the use of end anchorage permits some form of redistribution of stress to take place. Without attempting to rationalize the precise character and action of anchorage, reliance is placed on tests which indicate that end anchorage is equivalent to increased bond resistance. Consequently, with effective end anchorage a somewhat higher bond stress may be allowed than is permitted for unanchored reinforcement.

(b) Since resistance to diagonal tension failure is primarily a function of bond resistance, increased shearing stresses are also permissible when special precautions are taken to prevent slipping of the reinforcement.

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* It is recognized that when end anchorage is used the assumptions upon which Formula (5) are based may not strictly apply. However, the committee believes that the use of Formula (5) with the higher allowable bond stresses permitted in Sec. 827 for end anchorage is amply supported by test data.

827. Unit Stresses with End Anchorage for Beams

The increased shearing and bond stresses recommended in Sec. 878 are based on the use of end anchorage, in accordance with Sec. 828, in addition to the ordinary extension requirements outlined in Sec. 829. Where these higher stresses are used all of the longitudinal bars should be provided with end anchorage, except those which are bent across the web at an angle not less than 15 deg. with the neutral plane and made continuous with the reinforcement along the opposite face of the beam.

828. Allowable Capacity of End Anchorage—Hooks

Anchorage, transmitting direct stress, tension or compression, within the limits of allowable normal bond stress is assumed to provide for the full working stress in the bar by uniform distribution of bond stress over the embedded surface. End anchorage, however, being a device to provide for increased bond and shearing stress should be limited to some definite amount. It is recommended that end anchorage be assumed to develop a maximum stress of 10,000 lb. per sq. in. in the bar so anchored. End anchorage may be an extension of the bar or a hook. In either case the additional length of bar should provide the needed anchorage by normal bond stress, assumed to be uniformly distributed over the additional embedded surface. A properly dimensioned hook is one in which the bar is bent in a full semicircle, with a radius of bend not less than three diameters, plus an extension at the free end of at least four bar diameters. Right angle or other abrupt bends, which do not engage a structural steel member, are not to be considered as anchorage unless the radius of the bend is at least 4 bar diameters and the total length from beginning of bend to the free end of the bar is at least 16 bar diameters.

829. Extension of Reinforcement

(a) To provide for contingencies arising from unanticipated distribution of loads, yielding of supports, shifting of points of inflection, or other lack of agreement with assumed conditions governing the design of elastic structures, it is recommended that the reinforcement be extended at the supports and at other points between the supports as indicated in *(b)* to *(f)* below. These paragraphs relate to ordinary anchorage and are the minimum requirements under which normal working stresses for bond or shear are permitted.

(b) Negative tensile reinforcement at the supported end of a restrained or cantilever beam or member of a "rigid frame" should be extended in or through the supporting member in such a manner as to develop the maximum tension in the bar with a bond stress not exceeding the normal working stress provided in Sec. 878.

(c) Between the supports of continuous or freely supported beams, every reinforcing bar should be extended at least 12 diameters, but not less than one-twentieth of the span length, beyond the point at which computations indicate it is no longer needed to resist stress.

(d) In simply supported beams and freely supported ends of continuous beams, at least *one-third* of the positive reinforcement should extend into the supports a distance sufficient to develop one-half the allowable stress in the bars.

(e) In restrained or continuous beams at least *one-fourth* of the positive reinforcement should extend into the supports and the remainder treated as provided in *(c)*.

(f) In restrained or continuous beams at least *one-third* of the total reinforcement provided for negative moment should extend beyond the point of inflection a distance sufficient to develop one-half the allowable stress in the bars so extended. Negative steel not so extended should be treated as provided in *(c)*.

830. Anchorage of Web Reinforcement

(a) The stress in a stirrup or other web reinforcement should not exceed the capacity of its anchorage in the upper or lower one-half of the effective depth of the beam.

(b) Web reinforcement which is provided by bending into an inclined position one or more bars of the main tensile reinforcement where not required for resistance to positive or negative bending, may be considered completely anchored by continuity with the main tensile reinforcement, or by embedment of the requisite length in the upper or lower half of the beam, provided at least one-half of such embedment is as close to the upper or lower surface of the beam as the requirements of fire and rust protection allow. A hook placed close to the upper or lower surface of the beam may be substituted for a portion of such embedment.

(c) Stirrups should be anchored at both ends by one of the following methods, or by a combination thereof:

1. Rigid attachment, as by welding, to the main longitudinal reinforcement.
2. Bending around and closely in contact with a bar of the longitudinal reinforcement, in the form of a U-stirrup or hook.
3. A hook placed as close to the upper or lower surface of the beam as the requirements of fire and rust protection will allow. In estimating the capacity of this anchorage the stress developed by bond between mid-height of the beam and the center of bending of the hook may be added to the capacity of the hook.
4. An adequate length of embedment in the upper or lower one-half of the effective depth of the beam, whether straight or bent. Anchorage of this type alone should not be relied on for stirrups in cases where the shearing stress in the web exceeds that recommended for beams without end anchorage of the reinforcement. (See Sec. 878.)

Flat Slabs

831. General

The design of flat slabs is based on generally accepted empirical methods. These methods have been developed partly by analysis and partly by tests on models, full size test panels, and on a wide range of completed structures. Accordingly, the special provisions relating to the design of flat slabs apply only where certain general limitations are observed.

832. Limitations

(a) These provisions apply to:

1. Concrete slabs, without beams or girders, built monolithically with the supporting columns. These slabs may be increased in thickness at the supports by the use of drop panels, or along the margins to form paneled ceilings.
2. A series of rectangular slabs of approximately uniform dimensions arranged in three or more rows of panels in each direction, and in which the ratio of length to width of panel does not exceed 1.33.
3. Slabs with drop panels having a length in each direction of approximately one-third of the panel length in that direction. Also to continuous drop panels that form paneled ceilings, in which the continuous drops have a width approximately one-third of the panel width.
4. Slabs with drop panels in which the total thickness of the slabs through the drops does not exceed one and one-half times the thickness of the slabs beyond the drops.

(b) Structures having a width of less than three rows of panels, or in which the adjacent panel dimensions vary by more than 15 percent, are outside the scope of these provisions and require special analysis.

833. Notation

The following notation applies to the design of flat slabs except when otherwise specifically stated:

M_o = Sum of the total positive and negative bending moments at the principal design sections in either direction, the sections being parallel to the margins of the panels.

c = Effective diameter in feet of a round column capital, at the underside of the slab or drop panel. No portion of the column capital should be considered effective which lies outside of the largest 90 deg. cone that can be included within the outlines of the column capital. When a square, or other symmetrically shaped capital is used, c is the diameter of a circle whose area is equal to the area of the base of the largest 90 deg. pyramid which can be included within the outlines of the column capital.

l = Span length, in feet, center to center of the columns along the panel margins, in the direction in which moments are computed.

l_1 = Span length, in feet, center to center of columns perpendicular to the direction of the span for which moments are computed.

w = Total dead and live load in lb. per sq. ft. of loaded area.

d = Effective depth, in inches, of the slab at any point.

t_1 = Total thickness, in inches, of the slab with or without drops, at the boundary of the column capitals.

t_2 = Total thickness, in inches, of the slab beyond the boundary of the drop.

834. Panel Strips and Principal Design Sections

(a) A flat slab panel is considered as consisting of strips in each direction as follows:

A middle strip one-half panel in width, symmetrical about panel center line and extending through the panel in the direction in which moments are considered.

A column strip one-half panel in width occupying the two quarter-panel areas outside of the middle strip.

(b) The critical sections for moment calculations are referred to as principal design sections and are located as follows:

Sections for negative moment along the edges of the panel, on lines joining the column centers, except that they follow the perimeter of the column capital instead of passing through it.

Sections for positive moment along the center lines of the panel.

(c) In the two-way system it is assumed that the tensile stresses due to the moments in the various strips are resisted by the band of reinforcing bars located within the strip.

(d) In the four-way system, or any other system of reinforcement, in which a part or all of the reinforcement is not parallel to the direction of the span, it may be assumed that the tension due to bending moments at any section of a strip is resisted by the components, in the direction of the span, of all the reinforcement included within the boundary of the section under consideration.

(e) The width of the column head section for computing compression should be taken as the width of the drop or half the width of the panel ($0.5l_1$) where no drop is used.

835. Bending Moments in Rectangular Flat Slabs

(a) The total bending moment M_o, in the direction of either side of the panel, is divided between the sections of positive and negative moment, the basis of division de-

pending on the size of columns, column capitals, and dimensions of the panels. For average conditions, approximately three-eighths of the total may be considered positive, and five-eighths negative moment. Slabs with drops are assumed to develop about 5 percent more negative moment than slabs of uniform thickness, and to have a corresponding decrease in the positive moment. Furthermore, the column strips are assumed to take 75 to 80 percent of the total negative moment and 50 to 56 percent of the total positive moment. The detail distribution of the total moment varies to a moderate extent depending on the system of reinforcement employed.

(b) Total Bending Moment.—For interior panels carrying an assumed uniformly distributed load the numerical sum of the positive and negative moments at the principal design sections in the direction of either side of a rectangular panel is given by the formula:

$$M_o = .09\left(l - \frac{2}{3}c\right)^2 w l_1 \qquad (6)$$

(c) Distribution of Moments.—For interior panels the distribution of the total moment M_o at the principal design sections is given in Table 6. This distribution agrees with the 1924 Joint Committee Report and with well-established requirements in this country, and is in close agreement with European practice.

TABLE 6—MOMENTS TO BE USED IN DESIGN OF FLAT SLABS FOR INTERIOR PANELS

Strip	*Flat Slabs without Drops* *Negative*	*Flat Slabs without Drops* *Positive*	*Flat Slabs with Drops* *Negative*	*Flat Slabs with Drops* *Positive*
		Slabs with Two-Way Reinforcement		
Column strip	$0.46M_o$	$0.22M_o$	$0.50M_o$	$0.20M_o$
Middle strip	$0.16M_o$	$0.16M_o$	$0.15M_o$	$0.15M_o$
		Slabs with Four-Way Reinforcement		
Column strip	$0.50M_o$	$0.20M_o$	$0.54M_o$	$0.19M_o$
Middle strip	$0.10M_o$	$0.20M_o$	$0.08M_o$	$0.19M_o$

836. Tolerances Applicable to Table 6

(a) The moment coefficients given in Table 6 may be varied by not more than six percent, provided the numerical sum of the positive and the negative moments at the principal design sections is not reduced.

(b) The ratio of reinforcement at any section of any band should not be less than 0.0025.

837. Conditions of Restraint at Discontinuous Edges

The modifications of moments at discontinuous edges are based on the assumption that the slab is restrained by the supporting beam framed into columns of adequate rigidity. A column (or two columns one above the other) having a stiffness factor $\left[\frac{I}{h}\right]$ at least equal to 1½ times the stiffness factor of the slab $\left[\frac{I}{l}\right]$ may be assumed as adequate. The moment of inertia *(I)* of the slab section may be computed on the basis of a width equal to the column spacing and a depth equal to the slab thickness plus one-third the depth of the drop.

838. Moments in Discontinuous Panels

(a) In the case of end or side panels when the slab is not continuous on one edge or two adjacent edges, and in which the restraint at the discontinuous edge is as defined in Sec. 837, the bending moments as given in Table 6 should be modified as follows:

1. In the column strip the negative moment at the first interior column line and the positive moment at the center of the end panel should be increased 15 percent over the moments given for interior panels. For the middle strip the corresponding moments should be increased 30 percent.
2. At the wall or discontinuous edge the negative moments in the column strip and middle strips perpendicular to such edge may be reduced by 20 percent from those given for interior panels.
3. The half column strip adjacent and parallel to a supported edge may be designed for one-quarter of the full column strip moment given in Table 6.

(b) In slabs supported at the discontinuous edge by bearing walls, or where they are not restrained, the positive moments in the strips perpendicular to the wall should be increased 50 percent.

(c) When there is a beam or bearing wall at the center line of columns in the interior portion of a continuous flat slab, the negative moment in the middle strip perpendicular to the wall or beam should be increased 30 percent. The column strip adjacent and parallel to the wall may be treated as in *(a)*3, the remaining strips as in Table 6.

(d) At discontinuous edges the positive and negative reinforcement should extend to within two inches of the edge of the panel and be anchored in accordance with Sec. 828.

839. Thickness of Slab and Drop Panel

(a) The effective depth of the slab, with or without drop, is determined on the basis of negative bending moment and shear at the support and the allowable stresses. Since the negative moment is not uniform over the full width of the column strip, being higher at the center line than at the edges, the thickness determined on the basis of coefficients given in Table 6 and the allowable unit stress will result in excess compressive stress at the middle of the section. The thickness computed in this manner, therefore, is to be increased as provided in *(c)*.

(b) In order to prevent undue deflection, and provide adequate depth where two or more bands of reinforcement are placed in layers at any section, the thickness at the center of the panel should not be less than the following limiting values, regardless of the values determined under *(c)*.

1. Floor slabs with drop panels, 4½ in.
   Floor slabs without drop panels, 5 in.
2. Roof slabs with drop panels, 3½ in.
   Roof slabs without drop panels, 4 in.
3. Floor slabs: 2,500-lb. concrete
   a. End panels, $0.030l$
   b. Interior panels, $0.026l$
4. Roof slabs: 2,500-lb. concrete
   a. End spans, $0.025l$
   b. Interior spans, $0.023l$
5. For concrete having a 28-day compressive strength other than 2,500 p.s.i., limitations 3 and 4 may be modified by multiplying the coefficients by $\sqrt[3]{\frac{2,500}{f'_c}}$

(c) Interior Panels.—The total thickness, t_1, of the slab with or without drops, may be determined from Formula (7) as follows:

$$t_1 = 1.2d + 1\frac{1}{2} \text{ in.} \quad \ldots\ldots(7)$$

in which d = the effective depth of the slab, computed on the basis of the negative moments given in Table 6 and the assumed unit stresses governing the case under consideration (using balanced reinforcement).

For slabs with drops the width of the section resisting negative bending in the column strip should be limited to the width of the drop. For slabs without drops the full width of the column strip may be used.

The thickness, t_2, of the slab beyond the boundary of the drop should not be less than two thirds of t_1.

(d) Exterior Panel—For exterior panels the thickness of the slabs will vary according to the modifications in moment coefficients given in Sec. 838.*

840. Beams in Flat Slab Construction

(a) Marginal Beams Framing into Columns.—Beams or thickened margins should be used at all discontinuous edges of flat slabs. They may be placed above or below the slab and should be cast monolithically with it. Such beams should be designed to carry, in addition to the loads directly upon them, a uniformly distributed load equal to one-fourth the total dead and live load for which the adjacent panel is designed.

(b) Interior Beams.—When an interior beam framing into columns is required for some special load, it should be designed as a T-beam to carry in addition to the special load a uniformly distributed load equal to one-quarter of the total load on the adjacent panels.

Where interior beams are supported by girders that frame into columns the whole panel should be framed to avoid uncertainty of moment and load distribution.

841. Column Capitals—Brackets—Drops

(a) The effective diameter of the column capital as defined in Sec. 833 should not be less than $0.20l$, where l = span length in square panels or the average span length in rectangular panels.

(b) Brackets.—Brackets on exterior columns may be substituted for capitals, provided the sloping face of the bracket makes an angle of not more than 45 deg. with the face of the column, and is not less in width than the column. The value of c is twice the distance from center of column to the point where the bracket is 1½ in. in depth.

(c) Drops.—The drop should have a length in each direction not less than one-third of the panel length in that direction. If the shearing stresses at the edge of the drop exceed the allowable values given in Sec. 878, then the dimensions of the drop or the slab thickness outside the drop should be increased.

(d) If drop panels are used for interior columns they should also be used for wall columns.

842. Points of Inflection

For purposes of design the point of inflection in any line parallel to a panel edge in interior panels of symmetrical slabs without drop panels should be assumed to be at a distance from the center of the span equal to three-tenths of the distance between two sections of critical negative moments; for slabs having drop panels, the coefficient should be 0.25. For end spans the position of the point of inflection is to be modified in accordance with the mechanics of restrained beams.

* For end spans equal in length to interior spans, the increase in thickness is approximately 8 percent. A uniform slab thickness throughout the floor construction may, therefore, be obtained by making end panels 8 percent shorter than the interior spans.

843. Arrangement of Reinforcement

The design should include adequate provision for securing the reinforcement in place so as to resist not only the critical moments but the moments at intermediate sections. Provision should be made for possible shifting of the point of inflection by carrying all bars in rectangular or diagonal directions, each side of a section of critical moment, either positive or negative, to points at least one-fifeenth of the span length beyond the assumed point of inflection as recommended in Sec. 842. Lapped splices should not be permitted at or near regions of maximum stress. At least four-tenths of all bars in each direction should be of such length and should be so placed as to provide reinforcement at two sections of critical negative moment and at the intermediate section of critical positive moment. Not less than one-quarter of the bars used for positive reinforcement in the column strip should extend into the drop not less than 20 diameters of the bar, or in case no drop is used, should extend to a point *not more than* one-twelfth of the span length from the center line of the column or the support. Where drop panels are used, at least half of the cross-sectional area of the negative reinforcement in the column strip should be within the width of the strip directly above the drop panel.

844. Tensile Stress and Area of Steel Reinforcement

The tensile stress f_s in the steel and the total area A_s of the reinforcement for any critical section of design strips may be computed by the formula:

$$f_s = \frac{M_s}{A_s jd} \qquad (8)$$

Wherein M_s = the moment given in Table 6 for column strip or for middle strip.
j = the usual ratio of the moment arm of the internal force couple to the effective depth.
d = effective depth of slab at the point in question; that is, the distance from the centroid of the tensile steel to the compressive face.
A_s = effective cross-sectional area of the reinforcement which crosses any of the principal design sections and meets the requirements of Sec. 834*(d)*.

The stress so computed should not exceed the allowable working stress given in Sec. 878.

845. Compressive Stresses and Compression Reinforcement

Tests indicate that stresses are not uniformly distributed along the width of the column strip. This has been recognized in Sec. 839 where provision is made for thickness of slab. Cases occur, however, as in the end spans, where it is desirable to maintain the same slab thickness as for interior panels. This can be done by the introduction of compression reinforcement at the section of maximum negative moment.

846. Shearing Stresses in Flat Slabs

See Sec. 820.

847. Bond Stresses

See Sec. 823 to 830.

848. Openings in Flat Slabs

Openings of any size may be cut through a flat slab if provision is made for the total positive and negative resisting moments as required in Sec. 835 without exceeding the allowable stresses as given in Sec. 878.

849. Columns Supporting Flat Slabs

For requirements relating to bending moments in columns and limitation of column dimensions in connection with flat slab construction, see Sec. 859.

850. Special Construction

(a) The preceding recommendations for the design of flat slabs should not be applied to other than the two systems of reinforcement described, or to those systems where brackets or column capitals are omitted, unless analysis supported by adequate test data indicates that the stresses at the principal design and intermediate sections do not exceed the allowable unit stresses specified in Sec. 878.

(b) For structures having a width of one or two panels, or having panels of markedly different dimensions, an analysis should be made of the moments developed in both the slabs and the columns, and the requirements recommended in the preceding sections modified accordingly.

Reinforced Concrete Columns

851. General

(a) The following recommendations are based largely on the results of the extensive American Concrete Institute Column Investigation. Recognizing the presence of undesirable column shortening due to creep and shrinkage when small percentages of vertical steel are used, the minimum value is set at one percent; furthermore, a varying factor of safety is used, ranging, for axially loaded spiral columns, from about 3.6 for $p = 0.01$ to 2.75 for $p = 0.08$. A similar variation from about 4.5 for $p = 0.01$ to 4.0 for $p = 0.04$ is used with tied columns.

(b) The formula for spiral columns is based upon recognition of the fact that the strength produced by spirals is accompanied by spalling of the column shell and excessive column shortening, hence the spiral is utilized only as a toughening element or an insurance against a sudden and complete collapse of the column. With spiral reinforcement provided, which is somewhat stronger than the protective shell, these two elements of strength (which cannot act simultaneously) become interchangeable, and justify the formula which uses gross area of column and omits any reference to the spiral. The formulas for tied and spiral columns are thus made identical, except that the latter is allowed 25 percent greater load-carrying capacity because of the presence of adequate spiral reinforcement to carry part of the load if the outer shell should spall.

(c) The design of long columns, both tied and spirally reinforced, is covered by a single equation based on the height-diameter ratio. With the test data available, no increase in accuracy would be attained by basing the slenderness ratio on the radius of gyration.

(d) The treatment of bending in columns is intended to correlate with the methods given in Sec. 805 for continuous beams and frames. Recent studies of creep indicate that the current analyses of combined bending and direct stress are not accurate, and that for cases in which the compressive stress governs the design, the theory of the uncracked concrete section applies without serious error. The permissible combined stresses in Sec. 860–861 are based on test data; they embody the fact that permissible bending stresses may be greater than axial stresses, and they are based on the conventional value of n, which produces the most severe of the probable conditions that the concrete may meet under sustained loading.

852. Limiting Dimensions

The following sections on reinforced concrete and composite columns (except Sec. 858) apply to a short column, for which the unsupported length is not greater than 10 times the least lateral dimension. When the unsupported length exceeds this value the design should be modified as shown in Sec. 858. Principal columns in buildings should have a minimum diameter or thickness of 10 in. Posts, bearing walls, piers, or mullions, that are not continuous from story to story should have a minimum diameter or thickness of 6 in.

853. Unsupported Length of Columns

(a) For purposes of determining the limiting dimensions of columns, the unsupported length of reinforced concrete columns should be taken as the clear distance between floor slabs with the following exceptions:

1. In flat slab construction, it should be the clear distance between the floor and the lower extremity of the capital.
2. In beam and slab construction, it should be the clear distance between the floor and the underside of the deepest beam framing into the column in each direction at the next higher floor level.
3. In columns restrained laterally by struts, it should be the clear distance between consecutive struts in each vertical plane; provided that to be an adequate support, two such struts should meet the column at approximately the same level and the angle between vertical planes through the struts should not vary more than 30 deg. from a right angle. Such struts should be of adequate dimensions and anchorage to restrain the column against lateral deflection.
4. In columns restrained laterally by struts or beams, with brackets used at the junction, it should be the clear distance between the floor and the lower edge of the bracket, provided that the bracket width equals that of the beam or strut and is at least half that of the column, and provided further that the face of the bracket makes an angle with the face of the column of at least 45 deg.

(b) For all columns, that length should be considered which produces the greatest ratio of length to depth of section.

854. Spirally Reinforced Columns

(a) Allowable Load.—The maximum allowable axial load, P, on columns reinforced with longitudinal bars and closely spaced spirals enclosing a circular core is given by formula (9).*

$$P = 0.225 f'_c A_g + A_s f_s \quad \text{.....} \quad (9)$$

Wherein A_g = the overall or gross area of the column.
f'_c = compressive strength of the concrete, as found by tests of standard 6 by 12-in. control cylinders, as prescribed in Sec. 310.
f_s = nominal working stress in vertical column reinforcement, to be taken at 40 percent of the minimum specification value of the yield point; viz., 16,000 p.s.i. for intermediate grade steel and 20,000 p.s.i. for hard grade or rail steel.**
$A_s = p_g A_g$.
p_g = ratio of the effective cross-sectional area of vertical reinforcement to the gross area, A_g.

(b) Longitudinal Reinforcement—Amount and Spacing.—The ratio p_g should not be less than 0.01 nor more than 0.08. The minimum number of bars should be six, and the minimum diameter of bar should be ⅝ in. The center to center spacing of bars within

* To be logical the area of the steel should be subtracted from A_g in the formula. However, the effect of the small area of concrete displaced by the reinforcement has been taken into consideration in arriving at the coefficient 0.225 applied to f'_c.

** Nominal working stresses for reinforcement of higher yield point may be established 40 percent of the yield point stress, but not more than 30,000 p.s.i., when the properties of such reinforcing steels have been definitely specified by standards of ASTM designation. If this is done, the lengths of splice required by *(c)* shall be increased accordingly.

the periphery of the column core should not be less than 2½ times the diameter for round bars or 3 times the side dimension for square bars. The clear spacing between individual bars or between pairs of bars at lapped splices should not be less than 1½ in. or 1½ times the maximum size of the coarse aggregate used. (See Sec. 504.)

(c) Splices in Longitudinal Reinforcement.—Where lapped splices in the column verticals are used, the minimum amount of lap should be as follows:

1. *For deformed bars.*—With concrete having a strength of 3,000 p.s.i. or above, 24 diameters of bar of intermediate grade steel and 30 diameters of bar of hard grade steel. For bars of higher yield point, the amount of lap should be increased in proportion to the nominal working stress. When the concrete strengths are less than 3,000 p.s.i. the amount of lap should be one-third greater than the values just given.

2. *For plain bars.*—The minimum amount of lap should be 25 percent greater than that specified for deformed bars.

Where changes in the cross section of a column occur, the longitudinal bars should be sloped for the full length of the column, or offset in a region where lateral support is afforded by concrete capital, floor slab, metal ties, or reinforcing spirals. Where bars are offset, the slope of the inclined portion from the axis of the column should not exceed 1 in 6 and the bars on each side of the offset should be parallel to the axis of the column.

Welded splices or other positive connections may be used instead of lapped splices. Welded splices should preferably be used in cases where the bar diameter exceeds 1¼ in. An approved welded splice should be defined as one in which the bars are butted and welded and that will develop in tension at least the yield point stress of the reinforcing steel used.

(d) Spiral Reinforcement.—The ratio of spiral reinforcement, p', should not be less than the value given by Formula (10).

$$p' = 0.45 \left[\frac{A_g}{A_c} - 1\right]\frac{f'_c}{f'_s} \qquad (10)$$

Wherein p' = ratio of volume of spiral reinforcement to the volume of the concrete core (out to out of spirals).

A_g/A_c = ratio of gross area to core area of column.

f'_s = useful limit stress of spiral reinforcement to be taken as 40,000 p.s.i. for hot rolled rod of intermediate grade, 50,000 p.s.i. for hard grade and 60,000 p.s.i. for cold drawn wire.

Spiral reinforcement should consist of evenly spaced continuous spirals held firmly in place and true to line by at least three vertical spacer bars. For columns up to 18-in. core diameter, the minimum diameter of spiral bars should be ¼ inch. For columns larger than 18-in. core diameter, the minimum diameter of spiral bars should be ⅜ in. Anchorage of spiral reinforcement should be provided by 1½ extra turns of spiral rod or wire at ench end of the spiral unit. Splices, where necessary, should be made in spiral rod or wire by welding or by a lap of 1½ turns. The center to center spacing of the spirals should not exceed one-sixth of the core diameter. The clear spacing between spirals should not exceed 3 in. nor be less than 1⅜ in. or 1½ times the maximum size of coarse aggregate used. The column reinforcement should be protected everywhere by a covering of concrete cast monolithically with the core, for which the thickness should not be less than 1½ in. nor less than 1½ times the maximum size of the coarse aggregate, nor should it be less than required by the fire protection and weathering provisions of

Sec. 505 and 506. The reinforcing spiral should extend from the floor level in any story to the level of the lowest horizontal reinforcement in the slab, drop panel, or beam above. In a column with a capital, it should extend to the plane at which the sectional area of the capital is twice that of the column.

(e) Limits of Column Section.—For columns built monolithically with concrete walls or piers, the outer boundaries of the column section should be taken as a circle 1½ in. outside the column spiral or as a square the sides of which are 1½ in. outside the spiral. In case two or more spirals are used in such a column the outer boundary should be taken as a rectangle the sides of which are at any point at least 1½ in. outside of the spirals. For these types of spirally reinforced columns the value of A_g thus defined should be used in both Formulas (9) and (10).

(f) Equivalent Circular Columns.—As an exception to the general procedure of utilizing the full gross area of the column section, it should be permissible to design a circular column and to build it with a square, octagonal, or other shaped section of the same least lateral dimension. In such case, the allowable load, the gross area considered, and the required percentages of reinforcement should be taken as those of the circular column.

855. Tied Columns

(a) Allowable Load.—The maximum allowable axial load on columns reinforced with longitudinal bars and separate lateral ties should be 80 percent of that given by Formula (9). The ratio, p_g, to be considered in tied columns should not be less than 0.01 nor more than 0.04. The longitudinal reinforcement should consist of at least four bars of minimum diameter of ⅝ in. placed with a clear distance from the column face of not less than 1½ in. plus the thickness of the tie, provided that when nearer a corner than 4 in. this covering shall be increased to 2 in. Splices in reinforcing bars shall be made as described in Sec. 854*(c)*.

(b) Lateral Ties.—Lateral ties should be at least ¼ in. in diameter and should be spaced apart not over 16 bar diameters, 48 tie diameters, or the least dimension of the column. When there are more than four vertical bars, additional ties should be provided so that every longitudinal bar is held firmly in its designed position.

(c) Limits of Column Section.—In a tied column which for architectural reasons has a larger cross section than required by considerations of loading, a reduced effective area A_g not less than one-half of the total area may be used in applying the provisions of Sec. 855*(a)*, but the longitudinal reinforcement should be distributed over the full column section.

856. Composite Columns

(a) Allowable Load.—The allowable load on a composite column consisting of a structural steel or cast-iron column thoroughly encased in concrete reinforced with both longitudinal and spiral reinforcement, should not exceed that given by Formula (11).

$$P = 0.225A_cf'_c + f_sA_s + f_rA_r \quad \text{(11)}$$

Wherein A_c = net area of concrete section = $A_g - A_s - A_r$.
A_s = cross-sectional area of longitudinal bar reinforcement.
A_r = cross-sectional area of the steel or cast-iron core.
f_r = allowable unit stress in metal core, not to exceed 16,000 p.s.i. for a steel core; or 10,000 p.s.i. for a cast-iron core.

The remaining notation is that of Sec. 854.

(b) Details of Metal Core and Reinforcement.—The cross-sectional area of the metal core should not exceed 20 percent of the gross area of the column. If a hollow

metal core is used it should be filled with concrete. The amounts of longitudinal and spiral reinforcement and the requirements as to spacing of bars, details of splices, and thickness of protective shell outside the spiral should conform to the limiting values specified in Sec. 854*(b)*, *(c)*, and *(d)*. A clearance of at least three inches should be maintained between the spiral and the metal core at all points except that when the core consists of a structural steel H-column, the minimum clearance may be reduced to two inches.

(c) Splices and Connections.—Metal cores in composite columns shall be accurately milled at splices and positive provision shall be made for alignment of one core above another. Transfer of loads to the metal core should be provided for by the use of bearing members such as billets, brackets, or other positive connections; these should be provided at the top of the metal core and at intermediate floor levels where required. Ample section of concrete and continuity of reinforcement should be provided at the junction with beams and girders. The column as a whole should satisfy the requirements of Formula (11) at every section; in addition to this, the reinforced concrete portion should be designed to carry, in accordance with Formula (9), all floor loads brought onto the column at levels between the metal brackets or connections. In applying Formula (9) to a hollow core filled with concrete, the area of the concrete within the core should not be included in the area defined as A_g. At the column base, provision should be made to transfer the load to the footing at safe unit stresses in accordance with Sec. 870. The base of the metal core should be designed to transfer the load from the entire composite column to the footing, or it may be designed to transfer the load from the metal section only, provided it is so placed in the pier or pedestal as to leave ample section of concrete above the base for the transfer of load from the reinforced concrete section of the column by means of bond on the vertical reinforcement and by direct compression on the concrete.

(d) Allowable Load on Bare Metal Core.—The metal cores of composite columns should be designed to carry safely any construction or other loads to be placed upon them prior to their encasement in concrete.

857. Combination and Pipe Columns

(a) Combination Columns; Steel Columns Encased in Concrete.—The allowable load on a structural steel column which is encased in concrete at least 2½ in. thick over all metal (except rivet heads) reinforced as hereinafter required, should be computed by Formula (12).

$$P = A_r f'_r \left[1 + \frac{A_c}{100 A_r} \right] \qquad (12)$$

Wherein A_r = cross-sectional area of steel column.
f'_r = allowable stress for unencased steel column.
A_c = total area of concrete section, $= A_g - A_r$.

The concrete used should develop a compressive strength, f'_c, of at least 2,000 p.s.i. when tested according to the provisions of Sec. 310. The concrete should be reinforced by welded wire mesh having wire not smaller than No. 10 gage, spaced in the vertical direction not more than 4 in., and in the horizontal direction not more than 8 in. This mesh should extend entirely around the column at a distance of 1 in. inside the outer concrete surface and should be lap-spliced at least 40 wire diameters and wired at the splice.

Special brackets should be used to receive the entire floor load at each floor level. The steel column should be designed to carry safely any construction or other loads to be placed upon it prior to its encasement in concrete.

(b) Pipe Columns.—The allowable load on columns consisting of steel pipe filled with concrete should not exceed that given by Formula (13).

$$P = 0.225 f'_c A_c + f'_r A_r \quad \text{.......} (13)$$

The value of f'_r should be that given by Formula (14).

$$f'_r = \left[18{,}000 - 70 \frac{h}{R} \right] F \quad \text{.......} (14)$$

Wherein f'_r = allowable stress in the steel pipe section.
h = unsupported length of column.
R = radius of gyration of steel pipe section.
$F = \dfrac{\text{tensile yield point of pipe material}}{45{,}000}$

If the yield point is not known, the factor F shall be taken as 0.5.
If the concrete strength f' is not known it shall be assumed at 2,500 p.s.i.

858. Long Columns

(a) The maximum allowable load P' on axially loaded reinforced concrete or composite columns having a length, h, greater than 10 times the least lateral dimension, d, is given by Formula (15)

$$P' = P \left[1.3 - .03 \frac{h}{d} \right] \quad \text{.......} (15)$$

Wherein P = the allowable axial load on a short column as given by Formulas (9) and (11).

(b) The maximum allowable load P' on eccentrically loaded columns in which h/d exceeds 10 is also given by Formula (15) in which P is the allowable eccentrically applied load on a short column as determined by the provisions of Sec. 860–861. In long columns subjected to definite bending stresses, as determined in Sec. 859, the ratio h/d should not exceed 20.

859. Bending Moments in Columns

The bending moments in the columns of all reinforced concrete structures should be determined on the basis of loading conditions and restraint and should be provided for in the design. When the stiffness and strength of the columns are utilized to reduce moments in beams, girders, or slabs, as in the case of rigid frames in general, the need for recognizing column moments is obvious; in other forms of continuous construction where column moments are unavoidable, they should also be provided for in the design. In building frames, particular attention should be given to cases of unbalanced floor loads on both exterior and interior columns and of eccentric loading due to other causes. Wall columns should be designed to resist moments produced by: *(a)* loads on all floors of the building, *(b)* loads on a single exterior bay at two adjacent floor levels, or *(c)* loads on a single exterior bay at one floor level. Resistance to bending moments at any floor level should be provided by distributing the moment between the columns immediately above and below the given floor in proportion to their relative stiffnesses and conditions of restraint.

860. Combined Axial and Bending Stress

(a) In reinforced concrete columns subjected to bending moments, the recognized methods of analysis should be followed in calculating the stresses due to combined axial

load and bending. The maximum fiber stress in compression and (in the case of large eccentricities of loading) the tensile stress in the vertical bars will govern the design. The gross area of both spiral and tied columns should be used in the computations.

(b) For preliminary designs it will usually give satisfactory results to compute the combined fiber stress in compression on the basis of an uncracked section of the column using Formula (16).*

$$f_c = \frac{P}{A_g} \frac{\left[1 + \frac{ec}{R^2}\right]}{1 + (n - 1)p_g} \qquad (16)$$

Wherein e = eccentricity of resultant load, measured from the gravity axis.
c = distance from gravity axis to extreme fiber in compression.
R = radius of gyration of equivalent concrete section.
n = as given in Sec. 878.
Other terms as in Sec. 854.

The term $\frac{ec}{R^2}$ may be replaced by the value $\frac{6e}{t}$ for rectangular columns and $8e/t$ for round columns without appreciable error (t = overall depth of section). This design may then be analyzed by more accurate methods to insure that allowable stresses are not exceeded.

861. Allowable Combined Axial and Bending Stresses

(a) For spiral and tied columns, eccentrically loaded or otherwise subjected to combined axial compression and flexural stress, the maximum allowable compressive fiber stress, f_c, is given by Formula (17).

$$f_c = f_a \frac{1 + \frac{ec}{R^2}}{1 + C\frac{ec}{R^2}} \qquad (17)$$

Wherein the notation is that of Sec. 854 and 860, and in addition, f_a is the average allowable stress on an equivalent axially loaded concrete column, and C is the ratio of f_a to the allowable fiber stress for members in flexure.

Thus, $f_a = \frac{0.225f'_c + f_s p_g}{1 + (n - 1)p_g}$ for spiral columns, and 0.8 of this value for tied columns.

$$C = \frac{f_a}{0.45f'_c}.$$

(b) The allowable tensile stress in the longitudinal reinforcement may equal that specified for flexural members, provided however that splices in the tensile steel at or near the section of maximum column moment are capable of developing fully the yield point strength of the reinforcement.

862. Wind or Earthquake Stresses

When columns are subject to wind or earthquake stresses in addition to combined axial load and bending, the column section need not be increased unless the allowable stress given by Formula (17) is exceeded by more than one-third.

* This will result in a fairly accurate design if the eccentricity is less than ½ the overall column width, and the value of $p_g n$ is 0.3 or more.

Footings

863. General

These recommendations include the design of wall, isolated and combined footings. and raft foundations.

For purposes of design it is assumed that foundations may be divided into combinations of simple, continuous, or cantilever beams—statically determinate—and proportioned accordingly.

It is recommended that projecting portions of all footings, whether isolated or combined, be treated as simple cantilever beams. This differs from the practice of considering trapezoidal areas in computing bending moments, in that the moment of the forces over the entire area on one side of any section is included in the bending moment for that section. This provides a general method of computing cantilever moments in irregular as well as symmetrically shaped footings.

864. Unit Stresses

Footings should be designed to sustain the applied loads without exceeding the allowable working stresses given in Sec. 878. It should be noted that the allowable bond stress is reduced 25 percent in all tension regions requiring moment reinforcement in more than one direction. See also Sec. 821–827, and 830.

865. Calculation of Stresses

(a) The bending, shearing, and bond stresses in isolated or combined footings should be determined for the critical sections indicated in Sec. 866. For the projecting portion of a footing the bending moment at any section may be considered as the statical moment of the forces over the entire area of the footing on one side of a vertical plane passing through that section. In two-way isolated footings, tensile reinforcement should be determined on the basis of 85 percent of the moments thus computed; in one-way footings, such as wall footings, the full moment should be used.

(b) For isolated footings cast as a unit, the section resisting bending in any direction may be the full vertical section cut by the plane about which bending moment is computed, except for the cases of sloped or stepped footings, as treated below.

In sloped footings the section resisting bending may be as defined above provided the slope of the top is not such as to require special treatment of the projecting cantilever as a wedge-shaped beam. A slope of 1 vertical to 2 horizontal may be considered as a satisfactory limit. The slope of the footing top need not be uniform, provided the limit of 1 to 2 is not exceeded at any point.

For stepped footings, cast as a unit, the section resisting bending should be limited to the lower block, or to the area falling within the boundaries of an imaginary sloped footing which meets the above requirements as to slope and which lies entirely within the stepped footing.

In isolated footings the reinforcement should be distributed over the entire width of the section.

(c) In case the reinforcement does not cross at right angles a section at which bending moment is computed, only the component normal to the section should be considered effective, that is, the normal cross-sectional area of the bar multiplied by the sine of the angle which the bar makes with the section.

866. Critical Sections

(a) The critical section for bending in a concrete footing which supports a concrete column, pedestal, or wall, should be taken at the face of the column, pedestal or wall.

In the case of columns other than square or rectangular the critical section should be taken at the side of a concentric square of equivalent area. For footings under masonry walls where bond with the footings is reduced to friction value, the critical section should be assumed midway between the middle and the edge of the wall. For footings under metallic column bases the critical section should be assumed midway between the face of the column and the edge of the metallic base. The load may be considered as uniformly distributed over the column, pedestal, or wall, or metallic column base.

(b) The critical sections for bond should be taken at the same plane as those for bending, and the shear used for computing bond should be based on the same loading and section as for bending. Bond should also be investigated at planes where changes of section or of reinforcement occur.

(c) The critical section for diagonal tension in footings on soil should be considered as the concentric vertical section through the footing at a distance d from each face of the column, pedestal, or wall. This depth d should be measured from the top of the section to the plane of the centroid of longitudinal reinforcement.

(d) The critical section for diagonal tension for footings supported on piles should be considered as the concentric vertical section through the footing at a distance $d/2$ from each face of the column, pedestal, or wall, and any piles whose centers are at, or outside this section should be included in computing the shear.

(e) In sloped or stepped footings, analyses should be made of stresses at sections where the slope or depth changes outside the critical section as defined in *(a)*, *(b)*, *(c)*, and *(d)* above.

867. Plain Concrete Footings

(a) In plain concrete footings the section should be computed as a monolithic section of the entire width and depth measured from a plane two inches above the bottom of the footing. The maximum tensile fiber stress in the concrete should not exceed 0.03 of the ultimate compressive strength of the concrete. The average shearing stress should not exceed 0.02 of the ultimate compressive strength of the concrete, computed on a concentric vertical section through the footing at a distance ($d - 2$ in.) from each face of the column, pedestal, or wall, excluding 2 in. of depth nearest the bottom.

(b) The area of the top of the footing should not be less than that given by Formula (18), Sec. 870.

868. Combined Footings

(a) For reinforced concrete columns, the critical section for transverse bending should be taken at the faces of the columns or pedestals. For footings under metallic column bases, the critical section should be assumed midway between the face of the column and the edge of the metallic base. The transverse reinforcement should be divided into groups proportionate in sectional area to the column loads. The transverse reinforcement at each column should be placed uniformly within a band having a width not greater than the width of the column plus twice the effective depth of the footing. Longitudinal reinforcement should be distributed over the whole width.

(b) The critical sections for diagonal tension in combined footings should be taken at the faces of the supported members for all beam elements and also for all projecting cantilevers.

869. Raft Foundation

A raft foundation should be designed as an inverted floor system.

870. Transfer of Stress at Base of Column

(a) The compressive stress in the longitudinal reinforcement at the base of the column should be transferred to a pedestal or to a footing by extending the bars into the pedestal or footing or by the use of dowels. There should be at least one dowel for each column bar, and the total sectional area of the dowels should be not less than the sectional area of the longitudinal reinforcement in the column. The dowels or column bars should extend into the column, and into the pedestal or footing the distance required to transfer to the concrete, by allowable bond stresses, their full working strength. Hooks should not be considered as adding to bond resistance in compression. In addition to the provision for the transference of load by dowels there should be provided at the top of the footing or pedestal an area *(A)* which is equal to or greater than that given by the following formula:

$$A = \left[\frac{f_b}{.25f'_c}\right]^3 A' \qquad (18)$$

Wherein f_b = allowable working stress on the concrete in the column.
A' = area of the column.
f'_c = ultimate compressive strength of the concrete in the supporting member.

In all cases the concrete in the supporting member should be of such quality that the ratio of f_b to $.25f'_c$ does not exceed 1½.

(b) In sloped or stepped footings, A may be taken as the area of the uppermost horizontal surface of the footing or as the area of the lower base of the largest frustum of a pyramid or cone contained wholly within the footing and having for its upper base the loaded area A' and having side slopes of 1 vertical to 2 horizontal.

(c) Formula (18) may be applied to determine the area required at the top of the footing or pedestal under a metal base. In this case f_b is to be taken as the actual bearing stress over the loaded area, and the limitation given in *(a)* for the quality of concrete should apply.

871. Concentrically Loaded Pedestals and Pedestal Footings

Plain Concrete.—(a) The compressive stress on the gross area of a pedestal or the upper surface of a pedestal footing should not exceed $0.25f'_c$ unless reinforcement is provided and the member is designed as a reinforced concrete column.

(b) The depth and width of a pedestal or pedestal footing should be determined by consideration of shear and bending stresses as outlined under plain concrete footings (Sec. 867). A pedestal footing supported directly on piles should have a mat of reinforcing, of cross-sectional area not less than 0.20 sq. in per ft. in each direction, placed 3 in. above the top of the piles.

Retaining Walls

872. Investigation of Stability

(a) Retaining walls, both plain and reinforced concrete, should be designed to resist the pressures of the retained material including both dead and live load surcharge to which they may be subjected.

(b) The wall should be designed for stability against (1) overturning, (2) sliding, (3) maximum soil pressure, as well as for moment, shear, bond, and maximum pressure at sections of the wall at regular intervals of height.

873. Moments and Pressures

(a) The pressures and overturning moments exerted by the retained material and the surcharge thereon, if not determined experimentally, should be determined by means of analysis conforming with accepted practice.*

(b) Where a retaining wall is subjected to the various pressures of different materials along its height, each height of wall should be analyzed for the filling material behind it, the material above each plane considered being computed as surcharge.

874. Foundation Pressures

Foundation pressures should be determined from the consideration of the location, magnitude, and direction of the resultant thrust at the base.

875. Allowable Unit Stresses and Critical Sections

(a) Retaining walls, including footings, both plain and reinforced, should be so designed that at no section or part of wall or footing should the allowable stresses for shear, bond, compression or tension as provided in Sec. 878 be exceeded.

(b) Critical sections in the various parts of the wall or footing should be taken as those recommended for beams, slabs, and footings.

876. Provisions for Stability

(a) For stability against sliding, resistance should be provided for at least twice the computed active horizontal thrust on the wall.

(b) For stability against overturning, the righting moment of the weight of the wall, fill, and other superimposed loads should be at least 50 percent greater than the overturning moment due to the thrust of the filling material together with that due to any dead load or live load surcharge. For walls resting on soils, the resultant pressure at the base should fall within the middle third of the base; and where vibration occurs, near the center of the base, to reduce unequal settlement.

(c) The maximum soil pressure resulting from the maximum thrust at the bottom of the footing inclusive of the effect of eccentricity of such thrust should not be greater than the permissible bearing power of the soil which supports the wall. Consideration should be given to a possible redistribution of the soil pressure due to such eccentricity and to the effect of possible vibration on such eccentricity and the resulting unequal settlement.

877. Details of Design and Construction

(a) In counterforted walls the counterforts may be designed as T-beam sections and the vertical wall computed as a continuous slab and so reinforced. Properly anchored stirrups or tie bars should be provided of required size and spacing to resist the earth thrust or soil pressure transferred by the slabs (wall or footing) to the counterforts.

(b) In buttressed walls the buttresses should be designed as rectangular beams and the vertical walls should be designed as a continuous slab reinforced for continuity.

(c) In designing the wall footing, consideration should be given to the necessity of tying the footing slab to the heel of the wall by adequate reinforcement when the downward pressure of the fill and the weight of concrete exceed the upward pressure of the soil. Where keys into the foundation are provided for resistance against sliding or for other reasons, they should be placed monolithically with the base.

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* Where the source of filling material is known in advance, investigation should be made of its unit weight, its angle of internal friction under various conditions of saturation and height. Consideration should be given to possible hydrostatic pressure and the reduction of weight of the filling material due to buoyancy.

(d) Longitudinal reinforcement for volume changes due to shrinkage and to changes in temperature should be provided in all reinforced concrete walls near the exposed face to an amount of not less than 0.50 sq. in. area per ft. of height with a maximum spacing of bars of 12 in. center to center.*

(e) No reinforcement should be less than two inches from any exposed face of the wall. Where concrete is in contact with soil, the reinforcement should be at least three inches from the surface.

(f) In reinforced concrete walls vertical construction joints with "V" notches at the face should be provided at sections preferably not over 30 ft. apart, with reinforcement carried through the joint. Expansion joints with grooved lock joints should be provided not more than 100 ft. apart for reinforced concrete walls; reinforcement should not be carried through expansion joints. In plain concrete walls similar expansion joints should be provided, preferably not more than 30 ft. apart.

(g) Construction and expansion joints in the coping and balustrade of retaining walls should be placed over all joints in the walls. Additional joints in balustrade and copings may be desirable.

(h) Drainage should be provided at the backs of retaining walls, preferably by the use of layers of broken stone extending horizontally for the full length of the wall at an elevation where water can readily be disposed of, together with vertical layers extending up to the coping at intervals of about 15 ft. along the wall. Weep holes at least 4 in. in diameter should be provided about 15 ft. apart, or at least one in each panel of a counterforted wall, at such elevation that the drainage water may readily escape.

(i) Exposed faces of walls should be given a slight batter (about ¼ in. to 1 ft.) to avoid appearance of tilting.

Unit Stresses

878. Allowable Working Stresses in Concrete and in Reinforcement

(a) The recommended unit stresses for concrete are based on the ultimate compressive strength, f'_c, of the concrete at 28 days. The methods of control, proportioning, and curing required to obtain the desired strength are given in Chapter III.

(b) The recommended working stresses in the steel reinforcement are based on the consideration of two important factors:

1. The yield point of the steel.
2. The extent to which cracks may develop on the tension face of flexural members.

The values given for tension are limited to approximately 50 percent of the yield point of the reinforcement, but with an upper limit of 20,000 p.s.i. for important structural members, and 25,000 p.s.i. for the special case of one-way slabs reinforced with wire mesh and small size bars. These upper limits are to apply for all grades of reinforcement regardless of yield point.

(c) Static and Impact Loads.—For static loads or for moving loads where appropriate allowances have been made for impact, the committee recommends the unit stresses given in Table 7.

(d) Maximum Combined Stresses.—Where stresses due to wind, earthquake, or other unusual forces, are combined with those due to static or impact loads, the sum of the stresses should not exceed the allowable values given in Table 7 by more than one-third.

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* It is desirable to use bars of small section and close spacing for this purpose.

TABLE 7—RECOMMENDED WORKING STRESSES (STATIC AND IMPACT LOADS)

Modular Ratio: n for use in flexural calculations involving percentage of tensile steel, or tensile stress in the reinforcement. The values given are for concrete made from normal weight aggregates: for lightweight concrete, the values of n should be double those shown.	f'_c = 2,000—2,400	n =15
	= 2,500—2,900	=12
	= 3,000—3,900	=10
	= 4,000—4,900	= 8
	above 5,000	= 6

CONCRETE

Flexure: fc

Extreme fiber stress in compression ---------- $f_c=0.45f'_c$
Extreme fiber stress in tension (for plain concrete footings only) ---------- $f_c=0.03f'_c$

Shear: v

Beams without web reinforcement and without end anchorage of longitudinal steel ---------- $v_c=0.02f'_c$
Beams without web reinforcement but with end anchorage of longitudinal steel ---------- $v_c=0.03f'_c$
Beams with properly designed web reinforcement, but without end anchorage of longitudinal steel ---------- $v_c=0.06f'_c$
Beams with properly designed web reinforcement and with end anchorage of longitudinal steel (when v_c, is in excess of $0.06f'_c$ web reinforcement should provide for total shear (see Sec. 817(e)) ---------- $v_c=0.12f'_c$
Flat slabs at distance d from edge of column capital, or dropped panel ---------- $v_c=0.03f'_c$
Footings with longitudinal bars having no end anchorage ---------- $v_c=0.02f'_c$
Footings with longitudinal bars having end anchorage ---------- $v_c=0.03f'_c$
Combined footings and raft foundations designed as beam elements with properly designed web reinforcement and end anchorage ---------- $v_c=0.06f'_c$

Bond: u

In beams and slabs and one-way footings:
Plain bars ---------- $u=0.04f'_c$ but not to exceed 160 p.s.i.
Deformed bars ---------- $u=0.05f'_c$ but not to exceed 200 p.s.i.
In multiple-way footings:
Plain bars ---------- $u=0.03f'_c$ but not to exceed 160 p.s.i.
Deformed bars ---------- $u=0.0375f'_c$ but not to exceed 200 p.s.i.
(When end anchorage is provided (see Sec. 826), *one and one-half times* these values in bond may be used, but in no case to exceed 200 p.s.i. for plain bars and 250 p.s.i. for deformed bars.)

Bearing: fc

Full area loaded ---------- $f_c=0.25f'_c$
Load on partial area, f_c variable (see Sec. 870), maximum ---------- $f_c=0.375f'_c$

Axial Compression:

In Pedestals ---------- $f_c=0.25f'_c$
In Columns (see Sec. 854-855) ----------

TABLE 7—RECOMMENDED WORKING STRESSES (STATIC AND IMPACT LOADS)—Continued

REINFORCEMENT

Tension in Flexural Members, with or without axial loads:

Structural grade steel bars ---- f_s=18,000 p.s.i.
Structural steel shapes ---- f_s=18,000 p.s.i.
Intermediate grade steel bars, and hard-grade bars (billet steel, rail steel, or axle steel) ---- f_s=20,000 p.s.i.
Wire mesh or bars not exceeding ½ in. in diameter when used in one-way solid slabs only ---- f_s=50% of min. yield point, but not to exceed 25,000 p.s.i.

Tension in Web Reinforcement:

All grades of steel ---- f_s=16,000 p.s.i.

Tension in Column Spirals (see Sec. 854)

Compression in Column Verticals (see Sec. 854)

Intermediate grade steel bars ---- f_s=16,000 p.s.i.
Hard-grade steel bars (billet steel, rail steel, or axle steel) ---- f_s=20,000 p.s.i.

Compression in Composite and Combination Columns (see Sec. 856-857)

Compressive Reinforcement in Flexural Members (see Sec. 804(*c*))

Standard Specifications for Concrete and Reinforced Concrete

Materials

Cement

The cement to be used shall be one or more of the following types as designated by the Engineer.

201-S. Portland Cement

Normal Portland cement shall conform to the Standard Specifications for Portland Cement of the American Society for Testing Materials (C9–38).

202-S. High Early Strength Portland Cement

High early strength Portland cement shall conform to Standard Specifications of the American Society for Testing Materials (C74–39).

203-S. Special Cements

Special cements shall conform to the following requirements: (See Recommended Practice—Sec. 202).

Admixtures

204-S. General

Materials used as admixtures shall conform to the following requirements: (see Recommended Practice—Sec. 203).

Water

205-S. General

Water for concrete shall be clean and free from injurious amounts of oil, acid, alkali, organic matter, or other deleterious substances.

206-S. Mortar Strength

When subjected to the mortar strength test (see Sec. 229–S for method of test) the strength at 28 days of mortar specimens made with the water under examination and normal Portland cement shall be at least 90 percent of the strength of similar specimens made with the same cement and with water of known satisfactory quality. (See Recommended Practice—Sec. 204.)

Fine Aggregate

207-S. General

Fine aggregate shall consist of natural sand, sand prepared from the product obtained by crushing stone, gravel, or air-cooled blast-furnace slag; or, subject to the approval of the Engineer, other inert materials having similar characteristics. The particular type or types to be furnished shall be specified by the Engineer. (See also Sec. 226–S to 228–S.)

208-S. Grading

Fine aggregate shall be graded from coarse to fine within the limits shown in the following table. (See Recommended Practice, Sec. 205 and 206.)

Sieve Size	*Total Passing % by Weight*
3/8 in.	100
No. 4	95–100
No. 16	45–80
No. 50	5–30
No. 100	0–8

209-S. Uniformity

For the purpose of controlling the grading of fine aggregate from any one source, a preliminary sample shall be submitted prior to actual deliveries. This sample shall be representative of the material which it is proposed to furnish. Any shipment of fine aggregate made during the progress of the work which shows a variation in fineness modulus greater than 0.20 either way from the fineness modulus of the preliminary sample shall be rejected or, at the option of the Engineer, may be accepted subject to such changes in concrete proportions as may be necessary by reason of failure to comply with the requirements of this section.

210-S. Deleterious Substances

Deleterious substances shall not be present in excess of the amounts shown in the table below (see Recommended Practice, Sec. 205 and 208).

	Permissible Limits % by Weight	
	Recommended	*Maximum*
Clay lumps	1	1½
Coal and lignite	¼	1
Material finer than No. 200 sieve		
(a) In concrete subject to surface abrasion	2	3
(b) All other classes of structures	3	5
Other deleterious substances (as may be specified)	——	——

211-S. Organic Impurities

The fine aggregate when tested in accordance with the method of test for organic impurities (see Sec. 229–S*(c)*) shall show a color not darker than the standard color unless the material complies with the mortar strength test specified in Sec. 212–S.

212-S. Mortar Strength

Mortar specimens made with the fine aggregate when tested in accordance with the mortar strength test (see Sec. 229–S) shall have an average compressive strength of at least 90 percent of the strength of similar specimens made with the same cement and Ottawa sand graded as specified in ASTM Tentative Method of Test for Compressive Strength of Portland Cement Mortars (ASTM Designation: C109–37T) when tested at an age of not less than seven days when normal Portland cement is used and not less than three days when high early strength cement is used.*

213-S. Soundness

(a) The fine aggregate when subjected to five alternations of the sodium sulfate soundness test (see Sec. 229–S) shall conform to the following requirements: (See Recommended Practice, Sec. 205 and 209).

* Note: The above requirements are intended to assure the use of fine aggregate of satisfactory quality from the standpoint of concrete strength. The 10 percent tolerance is allowed to cover unavoidable variations in normal testing procedure.

	Permissible Limits Per Cent	
	Recommended	*Maximum*
Average weighted loss	8	12

(*b*) Fine aggregate failing to meet the requirement shown in (*a*) above may be accepted, provided it is shown by evidence satisfactory to the Engineer that concrete of comparable proportions made from similar aggregate from the same source has been exposed to natural weathering for a period of at least five years without appreciable disintegration.

(*c*) The requirements for soundness given in (*a*) and (*b*) above may be waived in the case of aggregate for use in structures or portions of structures not exposed to weathering.

Coarse Aggregate

214-S. General

Coarse aggregate shall consist of crushed stone, gravel, air-cooled blast-furnace slag, or, subject to the approval of the Engineer, other inert materials having similar characteristics. The particular type or types to be furnished shall be specified by the Engineer. (See also Sec. 220–S to 225–S.)

215-S. Grading

Coarse aggregate of the sizes designated shall conform to the following requirements:

Designated Sizes	*Percentage by Weight Passing Laboratory Sieves Having Square Openings*										
	4-In.	*3½-In.*	*2½-In.*	*2-In.*	*1½-In.*	*1-In.*	*¾-In.*	*½-In.*	*⅜-In.*	*No. 4*	*No. 8*
No. 4-½ in.	---	---	---	---	---	---	100	90–100	40–75	0–15	0–5
No. 4-¾ in.	---	---	---	---	---	100	90–100	---	20–55	0–10	0–5
No. 4-1 in.	---	---	---	---	100	90–100	---	25–60	---	0–10	---
No. 4-1½ in.	---	---	---	100	95–100	---	35–70	---	10–30	0–5	---
No. 4-2 in.	---	---	100	95–100	---	35–70	---	10–30	---	0–5	---
¾-1½ in.	---	---	---	100	90–100	20–55	0–15	---	---	---	---
1-2 in.	---	---	100	90–100	35–70	0–15	---	---	---	---	---
2-3½ in.	100	90–100	---	0–15	---	---	---	---	---	---	---

216-S. Deleterious Substances

Deleterious substances shall not be present in excess of the following amounts: (See Recommended Practice, Sec. 205 and 208).

	Permissible Limits % by Weight	
	Recommended	*Maximum*
Soft fragments	2	5
Coal and lignite	¼	1
Clay lumps	¼	¼
Material finer than No. 200 sieve	½*	1*
Other deleterious substances (as may be specified)	—	—

*Note: When the material finer than the No. 200 sieve consists essentially of crusher dust the maximum amounts permitted may be raised to ¾ and 1½ percent, respectively.

217-S. Soundness

(a) The coarse aggregate when subjected to five alternations of the sodium sulfate test (see Sec. 229–S) shall conform to the following requirement: (see Recommended Practice, Sec. 205 and 209).

	Permissible Limits Percent	
	Recommended	*Maximum*
Average weighted loss	12	15

(b) Coarse aggregate failing to meet the requirement shown in *(a)* above may be accepted, provided it is shown by evidence satisfactory to the Engineer that concrete of comparable proportions made from similar aggregate from the same source has been exposed to natural weathering for a period of at least five years without appreciable disintegration.

(c) The requirements for soundness given in *(a)* and *(b)* above may be waived in the case of aggregate for use in structures or portions of structures not exposed to weathering.

218-S. Weight per Cubic Foot of Slag

Blast-furnace slag graded as used shall meet the following requirements: (See Recommended Practice, Sec. 205).

	Recommended Permissible Limits		*Minimum Permissible Limits*	
	Concrete subject to surface abrasion	*Concrete not subject to surface abrasion*	*Concrete subject to surface abrasion*	*Concrete not subject to surface abrasion*
Weight, lb. per cu. ft., not less than	75	70	70	65

219-S. Resistance to Abrasion

Crushed stone and gravel to be used in concrete subject to surface abrasion, such as pavements, heavy duty floors, structures subjected to the abrasive action of floating ice, etc., shall meet the following requirements for abrasion loss when tested for resistance to abrasion (See Sec. 229–S). (See Recommended Practice, Sec. 212.)

	Permissible Limits % by Weight	
Material	*Recommended*	*Maximum*
Crushed stone	5	9
Gravel (100 per cent uncrushed)	10	20
Gravel (100 per cent crushed)	20	30
Gravel (--- per cent crushed)	----	----

Rubble and Cyclopean Aggregate

220-S. Rubble Aggregate

Rubble aggregate shall consist of clean, hard, durable stone or gravel retained on a 6-in. square opening and with individual particles weighing not more than 100 lb.

221-S. Cyclopean Aggregate

Cyclopean aggregate shall consist of clean, hard, durable stone or gravel with individual particles weighing more than 100 lb.

AGGREGATES FOR LIGHTWEIGHT CONCRETE

222-S. General

Lightweight aggregates shall consist of pumice, lava, tufa, cinders, specially prepared slag, coke, burnt clay, or other products having similar characteristics. Lightweight aggregates shall conform to the requirements of the general specifications for grading (Sec. 208–S to 215–S), organic impurities (Sec. 211–S), soundness (Sec. 213–S), and for mortar strength, as specified in Sec. 212–S, except that the minimum strength of the lightweight aggregate mortar made with aggregate in a saturated and surface dry condition shall be at least 70 percent of that of Ottawa sand mortar. (See Recommended Practice, Sec. 210.)

223-S. Deleterious Substances

Lightweight aggregates shall conform to the following requirements: (See Sec. 229–S for method of test).

	Fine Aggregate Percent	*Coarse Aggregate Percent*
Clay lumps, not more than	1.5	1.0
Coal, not more than	1.5*	1.5*
Material finer than No. 200 sieve, not more than	4.0	2.0
Other deleterious substances (as may be specified)	——	——

224-S. Weight per Cubic Foot

Lightweight aggregates shall meet the following requirements (See Sec. 210, Recommended Practice):

	Pounds
Maximum weight per cubic foot, dry and loose,	
Fine aggregate	70
Coarse aggregate	55

AGGREGATES FOR USE IN FIREPROOFING

225-S. Fireproofing Aggregate

(a) Aggregates meeting the requirements of Sec. 207–S to 219–S, inclusive, or Sec. 222–S to 224–S, inclusive, of these specifications are suitable for use in fireproof construction. When used in fireproof construction they shall be divided into two groups as follows:

Group 1.—Blast-furnace slag, limestone, calcareous gravel, trap rock, burnt clay or shale, cinders containing not more than 25 percent of combustible material and not more than 5 percent of volatile material, and other materials meeting the requirements of these specifications and containing not more than 30 percent of quartz, chert, flint, and similar materials.

Group 2.—Granite, quartzite, siliceous gravel, sandstone, gneiss, cinders containing more than 25 percent, but not more than 40 percent of combustible material and not more than 5 percent of volatile material and other materials meeting the requirements of these specifications, and containing more than 30 percent of quartz, chert, flint and similar materials.

(b) The fire protection requirements shown on the drawings are based on the use of aggregates in Group 1,—Group 2.**

* Shall not apply to aggregate derived from coal (cinders, coke, etc.).

** The Engineer shall strike out one of the two groups indicated. See Recommended Practice Sec. 505 for recommendations regarding minimum protection of reinforcement when using aggregates of either group.

Methods of Sampling and Testing

226-S. Methods of Sampling

Methods of sampling Portland cement and high early strength Portland cement shall be in accordance with ASTM Standard Methods of Sampling and Physical Testing of Portland Cement (ASTM Designation: C77–39).

227-S.

Methods of sampling aggregates shall be in accordance with ASTM Tentative Methods of Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials Including Some Material Survey Methods (ASTM Designation: D75–39T).

228-S. Methods of Testing

Portland cement and high early strength Portland cement shall be tested in accordance with ASTM Standard Methods of Sampling and Physical Testing of Portland cement (ASTM Designation: C77–39).

229-S.

Fine and coarse aggregate shall be tested in accordance with the following:

(a) Grading.—ASTM Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregate (ASTM Designation: C136–39).

(b) Uniformity of Grading—Fineness Modulus.—The fineness modulus of the aggregate shall be determined by adding the total percentages retained on the following U. S. Standard sieves and dividing by 100: 3-in., 1½-in., ¾-in., ⅜-in., No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100.

(c) Organic Impurities.—ASTM Standard Method of Test for Organic Impurities in Sands for Concrete (ASTM Designation: C40–33).

(d) Coal and Lignite.—ASTM Standard Method of Test for Coal and Lignite in Sand (ASTM Designation: C123–39).

(e) Fineness.—ASTM Standard Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates (ASTM Designation: C117–37).

(f) Clay Lumps.—The percentages of clay lumps shall be determined by examining the various fractions which remain after the test for grading. Any particles that can be broken up with the fingers shall be classified as clay lumps and the total percentages by weight of all clay lumps shall be determined on the basis of the total original weight of the sample.

(g) Mortar Strength.—ASTM Standard Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (ASTM Designation: C87–39).

(h) Soundness—Fine and Coarse Aggregate.—ASTM Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (ASTM Designation: C88–39T).

(i) Resistance to Abrasion

1. *Stone.*—ASTM Standard Method of Test for Abrasion of Rock by Use of the Deval Machine (ASTM Designation: D2–33).

2. *Gravel.*—ASTM Tentative Method of Test for Abrasion of Gravel by Use of the Deval Machine (ASTM Designation: D289–37T).

(j) Weight per Cubic Foot of Slag.—ASTM Standard Method of Test for Unit Weight of Aggregate (ASTM Designation: C29–39).

	Permissible Limits Per Cent Recommended	Maximum
Average weighted loss	8	12

(b) Fine aggregate failing to meet the requirement shown in *(a)* above may be accepted, provided it is shown by evidence satisfactory to the Engineer that concrete of comparable proportions made from similar aggregate from the same source has been exposed to natural weathering for a period of at least five years without appreciable disintegration.

(c) The requirements for soundness given in *(a)* and *(b)* above may be waived in the case of aggregate for use in structures or portions of structures not exposed to weathering.

Coarse Aggregate

214-S. General

Coarse aggregate shall consist of crushed stone, gravel, air-cooled blast-furnace slag, or, subject to the approval of the Engineer, other inert materials having similar characteristics. The particular type or types to be furnished shall be specified by the Engineer. (See also Sec. 220–S to 225–S.)

215-S. Grading

Coarse aggregate of the sizes designated shall conform to the following requirements:

Designated Sizes	*Percentage by Weight Passing Laboratory Sieves Having Square Openings*										
	4-In.	*3½-In.*	*2½-In.*	*2-In.*	*1½-In.*	*1-In.*	*¾-In.*	*½-In.*	*⅜-In.*	*No. 4*	*No. 8*
No. 4-½ in.	—	—	—	—	—	—	100	90–100	40–75	0–15	0–5
No. 4-¾ in.	—	—	—	—	—	100	90–100	—	20–55	0–10	0–5
No. 4-1 in.	—	—	—	—	100	90–100	—	25–60	—	0–10	—
No. 4-1½ in.	—	—	—	100	95–100	—	35–70	—	10–30	0–5	—
No. 4-2 in.	—	—	100	95–100	—	35–70		10–30	—	0–5	—
¾-1½ in.	—	—	—	100	90–100	20–55	0–15	—	—	—	—
1-2 in.	—	—	100	90–100	35–70	0–15	—	—	—	—	—
2-3½ in.	100	90–100	—	0–15	—	—	—	—	—	—	—

216-S. Deleterious Substances

Deleterious substances shall not be present in excess of the following amounts: (See Recommended Practice, Sec. 205 and 208).

	Permissible Limits % by Weight Recommended	Maximum
Soft fragments	2	5
Coal and lignite	¼	1
Clay lumps	¼	¼
Material finer than No. 200 sieve	½*	1*
Other deleterious substances (as may be specified)	—	—

*Note: When the material finer than the No. 200 sieve consists essentially of crusher dust the maximum amounts permitted may be raised to ¾ and 1½ percent, respectively.

217-S. Soundness

(a) The coarse aggregate when subjected to five alternations of the sodium sulfate test (see Sec. 229–S) shall conform to the following requirement: (see Recommended Practice, Sec. 205 and 209).

	Permissible Limits Percent	
	Recommended	*Maximum*
Average weighted loss	12	15

(b) Coarse aggregate failing to meet the requirement shown in *(a)* above may be accepted, provided it is shown by evidence satisfactory to the Engineer that concrete of comparable proportions made from similar aggregate from the same source has been exposed to natural weathering for a period of at least five years without appreciable disintegration.

(c) The requirements for soundness given in *(a)* and *(b)* above may be waived in the case of aggregate for use in structures or portions of structures not exposed to weathering.

218-S. Weight per Cubic Foot of Slag

Blast-furnace slag graded as used shall meet the following requirements: (See Recommended Practice, Sec. 205).

	Recommended Permissible Limits		*Minimum Permissible Limits*	
	Concrete subject to surface abrasion	*Concrete not subject to surface abrasion*	*Concrete subject to surface abrasion*	*Concrete not subject to surface abrasion*
Weight, lb. per cu. ft., not less than	75	70	70	65

219-S. Resistance to Abrasion

Crushed stone and gravel to be used in concrete subject to surface abrasion, such as pavements, heavy duty floors, structures subjected to the abrasive action of floating ice, etc., shall meet the following requirements for abrasion loss when tested for resistance to abrasion (See Sec. 229–S). (See Recommended Practice, Sec. 212.)

	Permissible Limits % by Weight	
Material	*Recommended*	*Maximum*
Crushed stone	5	9
Gravel (100 per cent uncrushed)	10	20
Gravel (100 per cent crushed)	20	30
Gravel (--- per cent crushed)	----	----

Rubble and Cyclopean Aggregate

220-S. Rubble Aggregate

Rubble aggregate shall consist of clean, hard, durable stone or gravel retained on a 6-in. square opening and with individual particles weighing not more than 100 lb.

221-S. Cyclopean Aggregate

Cyclopean aggregate shall consist of clean, hard, durable stone or gravel with individual particles weighing more than 100 lb.

305-SA. Changes in Consistency for Mechanical Vibration

When high frequency mechanical vibration is used for compacting concrete, the limiting consistencies in Table A may be modified subject to the approval of the Engineer. The proportions and consistencies, however, shall be such that with the vibratory equipment in use the full requirements of Sec. 304–SA shall be satisfied.

306-SA. Changes in Proportions or Materials by the Engineer

If, during the progress of the work, it is found impossible to secure concrete of the required workability and strength with the materials being furnished by the Contractor, the Engineer may order such changes in proportions or materials, or both, as may be necessary to secure the desired properties, subject to the limiting requirements shown in Table A. Any changes so ordered shall be made at the Contractor's expense, and no extra compensation will be allowed by reason of such changes.

307-SA. Changes in Materials by the Contractor

If, during the progress of the work, the Contractor desires to use materials other than those originally approved, or if the materials from the sources originally approved change in characteristics, he shall submit, for approval, evidence satisfactory to the Engineer that the new combination of materials will produce concrete meeting the requirements shown in Table A, and will not bring about objectionable changes in the color or appearance of the structure.

308-SA. Changes in Requirements

Regardless of the limitations of Table A, at any time during the progress of the work, the owner shall have the right to make such changes in the materials or proportions, or both, as he may consider necessary to meet the requirements of the structure. In such case, the Contractor shall be compensated in accordance with the terms of the contract for the additional cost of materials and additional handling and placing costs, if any, entailed by changed materials or mixtures, or both, which are not covered by the specification requirements shown in Table A for the respective portions of the work involved.

309-SA. Concrete Made with High Early Strength Portland Cement

When high early strength Portland cement is used in lieu of normal Portland cement, the requirements given in Table A shall apply, except that the "Minimum allowable strength at 28 days" specified for normal Portland cement shall be the minimum allowable strength at 7 days. The ages at time of test specified in Sec. 302–SA shall be 3 days and 7 days in lieu of the 7-day and 28-day ages specified for normal Portland cement.

Proportioning: Alternate B

Specifications Based Primarily on Designated Cement Content

301-SB. Proportions

All concrete shall be proportioned as indicated in Table B.

302-SB. Cement Factor

The cement factor given in column 3 of Table B indicates the weight of cement per cubic yard of concrete when the concrete is in a freshly mixed condition. The volume of the freshly mixed concrete shall be assumed to be the absolute volume of the cement, plus the volume of the mixing water, plus the displaced volumes of the saturated, surface-dry aggregates. The quantity of mixing water to be used in this calculation shall not include water absorbed by the aggregates.

TABLE B*

Class of Concrete	Estimated 28-Day Compressive Flexual Strength; p.s.i. *	Cement Factor Sacks Cement (94 lb.) per cu. yd. Concrete	Max. Water per 94 lb. Cement; Gal.	Max. Size Agg.; In.	Fine Agg.; % Total Agg. by Weight (range) *	Slump, Range; In.	Approx. Wts. Saturated Surface-Dry Agg. Per Sack (94 lb.) of Cement (See note A below)	
							Fine Agg. lb.	Coarse Agg. lb.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

NOTE A: The approximate weights in columns 8 and 9 have been determined on the assumption that the aggregates are in a saturated, surface-dry condition and have a bulk specific gravity of 2.65.

* The Engineer should fill in the details of Table B to indicate the characteristics of the concrete which are desired for each part of the work. See Sec. 305 and 307, Recommended Practice, for suggestions. The Engineer should strike out one of the words "Flexural" or "Compressive" in column 2 as may be required.

303-SB. Variations in Proportions

In order to obtain proper workability and a smooth, dense, homogeneous, plastic mixture, free from segregation, the percent of fine aggregate may be varied within the limits indicated with the approval of the Engineer. The estimated 28-day strengths indicated in column 2 of Table B are the strengths used in the design calculations.

The Engineer will verify strengths by tests made during the progress of the work and in accordance with the requirements of Sec. 321–S to 325–S. When a ratio between 7-day and 28-day strengths has been established by these tests or by preliminary tests, the 7-day strengths may be taken as a satisfactory indication of the 28-day strengths. In the event that cement in excess of that indicated in Table B is necessary to produce concrete of the indicated strength or workability, the cement factor shall be increased as directed by the Engineer, and the Contractor shall receive extra compensation for the additional cement so used. In the event that cement less than that indicated in Table B is sufficient to produce concrete of the indicated strength or workability the Engineer may order a reduction in the cement factor, in which case there shall be an adjustment in contract price equal to the actual difference in cost to the Contractor of the required cement and aggregates.

304-SB. Water Content and Slump Range

The maximum quantity of water per 94 lb. of cement specified in Table B shall include the free water in the aggregates; however, moisture absorbed by the aggregates shall not be included. The slump range indicated in Table B is intended as a guide to the Contractor for the determination of placing and compacting procedures and equipment. Within the range specified, the slump shall be as directed by the Engineer. If the concrete has a greater slump than the maximum indicated, the quantity of water shall be reduced to meet the slump requirements. If the concrete has a smaller slump than the minimum indicated, changes in the mixture shall be made as specified in Sec. 303–SB.

305-SB. Changes in Consistency for Mechanical Vibration

When high frequency mechanical vibration is used for compacting the concrete, the proportions and consistencies in Table B shall be modified as required to produce the type of concrete specified in Sec. 303–SB and 304–SB.

306-SB. Concrete Made with High Early Strength Portland Cement

When high early strength Portland cement is used in lieu of normal Portland cement, the requirements given in Table B shall apply, except that the estimated 28-day strength indicated for normal Portland cement concrete shall be the estimated 7-day strength when high early strength Portland cement concrete is used. The ages at time of test specified in Sec. 303–SB shall be 3 days and 7 days, respectively, in lieu of the 7-day and 28-day ages specified for normal Portland cement.

310-S. Measurements of Materials

(a) Materials shall be measured by weighing, except as otherwise specified or where other methods are specifically authorized by the Engineer. The apparatus provided for weighing the aggregates and cement shall be suitably designed and constructed for this purpose. Each size of aggregate and the cement shall be weighed separately. The accuracy of all weighing devices shall be such that successive quantities can be measured to within one percent of the desired amount. Cement in standard packages (sack) need not be weighed, but bulk cement and fractional packages shall be weighed. The mixing water shall be measured by volume or by weight. The water measuring device shall be susceptible of control accurate to plus or minus ½ percent of the capacity of the tank. All measuring devices shall be subject to approval.

(b) Where volumetric measurements are authorized by the Engineer, the weight proportions shall be converted to equivalent volumetric proportions. In such case, suitable allowance shall be made for variations in the moisture condition of the aggregates, including the bulking effect in the fine aggregate.

Mixing

311-S. Equipment

The mixing equipment shall be capable of combining the aggregates, cement, and water within the specified time into a thoroughly mixed and uniform mass, and of discharging the mixture without segregation.

312-S. Machine Mixing (at Site or at Central Mixing Plant)

Unless otherwise authorized by the Engineer, the mixing of concrete shall be done in a batch mixer of approved type which will insure a uniform distribution of the material throughout the mass. The equipment at the mixing plant shall be so constructed that all materials (including the water) entering the drum can be accurately proportioned and be under control. The entire batch shall be discharged before recharging. The volume of the mixed material per batch shall not exceed the manufacturer's rated capacity of the mixer. Except as qualified in Sec. 314–S, mixing of each batch shall continue for the periods indicated below* during which time the drum shall rotate at a peripheral speed of about 200 ft. per min. The mixing periods shall be measured from the time when all of the solid materials are in the mixer drum, provided that all of the mixing water shall be introduced before one-fourth of the mixing time has elapsed.

Mixing time shall be as follows:

1. For mixers of a capacity of one cubic yard or less—1 min.

2. For mixers of capacities larger than one cubic yard, the time of mixing shall be increased 15 sec. for each additional half-cubic yard capacity or fraction thereof.

* When, in the judgment of the Engineer, longer mixing times are necessary he should so specify.

313-S. Truck Mixing

Truck mixers, unless otherwise authorized by the Engineer, shall be of the revolving drum type, watertight, and so constructed that the concrete can be mixed to insure a uniform distribution of materials throughout the mass. All solid materials for the concrete shall be accurately measured in accordance with Sec. 310–S and charged into the drum at the proportioning plant. Except as subsequently provided, the truck mixer shall be equipped with a tank for carrying mixing water. Only the prescribed amount of water shall be placed in the tank unless the tank is equipped with a device by which the quantity of water added can be readily verified. The mixing water may be added directly to the batch, in which case a tank shall not be required. Truck mixers may be required to be provided with means by which the mixing time can be readily verified by the Engineer. The maximum size of batch in truck mixers shall be in accordance with the specified rating.* Truck mixing shall be continued for not less than 50 revolutions after all ingredients, including the water, are in the drum. The speed shall not be less than 4 r.p.m., nor more than a speed resulting in a peripheral velocity of the drum of 225 ft. per min. Not more than 150 revolutions of mixing shall be at a speed in excess of 6 r.p.m. Mixing shall begin within 30 min.** after the cement has been added either to the water or aggregate.

314-S. Partial Mixing at the Central Plant

When a truck mixer, or an agitator provided with adequate mixing blades, is used for transportation, the mixing time at the stationary machine mixer may be reduced to 30 sec. and the mixing completed in a truck mixer or agitator. The mixing time in the truck mixer or agitator equipped with adequate mixing blades shall be as specified for truck mixing in Sec. 313–S.

315-S. Time of Hauling Ready-Mixed Concrete

Concrete transported in a truck mixer, agitator, or other transportation device shall be discharged at the job within 1½ hours† after the cement has been added to the water or the aggregates. The maximum volume of mixed concrete transported in an agitator shall be in accordance with the specified rating.

316-S. Hand Mixing

When hand mixing is authorized it shall be done on a watertight platform and in such a manner as to insure a uniform distribution of the materials throughout the mass. Mixing shall be continued until a homogeneous mixture of the required consistency is obtained.

317-S. Retempering

The retempering of concrete or mortar which has partially hardened, that is, mixing with or without additional cement, aggregate, or water, will not be permitted.

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* See Sec. 308 of Recommended Practice.

** When cement is charged into a mixer drum containing water or surface-wet aggregate and when the temperature is above 90 deg. F., or when high early strength Portland cement is used, this limit shall be reduced to 15 min.; the limitation on time between the introduction of the cement to the aggregates and the beginning of the mixing may be waived when, in the judgment of the Engineer, the aggregates are sufficiently free from moisture, so that there will be no harmful effects on the cement.

† See Sec. 308 of Recommended Practice.

Curing of Concrete

318-S. Protection

(a) All concrete, except as noted under *(c)* below, placed under these specifications shall be so protected that the temperature at the surface will not fall below 50 deg. F., or that there will be no loss of moisture from the surface for the periods indicated below.

1. Where normal Portland cement is used—seven days.
2. Where high early strength Portland cement is used—three days.

(b) The Contractor shall submit for the approval of the Engineer the methods he proposes to use for protecting the concrete against low temperatures.

(c) The requirement in *(a)* and *(b)* above concerning the temperature at the surface is intended to apply to the placing of concrete in those seasons of the year, or in such places where the possibility of freezing or continued low temperatures is to be expected. It is not intended to apply where temperatures below 40 deg. F. are a rarity. In any case, however, concrete must be protected from freezing temperatures at any time during the first 72 hours where normal Portland cement is used, or 24 hours where high early strength Portland cement is used.

(d) Protection against loss of moisture from the surface of the concrete shall be accomplished by keeping the surface continuously wet. One of the following methods shall be used:*

Field Tests of Concrete

320-S. Field Tests

During the progress of construction the Engineer will have tests made to determine whether the concrete as being produced complies with the standards of quality specified in Sec. 301–S(A or B). These tests will be made in accordance with Sec. 321–S to 325–S. The Contractor shall cooperate in the making of such tests to the extent of allowing free access to the work for the selection of samples and storage of specimens, and in affording protection to the specimens against injury or loss through his operations.

321-S. Test Pieces

Three cylinders or beams will generally be made for each class of concrete used in any one day's operation. In special cases this normal number of control specimens may be exceeded when in the opinion of the Engineer such additional tests are necessary. The Contractor, however, shall not be required to furnish for such additional tests more than 2 cu. ft. of concrete from each 100 cu. yd. of concrete being placed.

322-S. Sampling and Curing of Test Pieces

Samples of concrete for test specimens shall be taken at the mixer, or in the case of ready mixed concrete, from the transportation vehicle during discharge. When, in the opinion of the Engineer, it is desirable to take samples elsewhere, they shall be taken as directed by him. The test specimens shall be molded immediately after the sample is taken, placed in a protected spot and kept under moist curing conditions at approximately 70 deg. F. for 24 hours, whereupon they shall be removed to the testing laboratory.** In the laboratory they shall be kept under standard moist curing conditions at 70 deg. F. (±5 deg. F.) until time of test and shall be tested in the damp condition.

* The Engineer shall list the methods which he is willing to approve. See Recommended Practice Sec. 309*(b)* for suggestions.

** The temperature and other storage conditions of the test specimens during the first few days is a vital factor in the strength results. It is the intent of these specifications that the requirements herein specified shall be complied with minutely; however, the exact details of storage and transportation facilities shall be those best suited to the individual requirements.

323-S. Age

The tests shall be made at the age of the concrete corresponding to that for which the strengths are specified in Tables A or B.

324-S. Compression Tests

For compression tests, the size of cylinder and the manner of molding, capping, and testing shall be in accordance with the ASTM Standard Method of Test for Compressive Strength of Concrete (ASTM Designation: C39–39).

325-S. Flexure Tests

For flexure tests, the size and shape of specimens and the manner of molding and testing shall be in accordance with the ASTM Standard Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third-Point Loading), (ASTM Designation C78–39).

Enforcement of Strength Requirements

326-SA. Failure to Meet Requirements

Should the strengths shown by the test specimens made and tested in accordance with the provisions of Sec. 320–S fall below the values given in Sec. 301–SA, the Engineer shall have the right to require changes in proportions as outlined in Sec. 306–SA to apply on the remainder of the work. Furthermore, the Engineer shall have the right to require additional curing, as specified in Sec. 328–SA, on those portions of the structure represented by the test specimens which failed. In the event that such additional curing does not give the strength required the Engineer shall have the right to require strengthening or replacement of those portions of the structure which fail to develop the required strength.

327-SA. Definition of Failure

The specimens will be considered to have failed when the average strength for any period of placing is less than the values indicated in the following table:

No. Days Consecutive Placing of Any One Class of Concrete	*Percent of Strength Specified in Section 301-SA*
1	85
2	90
3	95
5 or more	100

328-SA. Additional Curing

When additional curing of portions of the structure is ordered by the Engineer in accordance with Sec. 326–SA, it shall be done at the Contractor's expense and no claim for extra compensation for such additional curing shall be allowed. Such additional curing shall consist in an extension of the periods of protection specified in Sec. 318–S as may, in the judgment of the Engineer, be necessary. In no case, however, shall the Contractor be required to provide such additional curing beyond a total of 21 days, except where the average strengths of specimens, representing concrete placed on any three consecutive days, fall below 80 percent of the value specified in Table A, Sec. 301–SA. In this case, curing shall be continued until cores drilled from portions of the structure involved show an average strength equal to that specified in Table A. Cores for this purpose shall have a diameter of approximately three times the maximum size of aggregate and shall be secured, capped, and tested in accordance with Standard Methods of Securing Specimens of Hardened Concrete from the Structure, (ASTM Designation: C42–39).

Forms and Placing

Forms

401-S. General

Forms shall conform to the shape, lines, grades, and dimensions of the concrete as called for on the drawings. Lumber used in forms for exposed surfaces shall be dressed to a uniform thickness, and shall be free from loose knots or other defects. Joints in forms shall be horizontal or vertical where appearance of the finished surface is of importance. For unexposed surfaces and rough work, undressed lumber may be used. Lumber once used in forms shall have nails withdrawn, and surfaces to be in contact with concrete thoroughly cleaned before being used again.

402-S. Design

(a) Forms shall be sufficiently tight to prevent leakage of mortar. They shall be properly braced or tied together so as to maintain the desired position and shape during and after placing concrete. In the case of very long spans where no intermediate supports are possible, the probable deflection in the forms due to the weight of the fresh concrete shall be taken into account so that the finished members shall conform accurately to the desired line and grade. If adequate foundation for shores cannot be secured, trussed supports shall be provided.

(b) Bolts and rods shall preferably be used for internal ties; they shall be so arranged that when the forms are removed no metal shall be within one inch of any surface. Shores supporting successive stories shall be placed directly over those below, or so designed and placed that the load will be transmitted directly to them.

403-S. Moldings

Unless otherwise specified suitable moldings or bevels shall be placed in the angles of forms to round or bevel the edges of the concrete.

404-S. Oiling

The inside of forms shall be coated with nonstaining mineral oil or other approved material, or in case of wood forms they shall be thoroughly wetted (except in freezing weather). Where oil is used, it shall be applied before the reinforcement is placed.

405-S. Inspection

Temporary openings shall be provided at the base of column and wall forms and at other points where necessary to facilitate cleaning and inspection immediately before depositing concrete.

406-S. Form Removal

The removal of forms shall not be started until the concrete has attained the necessary strength to support its own weight and any construction live loads.

Depositing Concrete

407-S. General

(a) Before beginning placement of concrete, hardened concrete and foreign materials shall be removed from the inner surface of the mixing and conveying equipment.

(b) Before depositing concrete, debris shall be removed from the space to be occupied by the concrete; forms if constructed of lumber shall be thoroughly wetted (except in freezing weather) or oiled. Reinforcement shall be thoroughly secured in position and approval by the Engineer obtained before concrete is placed.

408-S. Removal of Water

Water shall be removed from the space to be occupied by the concrete before concrete is deposited, unless otherwise directed by the Engineer. Any flow of water into an excavation shall be diverted through proper side drains to a sump, or be removed by other approved methods which will avoid washing the freshly deposited concrete. If directed by the Engineer water vent pipes and drains shall be filled by grouting or otherwise after the concrete has thoroughly hardened.

409-S. Handling

(a) Concrete shall be handled from the mixer, or in the case of ready-mixed concrete, from the transporting vehicle, to the place of final deposit as rapidly as practicable by methods which shall prevent the separation or loss of the ingredients. (See Sec. 315–S.) Under no circumstances shall concrete that has partially hardened be deposited in the work. Concrete shall be deposited in the forms as nearly as practicable in its final position to avoid rehandling. It shall be so deposited as to maintain, until the completion of the unit, a plastic surface approximately horizontal. Forms for walls or thin sections of considerable height shall be provided with openings or other devices that will permit the concrete to be placed in a manner that will prevent segregation and accumulations of hardened concrete on the forms or metal reinforcement above the level of the concrete.

(b) Concrete regardless of the type of transporting vehicle, shall have when deposited in the forms the quality required.

410-S. Chuting

When concrete is conveyed by chutes, the equipment shall be of such size and design as to insure a continuous flow in the chute. The chutes shall be of metal or metal lined and the different portions shall have approximately the same slope. The slope shall not be less than one vertical to two horizontal and shall be such as to prevent the segregation of the ingredients. The discharge end of the chute shall be provided with a baffle plate to prevent segregation. If the distance of the discharge end of the chute above the surface of the concrete is more than three times the thickness of the layer being deposited, but not more than five feet above the surface of the concrete, a spout shall be used, and the lower end maintained as near the surface of deposit as practicable. When the operation is intermittent, the chute shall discharge into a hopper. The chute shall be thoroughly cleaned before and after each run and the debris and any water used shall be discharged outside the forms.

411-S. Pneumatic Placing

(a) Where concrete is conveyed and placed by pneumatic means the equipment shall be suitable in kind and adequate in capacity for the work. The machine shall be located as close as practicable to the place of deposit. The position of the discharge end

of the line shall not be more than ten feet from the point of deposit. The discharge lines shall be horizontal or inclined upwards from the machine.

(b) At the conclusion of placement the entire equipment shall be thoroughly cleaned.

412-S. Pumping

Where concrete is conveyed and placed by mechanically applied pressure the equipment shall be suitable in kind and adequate in capacity for the work. The operation of the pump shall be such that a continuous stream of concrete without air pockets is produced. When pumping is completed, the concrete remaining in the pipeline, if it is to be used, shall be ejected in such a manner that there will be no contamination of the concrete or separation of the ingredients. After this operation the entire equipment shall be thoroughly cleaned. (See Recommended Practice, Sec. 403.)

413-S. Compacting

(a) Concrete during and immediately after depositing shall be thoroughly compacted by means of suitable tools. For thin walls or inaccessible portions of the forms, where spading, rodding, or forking is impracticable, the concrete shall be worked into place by vibrating, or hammering the forms lightly opposite the freshly deposited concrete. The concrete shall be thoroughly worked around the reinforcement, and around embedded fixtures, and into the corners of the forms.

(b) Accumulations of water on the surface of the concrete due to water gain, segregation or other causes, during placement and compacting, shall be prevented as far as possible by adjustments in the mixture. Provision shall be made for the removal of such water as may accumulate so that under no circumstances will concrete be placed in such accumulations. (See Recommended Practice, Sec. 404.)

(c) Concrete { shall / may / shall not } * be compacted by mechanical vibration.

When mechanical vibration is used the number and type of vibrators shall be subject to the approval of the Engineer.

414-S. Depositing Continuously

Concrete shall be deposited continuously, or in layers of such thickness that no concrete will be deposited on concrete which has hardened sufficiently to cause the formation of seams and planes of weakness within the section. If a section cannot be placed continuously, construction joints may be located at points as provided for in the drawings or approved by the Engineer. Such joints shall be made in accordance with the provisions in Sec. 508–S to 510–S.

415-S. Depositing in Cold Weather

Concrete when deposited shall have a temperature of not less than 50 deg. F. nor more than 120 deg. F. In freezing weather, suitable means shall be provided for maintaining the concrete at the temperature and for the periods specified in Sec. 318–S, or until the concrete has thoroughly hardened. Before placing the concrete, the forms shall be free from frost and ice, and after the concrete is placed it shall be protected on all exposed sides by straw, tarpaulins, or other means. Manure, if used for such protection, shall not come in contact with the concrete. The methods of heating the materials and protecting the concrete shall be approved by the Engineer. Salts, chemicals, or other foreign materials shall not be mixed with the concrete for the purpose of preventing freezing.

* The Engineer shall indicate which of these requirements is to apply.

416-S. Bonding

Before depositing new concrete on or against concrete which has hardened, the forms shall be retightened. The surface of the hardened concrete shall be roughened as required by the Engineer, in a manner that will not leave loosened particles of aggregate or damaged concrete at the surface. It shall be thoroughly cleaned of foreign matter and laitance, and saturated with water. To insure an excess of mortar at the juncture of the hardened and the newly deposited concrete, the cleaned and saturated surfaces, including vertical and inclined surfaces, shall first be thoroughly covered with a coating of mortar or neat cement grout against which the new concrete shall be placed before the grout has attained its initial set.

417-S. Protection and Curing

The concrete shall be protected and cured in accordance with requirements of Sec. 318–S.

418-S. Placing Cyclopean Concrete

Cyclopean aggregate shall be thoroughly embedded with no stone closer than one foot to any surface, and with a space of at least six-inch between adjacent stones. Stratified stone shall be laid on its natural bed. Cyclopean aggregate shall be carefully placed to avoid injury to forms or adjoining masonry.

419-S. Placing Rubble Concrete

Rubble aggregate shall be thoroughly embedded in the concrete.

The individual stones shall not be closer than four inches to any surface or adjacent stones. Rubble aggregate shall be carefully placed to avoid injury to forms or adjacent masonry.

420-S. Depositing Concrete Under Water

(a) When it is necessary to deposit concrete under water the methods, equipment, materials, and proportions of the mixture to be used shall be submitted to and be approved by the Engineer before the work is started.

(b) Concrete shall not be placed in water having a temperature below 35 deg. F. The temperature of the concrete, when deposited, shall not be less than 60 deg. F. nor more than 120 deg. F.

(c) The concrete shall contain not less than 7 sacks or 658 lb. of cement per cubic yard. The volume or weight of the coarse aggregate shall not be less than one and one-half, nor more than twice that of the fine aggregate. The concrete shall be mixed with sufficient water to produce a concrete having a slump of not less than four inches and not more than seven inches.

(d) Cofferdams or forms shall be sufficiently tight to reduce the flow or current of water to ten feet per minute through the space into which concrete is to be deposited. Cofferdams or forms in still water shall be sufficiently tight to prevent loss of mortar through the walls. Pumping will not be permitted while concrete is being placed, nor until 24 hours thereafter.

(e) Concrete shall be deposited continuously until it is brought to the required height. While depositing, the top surface shall be kept as nearly level as possible and the formation of seams avoided. The methods to be used for depositing concrete under water shall be one of the following:

1. *Tremie.*—The tremie shall be watertight and large enough to allow a free flow of concrete. It shall be kept filled with concrete at all times while depositing.

The concrete shall be discharged and spread by so moving the tremie as to maintain as nearly as practicable a uniform flow and avoid dropping the concrete through water. If the charge is lost, while depositing, the tremie shall be withdrawn and refilled. The slump of concrete shall be maintained between five and seven inches.

2. *Drop Bottom Bucket.*—The top of the bucket shall be open. The bottom doors shall open freely downward and outward when tripped. The bucket shall be completely filled and slowly lowered to avoid backwash. It shall not be dumped until it rests on the surface upon which the concrete is to be deposited and when discharged shall be withdrawn slowly until well above the concrete. The slump of concrete shall be maintained between four and six inches.

3. *Bags.*—Bags of at least one cubic foot capacity, of jute or other coarse cloth, shall be filled about two-thirds full of concrete and securely tied. They shall be placed carefully in header-and-stretcher courses so that the whole mass is interlocked. Bags used for this purpose shall be free from deleterious materials.

(f) To minimize the formation of laitance great care shall be exercised to disturb the concrete as little as possible while it is being deposited. Upon completion of a section of concrete, all laitance shall be entirely removed before work is resumed.

421-S. Depositing Concrete Exposed to Corrosive Waters or Soils

Where concrete may be exposed to the action of corrosive waters or soils, special care shall be taken to place it in accordance with Sec. 407–S to 416–S. Wherever possible placing shall be continuous until completion of the section or until the concrete is at least 18 in. above ground or water level. Corrosive waters or soils shall be kept from contact with the concrete during placement and for a period of at least 72 hours thereafter.

422-S. Pneumatically Applied Mortar

(a) General.—This section refers to premixed sand and cement pneumatically applied by suitable mechanism and competent operators, and to which mixture the water is added immediately previous to its expulsion from the nozzle.

(b) Quality of Materials.—The quality of cement, sand, and water shall be in accordance with Sec. 201–S to 213–S.

(c) Proportions.—The proportions of cement to sand shall be based on dry and loose volumes and shall not be less than one to four for encasement of steel members, one to three for concrete repair, nor one to four and a half for canal linings.

(d) Water Content.—The water content shall be maintained at a practicable minimum and not in excess of three gallons per sack of cement as placed.

(e) Mixing.—The cement and sand shall be thoroughly mixed before being charged into the machine. The sand shall contain not less than four percent moisture.

(f) Nozzle Velocity.—The velocity of the material as it leaves the nozzle must be maintained uniform at a rate determined for the given job conditions to produce minimum rebound.

(g) Nozzle Position.—The nozzle shall be held in such a position and at such distance that the stream of flowing material will impinge at approximately right angles to the surface being covered without excessive impact.

(h) Rebound Sand.—Rebound or accumulated loose sand shall be removed from the surface to be covered prior to placing of the original or succeeding layers of mortar.

(i) Forms.—The forms shall be structurally sufficient and of such design that rebound or accumulated loose sand can freely escape or be readily removed. Shooting

strips should be used at corners, edges, and on surfaces where necessary to obtain true lines and proper thickness.

(j) Joints.—The pneumatically applied mortar at the end of any day's work or similar stopping periods shall be sloped off to a thin edge. Before placing an adjacent section this sloped portion shall be thoroughly cleaned and wetted.

(k) Bond.—Surfaces to which pneumatically applied mortar is to be bonded shall be thoroughly cleaned of dirt, paint, grease, organic matter and loose particles. Absorptive surfaces shall be wetted before the application of the mortar.

(l) Curing.—Pneumatically applied mortar shall be so applied, protected, and cured as to prevent its temperature falling below 50 deg. F., or a loss of moisture from the surface for the periods indicated below.

1. Where normal Portland cement is used, seven days.
2. Where high early strength Portland cement is used, three days.

Pneumatically applied mortar shall be applied only with the permission of the Engineer when the air temperature is 50 deg. F. or less.

(m) Reinforcement.—The reinforcement when required shall be adequate from the standpoint of structural requirements and shall consist of mesh or round bars, spaced not less than two inches nor more than four inches apart either way, and having a diameter not less than that of No. 12 wire. The area of the reinforcement shall be at least 0.2 percent of the cross-sectional area of the mortar. The reinforcement shall be at least ¼ in. from the unexposed surface of the mortar and at least ¾ in. from the exposed surface.

Note: For recommended practice for pneumatically applied mortar see Sec. 406.

Details of Construction

Handling Metal Reinforcement

501-S. Cleaning

Metal reinforcement before being positioned shall be free from loose mill and rust scale and from coatings, including ice, that destroy or reduce the bond. Where there is delay in depositing concrete, reinforcement shall be reinspected and cleaned when necessary.

502-S. Fabrication

Reinforcement shall be accurately formed to the dimensions indicated on the drawings. Stirrups and tie bars shall be bent around a pin having a diameter not less than two times the minimum thickness of the bar. Bends for other bars shall be made around a pin having a diameter not less than six times the minimum thickness except for bars larger than one inch in which case the bends shall be made around a pin of eight bar diameters. All bars shall be bent cold.

503-S. Straightening and Rebending

Metal reinforcement shall not be straightened or rebent in a manner that will injure the material. Bars with kinks, or bends not shown on the drawings, shall not be used. Heating of the reinforcement will be permitted only when the entire operation is approved by the Engineer.

504-S. Placing Reinforcement

(a) Metal reinforcement shall be accurately positioned and secured against displacement by using annealed iron wire ties or suitable clips at intersections, and shall be supported by concrete or metal supports, spacers or metal hangers. Where indicated on the drawings or required by the specifications, metal clips or supports shall not be placed in contact with the forms.

(b) The minimum center to center distance between parallel bars shall be 2½ times the diameter of round or 3 times the side dimensions for square bars, but in no case shall the clear spacing between the bars be less than 1½ times the maximum size of the coarse aggregate nor less than 1 inch in beams and girders, nor less than 1½ inch in columns. Bars parallel to the exterior surface of any member not exposed to the weather shall be embedded at least one bar diameter for round bars, or diagonal dimension for square bars, but in no case less than ¾ inch from the exterior surface, nor less than shown on the drawings, or as required by Sec. 505–S.

505-S. Moisture Protection

(a) At those surfaces of footings and other principal structural members in which the concrete is deposited directly against the ground, metal reinforcement shall have a minimum covering of 3 in. of concrete. At other surfaces of concrete exposed to the ground or to severe weathering conditions, metal reinforcement shall be protected by not less than 2 in. of concrete for bars over ⅝ in. in diameter, and 1½ in. for bars ⅝ in. in diameter or less. At underside of slabs exposed to weather one inch shall be provided.

506-S. Splicing of Reinforcement

When it is necessary to splice reinforcement at points other than shown on the drawings, the character of the splice shall be determined by the Engineer. In such splices the bars shall be placed in contact and wired. Splices in adjacent bars shall be staggered.

507-S. Future Bonding

Exposed reinforcement intended for bonding with future extensions shall be effectively protected from corrosion.

Construction Joints

508-S. Location of Joints

(a) Columns.—Joints in columns shall be made at the underside of floor members and at floor levels. Haunches and column capitals shall be considered as part of and continuous with the floor or roof. At least two hours shall elapse after depositing concrete in columns or walls before depositing the concrete in the floor system.

(b) Floors.—Construction joints in the floor system shall be located at or near the middle of the span in slabs, beams, or girders, unless a beam intersects a girder at this point, in which case the joint in the girder shall be offset a distance equal to twice the width of the beam and provision satisfactory to the Engineer shall be made for shear by the use of inclined web reinforcement across the joint.

509-S. Procedure in Forming Joints

The procedure specified in Sec. 416–S for bonding new concrete to old shall be followed in the formation of all joints. The reinforcement shall continue through the joint. For concrete without reinforcement, shearing strength shall be provided by means of a concrete key or dowel bars as the Engineer may direct.

510-S. Extra Steel at Construction Joints

Where a construction joint is required in a section of a building more than 100 ft. long or more than 100 ft. between expansion joints, special reinforcement shall be placed at right angles to the joint and extending in both directions from the joint 40 diameters in the case of deformed bars and 50 diameters in the case of plain bars. This reinforcement shall be placed near the face of the member opposite from the main tensile reinforcement. The cross-sectional area of such reinforcement shall not be less than 0.5 percent of the section of the members cut by the joint.

511-S. Watertight Construction Joints

(a) Where a horizontal construction joint is required to resist water pressure, special care shall be taken in finishing the surface to which the succeeding concrete is to be bonded. The consistency of the concrete shall be carefully controlled so that it can be placed with a minimum of puddling with no free water showing. The surface shall be protected from loss of moisture and from mechanical injury. In applying the new concrete the procedure specified in 416–S shall be followed.

(b) Vertical construction joints shall not be made in watertight construction unless shown on the plans or authorized by the Engineer.

Appendices

Appendix 1—Effect of Various Substances on Portland Cement Concrete and Suggested Protective Treatments Where Required

Substance	*Effect on Unprotected Concrete*	*Protective Treatment*
Petroleum Oils		
Light feul oils above 30° Baumé	None—some loss from penetration	Fluosilicate, spar varnish, linseed oil, sodium silicate
Volatile oils—kerosene, benzine, naphtha, gasoline	None—considerable loss from penetration.	Fluosilicate, spar varnish, sodium silicate, phenol-formaldehyde varnish
Heavy oils—30° Baumé or heavier	None—very slight penetration	None
Coal-tar Distillates		
Phenol, cresol, lysol, creosote, carbolineum	Attack concrete slowly	Fluosilicate, sodium silicate, spar varnish, phenol formaldehyde varnish
Benzol, toluol, xylol and cumol	None—some loss from penetration	Fluosilicate, sodium silicate, linseed oil, spar varnish
Pitch, anthracene, carbonzol and paraffin	None	None
Inorganic Acid		
Sulphuric, nitric	Disintegrates	Glass, vitrified brick or tile laid in litharge, lead, and rubber give effective protection for temperatures below 150° F. and for concentrations of 50% or less.
Sulphurous	"	Glass, vitrified brick or tile laid in litharge, lead, and rubber give effective protection for all concentrations.
Hydrochloric	"	Lead, rubber only for temperatures below 150°F and for concentrations of 50% or less.
Hydrofluoric	"	

Appendix 1—Continued

Substance	*Effect on Unprotected Concrete*	*Protective Treatment*
	Organic Materials	
Acetic	Disintegrates slowly	Bituminous enamel, phenol-formaldehyde varnish, spar varnish, rubber
Carbonic in water	Attacks concrete slowly	Asphalt, bituminous, or coal-tar paints, fluosilicate, sodium silicate, spar varnish, phenolformaldehyde varnish, resin
Lactic or tannic	Attacks concrete slowly	Above group; also linseed oil, and paraffin
Fish oil	Very slight attack	Fluosilicate, sodium silicate, linseed oil
Lard and lard oil	" " "	Above group
Foot oil	" " "	" "
Linseed	Slight attack	None
Resin	" "	"
Cocoanut	" "	Fluosilicate, sodium silicate, linseed oil
Olive	" "	Above group; also spar or Bakelite varnish
Rape seed	" "	Above group; also spar or Bakelite varnish
Cotton seed	" "	None
Almond	" "	Fluosilicate, sodium silicate, linseed oil, varnish
Poppy seed	Very slight attack	Above group
Walnut	" " "	" "
Soy-bean	" " "	" "
Peanut	" " "	" "
Oxalic	None	None
Carbonic (dry)	"	"

Salts

Soluble inorganic salts attack concrete to a greater or less extent in the following order: sulphates, sulphides, nitrates, chlorides, and carbonates.

Sulphates of calcium, potassium, sodium magnesium, copper, zinc, aluminum, manganese, iron, nickel, cobalt.	Actively attack concrete	Suggested treatments are: fluosilicate, sodium silicate, linseed oil, bituminous, applications, glass, vitrified brick or tile laid in litharge cement and rubber
Sulphates of ammonia	Disintegrate	Above group
Chlorides of magnesium, iron, mercury, copper and ammonia	Slight attack	" "
Nitrate of ammonia	Disintegrates	" "
Sulphide ores and pyrite	Slight attack	" "

Appendix 1—Continued

Substance	*Effect on Unprotected Concrete*	*Protective Treatment*
Acid sulphate	Strong attack	Suggested treatments are: fluosilicate, sodium silicate, linseed oil, bituminous applications, glass, vitrified brick or tile laid in litharge cement and rubber.
Chlorides of sodium, potassium, calcium, strontium	None	None
Nitrates of calcium, potassium and sodium	”	”
Soluble sulphides except sulphide of ammonia	”	”
Carbonates	”	”
Fluorides	”	”
Silicates	”	”
	Miscellaneous	
Molasses	Slight attack	Suggested treatments are: fluosilicate, sodium silicate, linseed oil, bituminous applications, glass, vitrified brick or tile laid in litharge cement and rubber
Sulphite liquor	” ”	Above group
Milk	Attacks slowly	” ”
Corn syrup and glucose	Slight attack	” ”
Silage juices	Attack slowly	” ”
Ammonia water	None	None
Wood pulp	”	”
Tanning liquors (non acid)	”	”
Alcohol	”	”

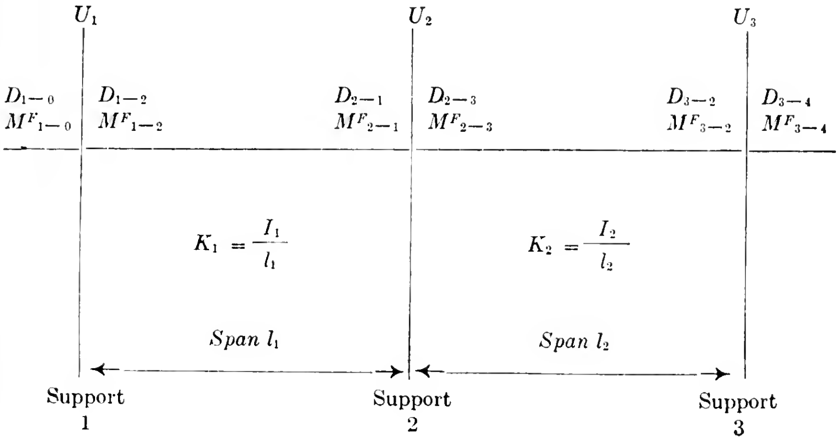
Appendix 2—Support Moments in Continuous Beams and Frames

A number of methods of frame analysis are available to the designer such as Moment Distribution, Slope Deflection, Virtual Work, etc. For preliminary designs and also for final designs in the ordinary cases, the following approximate general method may be used. The method is based in moment distribution and is approximate to the extent that it includes only two cycles of distribution* for fixed end moments at three successive supports or joints.

* For a more complete treatment of this method, see Continuous Frames of Reinforced Concrete, by Cross and Morgan (John Wiley and Sons, N. Y., 1932).

The method is general in that it is applicable to the fixed end moments for any type of loading in the four spans adjacent to the three supports or joints under consideration.

For notation refer to the following diagram and definitions:



Let joints 1, 2, and 3 in the order shown mark the ends of two spans l_1 and l_2.

Let MF_{2-1} = fixed end moment at the left of joint 2 due to the loads in the span between supports 2 and 1.

MF_{2-3} = fixed end moment at the right of joint 2 due to the loads in the span between supports 2 and 3.

U_2 = algebraic sum of the fixed end moments at joint 2, i.e. $MF_{2-1} + MF_{2-3}$

Similarly,

U_1 = algebraic sum of the fixed end moments at joint 1,

U_3 = algebraic sum of the fixed end moments at joint 3.

Fixed end moments are to be given positive sign if they tend to produce clockwise *rotation of the joint* and negative sign if counter clockwise.

The signs of U_1, U_2, and U_3 result from the addition of the two terms. If the clockwise term is the greater, the sign will be positive; if the counter clockwise term is greater, the sign will be negative.

$K_1 = \frac{I_1}{l_1}$ = stiffness factor for span 1–2.

$J_1 = \Sigma \frac{I}{l}$ for all members intersecting at joint 1.

Similarly for other joints.

D_{1-2} = Distribution factor at joint 1 $= \frac{K_1}{J_1}$

D_{2-1} = Distribution factor at joint 2 $= \frac{K_1}{J_2}$

D_{2-3} = Distribution factor at joint 2 $= \frac{K_2}{J_2}$

D_{3-2} = Distribution factor at joint 3 $= \frac{K_2}{J_3}$

With this notation, the final moment M_{2-1} at the left of joint 2 can be obtained from the following equation:

$$M_{2-1} = MF_{2-1} - D_{2-1}U_2 - \frac{D_{1-2}U_1}{2} + \frac{D_{2-1}}{2}(D_{1-2}U_1 + D_{3-2}U_3) \quad \ldots\ldots\ldots (1)$$

Similarly,

$$M_{2-3} = MF_{2-3} - D_{2-3}U_2 - \frac{D_{3-2}U_3}{2} + \frac{D_{2-3}}{2}(D_{3-2}U_3 + D_{1-2}U_1) \quad \ldots\ldots\ldots (2)$$

Collecting terms, these equations can be written,

$$M_{2-1} = MF_{2-1} - \frac{D_{1-2}U_1}{2} + \frac{D_{2-1}}{2}(D_{1-2}U_1 + D_{3-2}U_3 - 2U_2) \quad \ldots\ldots\ldots (3)$$

$$M_{2-3} = MF_{2-3} - \frac{D_{3-2}U_3}{2} + \frac{D_{2-3}}{2}(D_{1-2}U_1 + D_{3-2}U_3 - 2U_2) \quad \ldots\ldots\ldots (4)$$

Appendix 3—Maximum Moment Coefficients for One-Way Slabs (Solid or Ribbed) of Equal Spans Carrying Uniformly Distributed Loads

The coefficients given in the table below are for the special case of equal spans and uniformly distributed loads. They are based on the assumption of continuity over the supports with negligible restraints at end and intermediate supports. The numerical values given are coefficients of w_1L^2 and w_2L^2, respectively, in which w_1 equals the dead load, and w_2 equals the live load per unit of area.

No. Spans	*End Span*			*First Int. Support*		*Interior Span*			
	End Support	*Mid-Span*				*Mid-Span*		*Typical Support*	
	Neg.	*Pos.*	*Neg.*	*Pos.*	*Neg.*	*Pos.*	*Neg.*	*Pos.*	*Neg.*
				Dead Load					
1	—.040	.125							
2	—.040	.075			—.125				
3	—.040	.085			—.100	.030			
4 or more	—.040	.080			—.110	.040 .046*			—.080
				Live Load					
1	—.040	.125	.000						
2	—.040	.100	—.030	.000	—.125				
3	—.040	.105	—.025	.017	—.120	.080	—.050		
4 or more	—.040	.105	—.020	.015	—.120	.085	—.045	.036	—.115

* .046 for 5 or more spans.

To adapt the table for use in cases where the dead load is slightly different on the several spans w_1 may be taken as the least dead load carried by one span of the series under consideration, and w_2 as the difference between w_1 and the greatest unit total load on any of the spans in the series.

Appendix 4—Curing Portland Cement Concrete*

1. General

These specifications for Heat Curing and Wet Curing are based on requirements when normal Portland cements are used.

When moderate low-heat cements are used, the curing time herein specified shall be increased 25 percent.

When high early strength Portland cement is used, the curing period shall be not less than 40 percent of that specified for normal Portland cement.

2. Heat Curing

Concrete, when deposited in massive structures, shall have a temperature of not less than 40 deg. F.

When deposited in structures less than six feet in thickness the following table for temperatures will govern:

Temperature of Air Degrees F.	Minimum Temperature of Concrete When Placed Degrees F.
Below 30	70
Between 30 and 45	60
Above 45	45

In freezing weather, or when there is likelihood of freezing temperatures, within the specified curing period, suitable and sufficient measures must be provided for maintaining all concrete surfaces at a temperature of not less than 50 deg. F. for a period of not less than 5 days after the concrete is placed, when normal Portland cement is used, and not less than 48 hours when high early strength Portland cement is used.

The temperature of concrete surfaces shall be determined by thermometers placed against the surfaces of the concrete.

Provision shall be made in form construction to permit the removal of small sections of forms to accommodate the placing of thermometers against concrete surfaces at locations designated by the Engineer.

After thermometers are placed, the apertures in forms shall be covered in a way to closely simulate the protection afforded by the forms.

In determining the temperatures at angles and corners of a structure, thermometers should be placed not more than eight inches from the angles and corners.

Temperature readings shall be taken and recorded at intervals to be designated by the Engineer, over the entire curing period specified, and the temperatures so recorded shall be interpreted as the temperature of the concrete surfaces where thermometers were placed.

When protection from cold is needed to insure meeting these specification requirements, all necessary materials for covering or housing must be delivered at the site of the work before concreting is started and must be effectively applied or installed, together with such added heat furnished as may be necessary without depending in any way upon the heat of hydration during the first 24 hours after concrete is placed, when normal Portland cement is used, or the first 18 hours when high early strength Portland cement is used.

When heat is supplied by steam or salamanders, covering or housing of the structure shall be so placed as to permit free circulation of air above and around the concrete

* Manual Am. Ry. Eng. Assn., 1939; Specifications for Portland Cement Concrete, Plain and Reinforced, Sec. 8, page 25.

within the enclosure, but to the exclusion of air currents from without, excepting that where salamanders are used, sufficient ventilation shall be provided to carry off gases. Special care shall be exercised to exclude cold drafts from angles and corners and from all projecting reinforcing steel.

When salamanders are used, water vessels must be placed over them or other means provided to maintain a high humidity within enclosures.

3. Wet Curing

When not otherwise specified, all concrete surfaces when not protected by forms, must be kept constantly wet for a period of not less than 7 days after concrete is placed, when normal Portland cement is used, and not less than 67 hours when high early strength Portland cement is used.

The wet curing period for all concrete which will be in contact with brine drip, sea water, salt spray, alkali or sulfate bearing soils or waters, or similar destructive agents, shall be increased to 50 percent more than the periods specified for normal exposures.

When wood forms are left in place during the curing period they shall be kept sufficiently damp at all times to prevent openings at the joints and drying of the concrete.

Inspection shall be made of all exposed surfaces at intervals as directed by the Engineer, and job records shall be kept indicating whether surfaces were wet at times of inspection, and if not wet, stating reasons why.

When wet curing is impracticable, liquid surface applications to prevent or minimize evaporation may be used in lieu of wet curing only when approved by the Engineer.

Appendix 5—List of Specifications Cited

American Society for Testing Materials*

A7–39 —Specifications for Steel for Bridges and Buildings
A15–39 —Specifications for Billet-Steel Bars for Concrete Reinforcement
A16–35 —Specifications for Rail-Steel Bars for Concrete Reinforcement
A44–39T—Specifications for Cast-Iron Pit-Cast Pipe for Water and other Liquids (Tentative)
A82–34 —Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement
A160–39 —Specifications for Axle-Steel Bars for Concrete Reinforcement
A184–37 —Specification for Fabricated Steel Bar or Rod Mats for Concrete Reinforcement
A185–37 —Specifications for Welded Steel Wire Fabric for Concrete Reinforcement
C9–38 —Specifications for Portland Cement
C29–39 —Method of Test for Unit Weight of Aggregate
C39–39 —Method of Test for Compressive Strength of Concrete
C40–33 —Method of Test for Organic Impurities in Sands for Concrete
C42–39 —Method of Securing Specimens of Hardened Concrete from the Structure
C74–39 —Specifications for High-Early-Strength Portland Cement
C77–39 —Methods of Sampling and Physical Testing of Portland Cement
C78–39 —Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading)
C87–39 —Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar

* A pamphlet containing the specifications and methods of test listed may be obtained by members of the AREA at 50 cents per copy by addressing the American Society for Testing Materials, 260 South Broad Street, Philadelphia, Pa.

C88–39T—Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (Tentative)
C109–37T—Method of Test for Compressive Strength of Portland Cement Mortars (Tentative)
C117–37 —Method of Test for Amount of Material Finer than No. 200 Sieve in Aggregates
C123–39 —Method of Test for Coal and Lignite in Sand
C136–39 —Method of Test for Sieve Analysis of Fine and Coarse Aggregates
D2–33 —Method of Test for Abrasion of Rock by Use of the Deval Machine
D75–39T—Methods of Sampling Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials, Including Some Material Survey Methods (Tentative)
D271–37 —Methods of Laboratory Sampling and Analysis of Coal and Coke
D289–37T—Method of Test for Abrasion of Gravel by Use of the Deval Machine (Tentative)

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Seventh Progress Report

Committee on Stresses in Railroad Track

1940

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Seventh Progress Report
Special Committee on Stresses in Railroad Track

A. N. Talbot, *Chairman*,
C. B. Bronson
W. J. Burton
Robert Faries**
C. W. Gennet, Jr.
F. M. Graham
H. E. Hale
F. S. Hewes
G. W. Kittredge
P. M. LaBach
F. R. Layng
J. de N. Macomb
G. M. Magee
John V. Neubert*
Louis Yager, *Vice-Chairman*,
W. H. Penfield
G. J. Ray
Albert Reichmann
H. R. Safford
F. E. Turneaure
J. E. Willoughby
Committee.

* Died June 4, 1940.
** Died September 8, 1940.

To the American Railway Engineering Association:

The Special Committee on Stresses in Railroad Track herewith presents its seventh progress report.

I. Introduction

1. **Preliminary.**—Since its organization in 1914 this committee has conducted analytical and experimental investigations on the action of railroad track under the loads of locomotives and cars running at various speeds and for a variety of conditions. The study has been supplemented by numerous laboratory tests. The field, laboratory and office work has been carried on by the staff of the committee. Through its continuing organization the committee has been able to outline constructive programs, carry out field and laboratory tests, and interpret results in a coordinated and impartial way.

At the beginning the committee was a joint committee of the American Railway Engineering Association and the American Society of Civil Engineers, with most of its membership common to the two societies and with funds contributed from both sources. In recent years, however, the connection with the American Society of Civil Engineers has been only nominal and the activities have been wholly those of the American Railway Engineering Association with the financial support coming entirely from the Association of American Railroads.

2. **Previous Progress Reports.**—Six progress reports have been published descriptive of the investigation and its results and various additional supplementary reports have been made. Experimental data in various stages require further work before being reported.

The six progress reports may be found in the Proceedings of the American Railway Engineering Association as follows: First Progress Report, Vol. 19, 1918, page 873; Second Progress Report, Vol. 21, 1920, page 645; Third Progress Report, Vol. 24, 1923, page 295; Fourth Progress Report, Vol. 26, 1925, page 1081; Fifth Progress Report, Vol. 31, 1930, page 65; Sixth Progress Report, Vol. 35, 1934, page 65.

An outline of the topics reported on in the first four progress reports is given in the Fifth Progress Report, and a short statement on the topics in the Fifth Progress Report is included in the Sixth Progress Report. Most of these outlines of content are in sufficient detail, taken together with the tables of contents, to enable a reader to find the location of the subjects considered in the various progress reports.

3. **Acknowledgment.**—The tests herein reported were made possible through the cooperation of the Pennsylvania Railroad in making a combined effort to obtain information on the action of various types of rail joints in track when subjected to the loads of locomotives and cars at speeds up to 90 miles per hour. The committee wishes to express appreciation to the railroad management for the opportunity to cooperate in this important series of tests and for the various services given. The opportunities were especially valuable because of the availability of the splendid equipment of magnetic strain gages, oscillographs and auxiliary apparatus, representing an investment of a number of thousands of dollars and especially designed and constructed for the purposes of such investigations. This unusual testing equipment enabled tests to be made accurately and expeditiously in a way that had not been accomplished before. It should be added too that the extensiveness of the tests and the great amount of detail in the large accumulation of data imposed a very considerable undertaking in the reduction of data and the analysis and interpretation of results.

Appreciation is expressed to W. D. Wiggins, chief engineer, and to Robert Faries, assistant chief engineer maintenance, Pennsylvania Railroad, for their support in making the conduct of the tests successful. Special credit should go to F. M. Graham, assistant engineer of standards, who was actively instrumental in planning, designing and purchasing the instrumental equipment. His part in planning and supervising the tests was in itself a most important contribution to the successful conduct of the tests. Several members of the testing staff of the Pennsylvania Railroad gave valuable service throughout the tests. Credit should likewise be given to the General Electric Company for their effective interest in the development and construction of special testing apparatus.

Members of the staff of the Stresses in Track investigation engaged in the field, laboratory and office work should likewise be given credit. E. E. Cress, assistant engineer of tests in charge of conduct of field and office work, because of experience with details, grasp of the problems and helpfulness in the study and preparation of the data, has given service of particular value. Randon Ferguson, assistant engineer, through technical skill and industry and insight in field and laboratory work and in the preparation of material for the report, has made contributions of value. R. L. Jordan and V. C. Norman have likewise been especially helpful in all the work on tests and report. Other members have given loyal and useful service.

The University of Illinois has continued to cooperate in the work by giving the use of laboratory, shop and office facilities, and through the service of members of the staff of the Engineering Experiment Station from time to time.

Appreciation is expressed to the Association of American Railroads for the financial support given to the investigation. The payment of the salaries of the staff and the cost of developing and purchasing testing equipment, including apparatus obtained since the tests herein reported were made, have come from the appropriations made by the association. It must be realized that research investigations of the nature of those carried on involve the expenditure of considerable sums and the continuing effort of a sizable and capable and experienced technical staff.

II. Track, Locomotives, Cars, Apparatus, and Methods of Testing

4. **Purposes of the Tests.**—The tests were undertaken particularly to obtain information on the action of different forms of rail joints in track under the traffic of locomotives and cars running at various speeds and to learn the magnitude of the bending moments developed in the joint bars as compared with those developed in the

full rail away from a joint. The ratio of the bending moment in the bars of a joint to that in the full rail (called the joint moment ratio) may be considered a measure of the usefulness of the joint as a load-carrying beam, and under similar conditions of rail support the joint moment ratio will give information on the relative stiffness of rail and joint and thus on the extent to which the ties at the joint will have higher pressures or lower pressures applied to them than are given to ties away from the joint. Information was also desired on the relative longitudinal movement between rail and bar at the upper fishing surfaces in the several forms of bar with the passage of a wheel over the joint, as tending to produce wear and increased deterioration of joint. and also information on the relative vertical movement between rail and bar at points along the length of the bar, whether with well fitting or poorly fitting bars or even worn bars. It was also desired to learn if possible how speed of train affects these various matters. To serve as a basis of comparison, the stresses and moments and depressions of the full rail in the same track under the action of the same locomotive and cars were needed.

With the availability of track and locomotive and the setup of testing equipment, advantage was taken of the opportunities to make a number of tests to judge the feasibility of obtaining results of some significance on various other matters, including the effect of batter of rail and flat spots and out-of-roundness of wheel upon stresses in rail, and also to make a number of tests on the effect of counterbalance of a steam locomotive on the stresses developed in rail and the corresponding rail depressions.

5. **The Track and the Test Layout.**—The tests were conducted on Track 4 (southbound passenger) at a point about one-half mile north of the station at Elkton, Md. A distance of more than five miles (slightly down grade) to the north was available for attaining the highest speed used and an adequate distance to the south for stopping the locomotive. The test site was on a 14-min. curve to the right with superelevation of 1½ in. Ahead of and behind this curve the compound curve became 33 min. The total curve extended over a distance of about a mile. New 131-lb. R.E. rail was placed in track over the distance A in Fig. 1 on May 28, 1937; these rails had been predrilled for the stress gages. The normal tie spacing was 22 ties to the 39-ft. rail, but in February, 1937, the ties were slightly re-spaced at gage locations 4, 5 and 6 in order that the instruments might be attached to the base of the rails at ten-foot intervals. The test site is situated on a relocation of the main line built in 1934, at

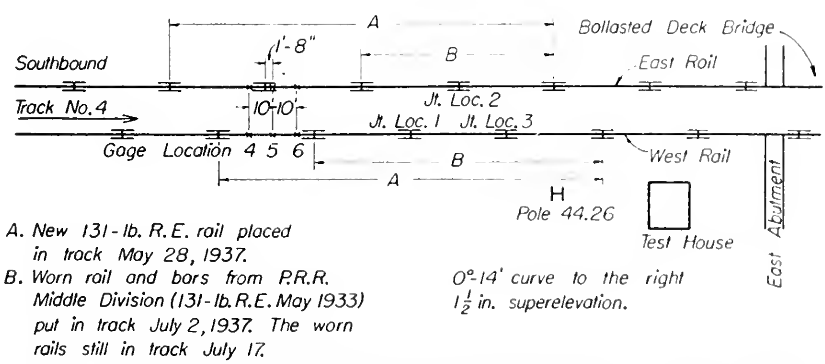

Fig. 1.—Sketch Showing General Layout of the Test Location on the Pennsylvania Railroad near Elkton, Md.

which time entirely new track was laid. Large trap rock ballast is reported to extend 18 in. under the bottoms of the ties on four feet of cinders. The sawn oak ties are 7 in. by 8 in. by 8 ft. 6 in. The heavy double-shoulder tieplates are 7½ in. by 14¾ in. Generally four driven spikes were used at a tieplate. At the test location there is about 15 ft. of fill to the west of Track 4, and 5 ft. of fill to the east of Track 1. The track had been maintained in excellent condition; in all, it was a stiff substantial track well above the ordinary. The track carried many fast passenger trains. There was the usual

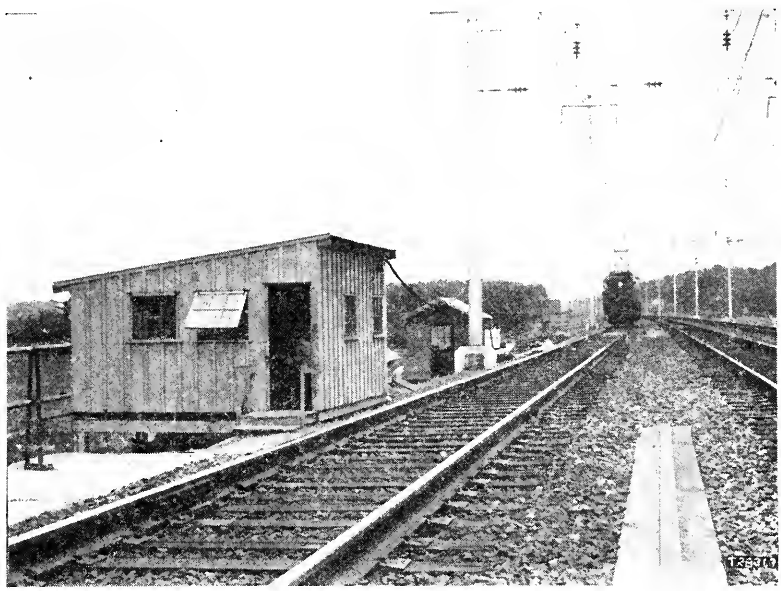

Fig. 2.—General View of Test Site on the Pennsylvania Railroad near Elkton, Md.

variation in play along the track from tie to tie between rail and tie plate or between rail and the ballast always found even on high grade track. At the places where the track depression was measured, the modulus of elasticity of rail support u averaged 2,500 lb. per in. In all it was a very stiff track even though the fill was relatively new and not fully compacted.

The general layout of the test location is shown in Fig. 1 and a view in Fig. 2. The test house was conveniently located close to the positions on the track where the recording instruments were placed. The wire leads extended from the instruments on the track to the recording apparatus in the test house. The six gages measuring longitudinal stress at the middle of the base of the rail and the six solenoid rail depression gages were located on opposite rails at gage locations 4, 5 and 6 spaced at 10-ft. intervals.

The tests on the rail joints were made at joint Locations 1, 2 and 3, Locations 1 and 3 being consecutive joints in the west rail and Location 2 being in the east rail between the other two. The special test joint bars were installed from day to day in the track at these three locations. Generally three pairs of bars of identical sections were placed in the three joint locations. One type of measuring gage was placed on the bars in joint Location 1, another type on the bars at Location 2, and the remaining gages on the bars in Location 3, all three sets of gages operating for a locomotive test run. Later the gages were twice interchanged so that all three types of gage were used on each joint, and runs were repeated for each of the three arrangements.

6. **Locomotives and Cars.**—In the principal tests Electric Locomotive 4779 of the P5a class (4–6–4) was used, except that Locomotive 4790 of the same class was substituted for one day. The wheel spacing and the average of the weighed wheel loads for each axle are given in Fig. 3. A view of the locomotive is shown in Fig. 4. This passenger locomotive has nominal wheel loads of 19,300 lb. on the front truck wheels, 38,000 lb. on the driving wheels, and 22,400 lb. on the rear truck wheels. The spacing of the 72-in. drivers is seen to be 10 ft. and the rigid wheel base is 20 ft. The frame

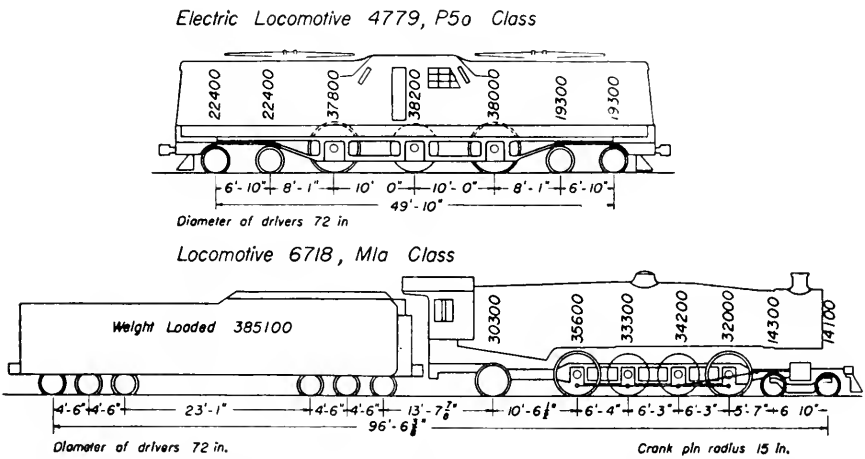

Fig. 3.—Diagrams of Wheel Spacings and Wheel Loads of Locomotives Used in the Tests on the Pennsylvania Railroad near Elkton, Md.

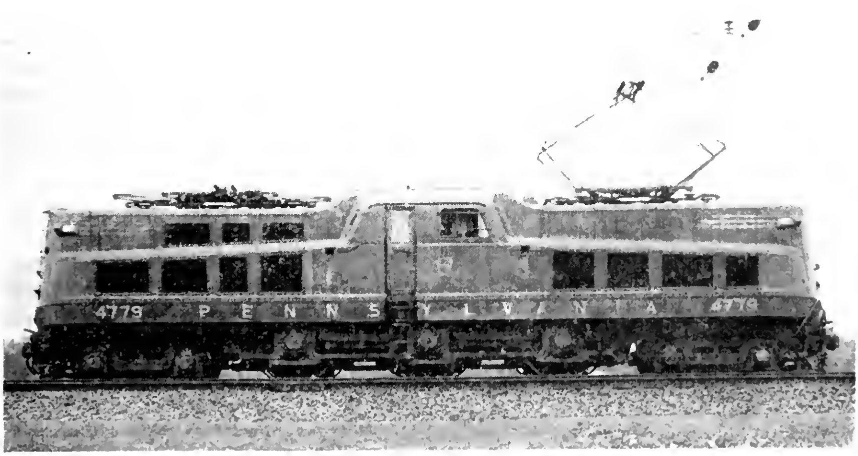

Fig. 4.—View of Electric Locomotive 4779.

supports a single cab that extends the length of the locomotive. A twin armature motor is mounted over each of the three driving axles. The armature shafts are geared to quills which turn the wheels through spring cups. The three motors will develop 3,750 hp. continuously. There are no mechanical connections between the driving axles. The power is supplied from an overhead line of 11,000 volts at 25 cycles.

The individual wheels of Locomotive 4779 were weighed on locomotive scales in 1935. For the right side, starting at the front end, the wheel weights were 16,300, 16,000, 41,800, 40,200, 39,500, 19,700 and 19,700 lb., respectively. For the left side, also starting at the No. 1 end, the wheel weights were 22,400, 22,600, 34,200, 36,300, 36,100, 25,100 and 25,100 lb., respectively. It is to be expected that the individual wheel weights will vary from time to time. The weights given above differ from the nominal weights. The unsprung weight for each driving axle was reported to be 13,500 lb.

Steam Locomotive 6718, a fast freight engine of the M1a class (4–8–2), was used for one set of tests with the rail stress and depression gages at speeds of 5 and 75 miles per hour. The locomotive had the individual wheels weighed on scales in 1935. For the right side, starting at the head end, the wheel weights were 14,700, 14,600, 30,900, 33,800, 34,600, 34,900 and 26,100 lb., respectively. For the left side the corresponding loads were 13,500, 14,000, 33,000, 34,700, 31,900, 36,300 and 34,600 lb. The wheel spacing and the average of the weighed wheel loads for each axle are shown in Fig. 3. The 72-in. driving wheels were reported to have an unsprung weight of 8,250 lb. for each main wheel and from 6,500 to 6,850 for the others. Both the second and third pairs of driving wheels are equipped with flangeless tires. The center of gravity of the locomotive is given as 78½ in. above the rail. The tender is especially large and heavy, holding 22,000 gallons of water and 31 tons of coal. When loaded the weight on each of the 12 tender wheels would average 32,000 lb. At the start of the test day there were 21,000 gal. of water and a full load of coal in the tender. After the last run about 7,000 gal. of water and 11 tons of coal had been used.

In several tests the electric locomotive pulled a heavy and a light car. The heavy car was a 70-ton coal hopper car (class H21a) overloaded with company coal, the average weight per wheel being 26,500 lb. The light car used in several tests was an empty steel box car equipped with non-harmonic truck 2DF12 with combination helical and elliptical springs. The average weight per wheel was about 6,000 lb.

7. **Testing Equipment.**—The magnetic strain gages and the greater part of the auxiliary equipment used in the tests were the property of the Pennsylvania Railroad. Much of this equipment was developed jointly by the Pennsylvania Railroad Laboratory and the General Electric Company and constructed by the latter. The testing equipment constitutes a marked advance in the means for obtaining information on high speed phenomena.

The test equipment consisted chiefly of three types of magnetic strain gages designed for the measurement of (1) stresses, (2) small movements and (3) depressions of track and also auxiliary apparatus required for the operation of these three types of gages. The auxiliary electrical apparatus consisted principally of two six-element oscillographs for recording gage indications, various power supplies, and necessary meters, switches, resistances and miscellaneous instruments and tools. A darkroom fitted out for the development of the films was one of the valuable facilities on the test location. Special instruments and tools were on hand for such static tests and incidental measurements as were required. A small work shop at the test stretch and various portable machine tools aided in the conduct of the tests and the maintenance of equipment.

A magnetic circuit in which the lines of magnetic force must travel through both a magnetic material and an air gap has a major part of its reluctance in the part of the path that is through the air gap even if that part of the path is very short. Therefore, a small change in the length of the air path will have a relatively large effect on the total reluctance of the circuit and on the current in the windings. This fact is the basis of all the magnetic strain gages used in these tests and previous tests.[1] [2] Three types of gages were used that differed principally in the range of movement they were designed to measure, their sensitivity and the mounting attachments for applying them to the test pieces.

A diagrammatic circuit for one gage is shown in Fig. 5. The indicating gage, it may be noted, is a part of an alternating current bridge circuit with a power supply to the bridge of 2,000 cycles frequency and 4 to 24 volts. Sixteen volts provided sufficient sensitivity and was used throughout the tests. This high frequency extends the frequency response range of the gage and increases the sensitivity. The balancing gage shown in the other side of the bridge circuit is an exactly similar gage but is set to a definite and fixed air gap and mounted in the test house. This duplication of the indicating gage was necessary to obtain the proper balancing of the bridge. The

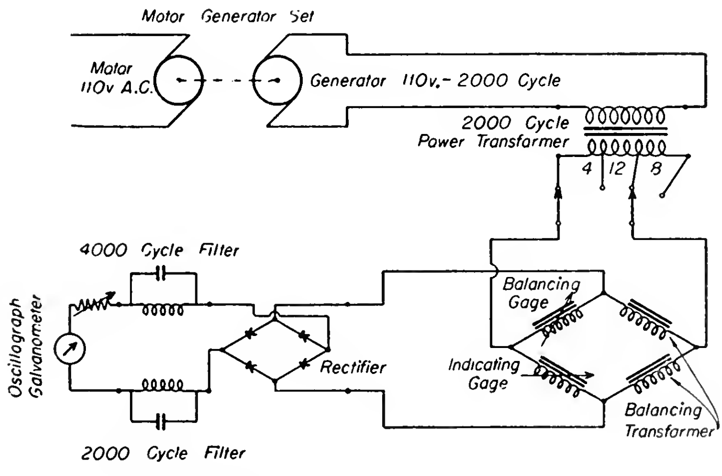

Fig. 5.—Diagrammatic Circuit of One Magnetic Strain Gage.

balance of an alternating current bridge is affected not only by the bridge proportions but by the wave shape and phase relations of the currents as well. The other two arms of the bridge marked "Balancing Transformer" are designed to give to this part of the bridge electrical characteristics similar to the two gages in the other two arms. The oscillograph galvanometer is connected between the two gages and the balancing transformers, and with the bridge balanced no current or a very small current will flow through the galvanometer. Interposed between the galvanometer and the bridge arms is seen a rectifier and filter circuit. The rectifier makes the 2,000-cycle current from the

[1] Sixth Progress Report, Special Committee on Stresses in Railroad Track, Proceedings, American Railway Engineering Association, Vol. 35, 1934, page 130, Chapter III. "Tests of Rail Joints on the Pennsylvania Railroad."

[2] "Rail Stresses and Locomotive Tracking Characteristics Found in Tests on the Great Northern Railway" by J. Paul Shamberger and B. F. Langer, Bulletin No. 339 (September, 1931) American Railway Engineering Association.

bridge uni-directional and the filter which has a high impedance to current of 2,000 and 4,000-cycle frequency smooths out the rectified current including any second order harmonics. The bridge is, of course, not operated by adjusting the galvanometer current to zero when an unbalance results from a stress change, but instead the variation of current from the unbalance is recorded by the oscillograph and these variations are interpreted by the calibration curves as will be discussed later. This description covers the essentials of the gage circuit. Of course, various resistances, meters, switches and other equipment aided in the adjustment and control of the setup but were merely details incidental to the efficient operation of the apparatus.

For the tests there were available twelve 2¼-in. strain gages of the sensitivity required for the measurement of stress. A view of two of these strain gages for measuring stresses attached to a joint bar at position *B* and *C* is shown in Fig. 6. As the effective range of travel was limited, each individual gage was calibrated to be used at a place where the highest values of the stresses were always tension or compression, as the case might be, depending on the position of the given gage on the test piece. The reason for this practice will be shown more clearly later. These gages for stress measurement were calibrated for three sensitivities: the gages gave a deflection on the film of approximately 1 in. for 10,000, 20,000, or 30,000 lb. per sq. in. stress. The sensitivity used for most of the tests was 1 in. deflection for a stress of 20,000 lb. per sq. in.

Six gages were designed to measure movements between the bar and the rail at the upper fishing surfaces, two gages being for the measurement of the relative longitudinal movement at the rail ends and four gages to measure the vertical movement at the two rail ends and the two ends of the bar. These gages are suitable to measure a greater range of movement than those used for stresses and had a lesser sensitivity. The range of movement that can be measured with this type of gage is about 0.05 in. and the sensitivity was adjusted so that a change of 0.01 in. gave 1 in. deflection on the film. Views of the movement gages attached to a joint bar are shown in Fig. 7. The gages for measuring longitudinal movement (L_5 and L_6) are shown in the upper view and those for measuring vertical movement, (V_1, V_2, V_3 and V_4) in the lower view. In both views a gage for measuring stress is attached to the lower part of the bar at position *C*, also indicating the position of the wheels along the track for interpretation of the movement records.

Six magnetic gages called solenoid depression gages were available for measuring depressions of the rail. The solenoid depression gages, so far as known, are the first instruments to record satisfactorily the depressions of rail at such high speeds as 90 miles per hour. The construction of these gages differs from the magnetic strain gages for measuring stresses and small movements, as can be seen in the views shown in Fig. 8. The upper view is the gage itself and the lower view shows it attached to the rail and to a channel supported on steel posts fixed in the roadbed. The part marked *A* in the upper view is attached to the base of the rail when in use and the cylindrical armature *B* moves up or down in the solenoid coil *C*, the coil being mounted on the channel D. The movement of the armature has an effect on the current in the bridge circuit similar to the change of the air gap in the other type gages. The channel supporting the coil part of the instrument was mounted on the posts in such a manner that the passage of the locomotive caused little deflection of the channel. The channel was mounted on posts driven deep into the earth below the track. These posts were driven through pipes that freed them from contact with the ballast and other track support for a distance of about six feet below the base of the rail. These solenoid gages are relatively insensitive compared with the other gages but have a much larger

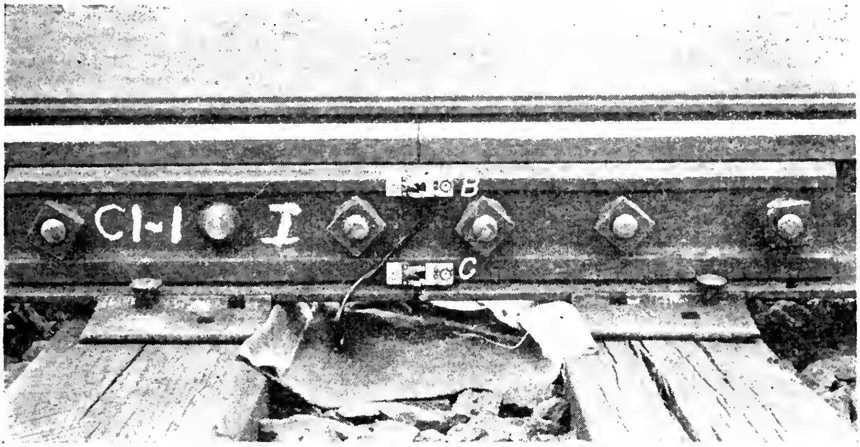

Fig. 6.—View of Two Magnetic Gages Attached to a Joint Bar at Positions B and C.

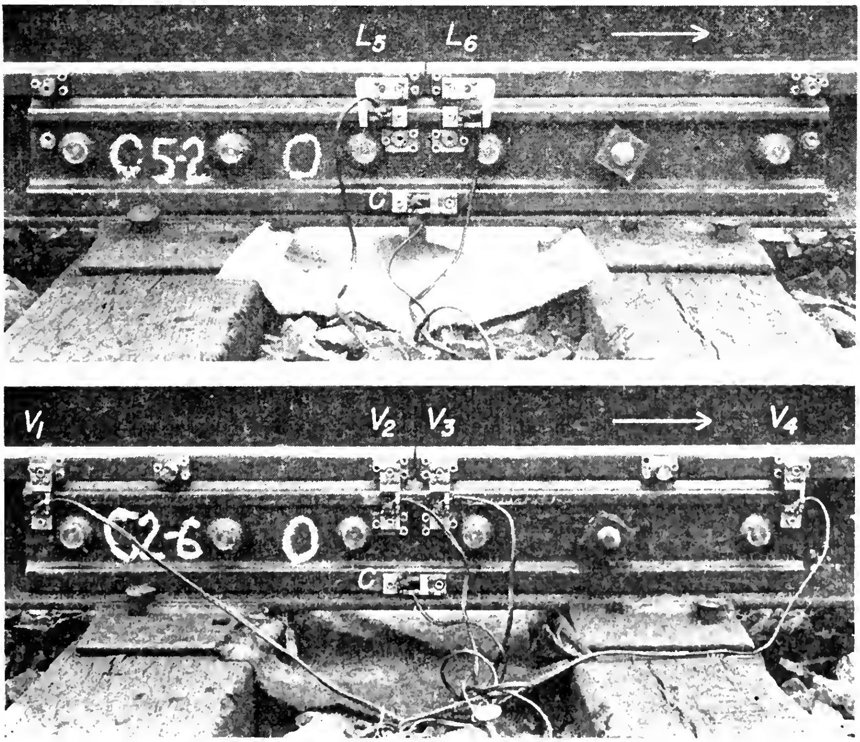

Fig. 7.—Views of Two Longitudinal Movement Gages and Four Vertical Movement Gages on a Rail-Joint.

effective range of indication. Movements of one inch can be measured without departure from the straight line portion of the calibration curve to any serious extent. For the tests a sensitivity was used that gave a four to one magnification of the rail movement on the film.

The indications of the gages were recorded on two six-element portable oscillographs designated as Oscillographs A and B for these tests and located in the test building. The oscillograph galvanometers have very small mirrors that rotate proportionally to the current in the circuit and the deflections of a light beam from the mirror due to this rotation are recorded on a moving strip of film six inches wide by five feet in length. The film in the oscillographs was driven from a shaft common to both oscillographs so both films had similar time scales. A timing vibrator in each oscillograph made a timing record on the film from a clock giving half-second intervals or from the power line giving one-sixtieth second intervals. Fig. 9 is a picture taken inside the test building showing the oscillographs, which may be seen on the bench to the right center, and the various balancing gages, resistances, transformers, meters and other equipment. At the extreme right beside the oscillographs may be seen a gear box in the film driving system that made available ten driving speeds for the film to suit the various speeds used in the tests. The darkroom for developing the fi m was in this building but is not visible in the picture.

The 2,000-cycle current for the gages was obtained from a motor-generator set operated from a utility power line extended to the test site for the tests. Direct current was available in large quantities with voltages up to 80 volts from a group of car lighting batteries. A tungar charger operating on the power line kept these batteries charged.

The gages for measuring stresses and movements were attached to the rails or bars by means of studs that screwed into tapped holes in the rails or bars or spacer blocks. Because of the large number of joints tested and the number of gages used, the drilling, tapping and facing of the various bars, rails and spacer blocks was a major item of the labor incidental to the tests. Various portable drills, facing tools, templets and jigs were available for this work.

The several types of electric strain gages were in general calibrated by mounting the gage on some mechanical device by which the gage length could be changed by known increments of movement and readings of galvanometer deflection observed on the ground glass screen of the oscillograph. This deflection corresponded to that which would be recorded on the film when the film replaced the ground glass screen. For the calibration of the strain gages for indicating stress a modification of the purely mechanical method of calibration was used. Johansson gage blocks gave standard readings by means of a very sensitive magnetic strain gage and microammeter. The gage and meter were then used as a sensitive secondary standard to move the gage being calibrated a known increment. These calibrations and certain preliminary work to determine some characteristics of the equipment and the relative importance of some of the details of operation occupied a considerable time. However, this work gave the members of the staff a thorough familiarity with the capabilities and limitations of the equipment and it was possible from the results of the work to avoid some important sources of error that would have arisen from an incomplete knowledge of the equipment.

The calibration of the strain gages for measuring stress required the greatest amount of care and accuracy. For a given calibration the balancing gage in the test house was set to a definite air gap, the optimum amount of which was determined as a result of the preliminary experimental work mentioned above and the resistance adjusted by a few trials to give the required sensitivity. The indicating gage was then

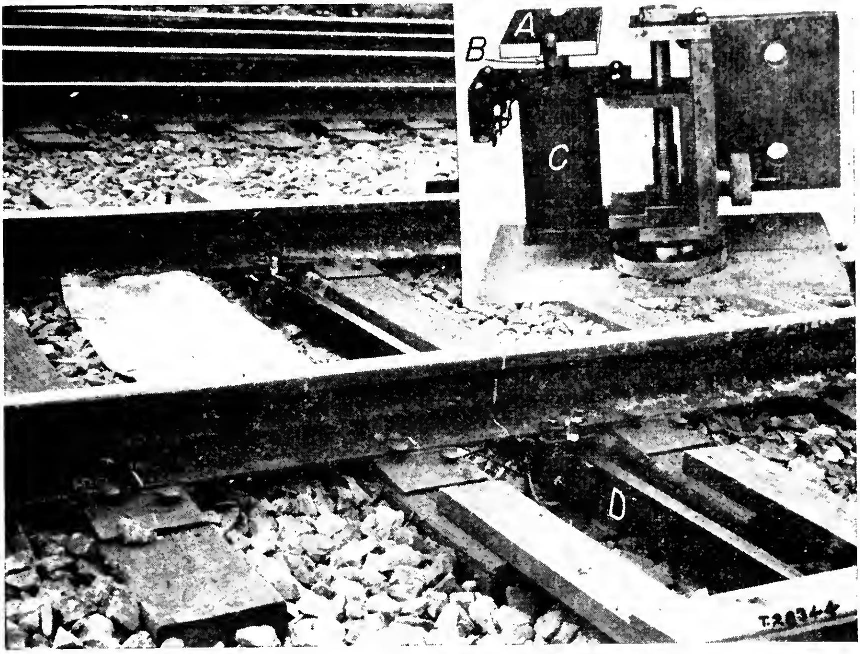

Fig. 8.—Views of Solenoid Depression Gages.

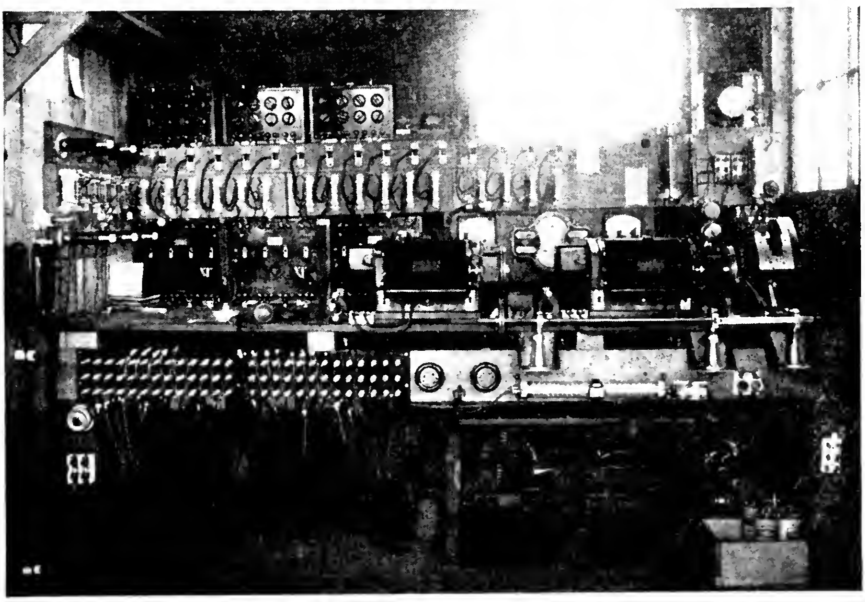

Fig. 9.—Recording and Auxiliary Equipment in Test Building.

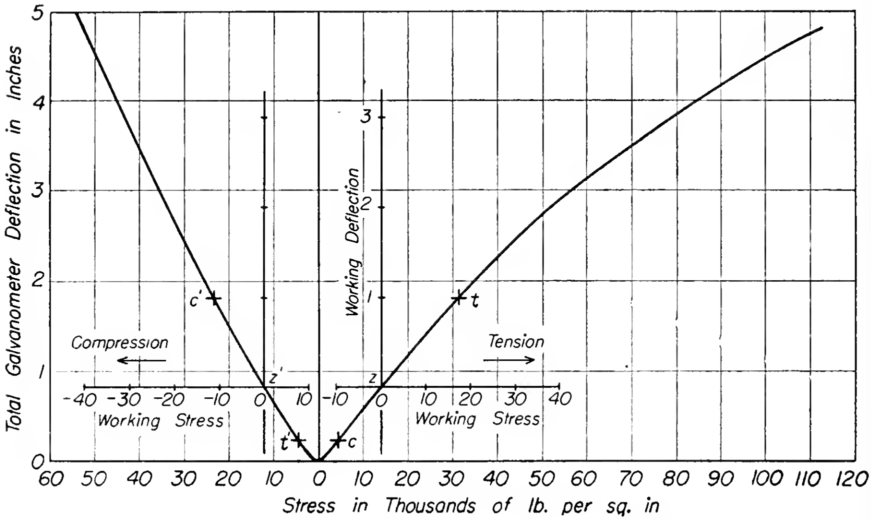

Fig. 10.—Typical Calibration Curves of One Gage.

compared with the high sensitivity secondary standard instrument through the useful range of travel of the gage. A typical calibration curve thus obtained is shown in Fig. 10. The ordinates are deflections of the galvanometer on the oscillograph screen in inches and the abscissas are changes in the air gap of the gages converted for greater convenience into stress in pounds per square inch for a 2¼-in. gage length. Ordinarily a calibration was run for only the right or left half of the curve. The side used depended on the position selected for the gage to be used. The nominal constant for the curve shown is 20,000 lb. per sq. in. stress for a deflection of 1 in. on the film.

Inspection of the calibration curve in Fig. 10 reveals several important characteristics of this gage governing the reduction of any data taken from it. The deflection never reverses direction but reaches a minimum value called the electrical zero. This electrical zero in the figure is practically the zero deflection of the galvanometer indicating a very small current and good bridge balance. There is no reversal of galvanometer deflection because the rectifier in the galvanometer circuit always converts the alternating current from the gage in the same manner so that only the amount of current varies and not its direction. It is desirable to have this minimum deflection as small as possible. A large deflection shows a lack of balance in the bridge and if caused by unbalanced harmonics may cause a wide trace on the film. In the vicinity of the point of minimum deflection the line is curved and the instrument relatively insensitive to changes of stress so that this region is unsuitable for use in measuring stress. On the right side of the figure the curve is approximately straight between points c and t and this part was selected for the operating range of the gage when the maximum values of the stresses to be measured were in tension. If the reverse condition of stress prevailed, a similar portion on the left side was selected as indicated by the points c' and t'.

A point z (or z') was picked on the straight line portion of the curve as the point of zero load stress with the gage in position on the test piece with no load so that the maximum limits of tension t and compression c expected would fall on suitable parts of the calibration curve. The adjustment of the deflection to the proper value for zero stress was effected by adjusting the air gap of the indicating gage with no load on the test piece. If the point z is located too far up on the curve as would be necessary when the gage is located in such a position that the compression stresses are the greater, the larger current flowing in the gage circuit during calibration causes errors in the indications that are dependent on the length of time the power is applied to the gage. This difficulty was avoided by using the other side of the curve for cases where the highest stresses are compressive and locating a similar point z' of zero load stress as low as feasible on the left hand portion of the curve.

With the position of zero load stress properly selected a calibration constant can be determined from the slope of a straight line through z drawn to minimize as much as possible the effect of the slight curvature in the calibration curve. The value of error selected as permissible was ± 500 lb. per sq. in. To keep within this limit it was usually necessary to use a different slope to determine the constant for compressive stress reduction than the slope for tensile stress reduction. Of course, the calibration curve itself could have been used for the determination of the stress from every individual deflection and thus have eliminated the error caused by the curvature but the volume of data taken would have made the reduction unduly long and the refinement was deemed unnecessary. The range of travel of the gage can be judged from the figure. For gage lengths other than 2¼ in. it should be remembered that the range of unit stress measured will be in inverse proportion to the change of gage length.

During the tests the location of the point z (point indicating zero load stress in the member) was found to shift. This was due to one or all of several causes, the most important of which were change of temperature and adjustment of newly applied joint bars under traffic. It was therefore essential to take readings at the oscillograph screen from time to time to determine the position of the point z on the calibration curve, and get the proper calibration constant for this position to reduce the results from the records affected. This procedure was necessary to keep the accuracy of the reduction within the limits of ± 500 lb. per sq. in. When the point z shifted unduly it was reset to the most desirable position. The shift was made by resetting the air gap of the indicating gage in the track according to the directions of the oscillograph operator. The resetting was facilitated by the telephone system between the test building and the gage locations. An effort was made to keep the shift below such amounts as would require the use of a different calibration constant but since four to seven runs were made on a film before the positions could be checked the shift sometimes exceeded the limits desired. It is obvious from the above discussion that a continuous and accurate record must be kept in regard to the position of the point of zero stress on the calibration curve to use these gages and keep within the limits of accuracy required for most purposes.

The gages were found to be rugged and unaffected by vibration. They were reliable and it is judged they gave sufficiently accurate results with the proper manipulation and understanding of their capabilities and limitations. The complication of the auxiliary apparatus and its quantity limit the applicability of the gages for many purposes. However, the gages are a very valuable tool for measurements of small changes of length that take place rapidly and in many cases the information obtainable by their use will justify the expense and time involved. The method of recording gives a definite time scale and if desired the time scale can be enlarged to separate changes occurring very quickly.

Various instruments and equipment were used for incidental measurements and tests. These include portable strain gages for static measurements of movements or strains, profile indicators for the rail running surface and the bar fishing surfaces, a level rod graduated in 0.01 in. for measuring static depressions, a camera equipped with a 20-in. telephoto lens for measuring depression of the track, and various dial gages, electrical meters and other equipment.

8. **Operation of the Tests and Reduction of the Data.**—The test equipment used was complicated and elaborate. Before the start of the field tests the entire equipment was assembled at the test plant at Altoona and calibrated. All contemplated field operations were thoroughly coordinated at this time. By this procedure the members of the field party became so familiar with the apparatus and its operation that practically no trouble or delay was experienced throughout the field tests due to the apparatus. So far as known, the testing equipment is the most elaborate ever assembled for a study of the action of railroad track.

In making a typical test the duties of each member of the operating staff of eight men were definite. Two experienced men operated the two oscillographs and auxiliary equipment in the test houses; before the runs were made it was their duty to adjust and space the records on the films in such a manner that the path of a record of one instrument would be expected to cause little or no interference with companion records. Before a set of locomotive runs was started each magnetic strain gage on the rail or joint bars was set in proper balance by a third man who adjusted the gage. Coordination of adjustment between the gage and its proper recording space on the film record were set by the gage man and an oscillograph operator by telephone headsets from their respective places; these adjustments were checked several times during the day. The oscillographs were started in operation just before the test locomotive reached the instruments on the track and turned off just after it had passed. A gear box driving the oscillographs made it possible to select a proper length of film record to correspond to the speed of the test locomotive. It was possible to record four or five runs on a 60-in. film. After the last run had been recorded on the pair of films, they were removed from the oscillographs and immediately developed by a photographer in the small dark room in the test house. After the films were dry a draftsman lettered the proper information on the films so that they could be readily identified and studied.

Two machinists were kept busy preparing the joint bars for testing by drilling the holes for the gages, transferring the gages from one test location to another and in the preparation of material for many of the auxiliary tests.

As the tests were made up of almost 600 individual test runs and as the gages were changed from point to point 42 times during the tests, usually from one set of joint bars to another, it was necessary to record in systematic detail all the operations that were made. Printed form data sheets aided the recorder in listing details of the test. As the tests were conducted on a very busy main line track, an operator (dispatcher) located at the test site made it possible to use the test track efficiently without interfering much with regular traffic.

In the calibration a proper amount of resistance was placed in each magnetic strain gage circuit to make a deflection of one inch on the film equivalent to a stress of 20,000 lb. per sq. in. For the six gages measuring longitudinal and vertical movements between rail and joint bars a deflection of 1 in. on the film usually corresponded to a movement at the gage of 0.01 in. The resistances in the solenoid gage circuits were set so that a deflection of 1 in. on the film corresponded to a rail depression of 0.25 in.

After the testing was completed, the deflections were measured from the films in the office. Light was projected through the film and a scale cross section paper was placed behind the film and the amount of deflection in one-hundredths of an inch at each wheel was measured and recorded. The negative values approximately one-half way between wheels were also read. After the deflections were thus taken from the films, the values were multiplied by the proper constants to reduce stress to pounds per square inch, rail depression to inches and movements between rail and joint bars to inches. For a group of runs the tabulated values were then averaged and plotted so that the data could be studied and interpreted.

In almost all of the films, even for the runs at 90 miles per hour, the deflections on the film could be read accurately to 0.02 in., which would correspond to a stress accuracy of about 400 lb. per sq. in. Naturally the measuring, recording, transferring to proper units, averaging and plotting of the more than 120,000 individual measurements was time-consuming. Measuring the values from the films was found to be more rapid and a more pleasant task than measuring a like number of readings from any of the mechanical recording gages with which the test party has had experience.

The extremely large volume of data taken in the field tests and a large amount of data in the laboratory test to correlate with the field tests required time for reduction. The analyses of the results and their interpretation, as checking the many ways in which the variable factors apply to findings, occupied the attention of the staff for a considerable period. In fact, this part of the preparation of the report was time-consuming and had to be handled with extreme care.

III. Stresses, Moments and Depressions in Rail with the Electric Locomotive and the Cars

9. **Stresses and Moments in Rail.**—The excellent testing equipment available gave opportunity to measure the stresses and depressions in rail developed under speeds ranging up to 90 miles per hour with a locomotive that was free from some of the complications given by the ordinary steam locomotive. The absence of unbalanced rotating parts in the electric locomotive also gave an opportunity to learn something of the variation in the load applied to the two rails through the transfer of vertical load from one of the wheels of an axle to its companion wheel. The main purpose of the measurement of stress in the rail, however, was to find the stresses and moments developed in the rail to serve as a basis of comparison for the discussion of the stresses and moments developed in the joint bars. The data obtained, although too limited to establish fully some of the relations between the action of the locomotive and the rail, will be found to be useful information.

The magnetic strain gages were placed at the middle of the base of rail; the reading then gives the mean longitudinal stress in the base of rail. As the six gages were placed opposite one another (three on each rail as shown in Fig. 1) with a spacing of ten feet (the same as the spacing of the driving wheels) simultaneous stress values are always obtained for the two wheels on one axle, and besides, at the instant the six driving wheels are over the six gages, simultaneous values of rail stress for all six driving wheels become available for this position, as well as simultaneous values for first and second wheels and second and third wheels at other instants. It should be appreciated, however, that the varying nature of the rail supports will result in some difference in the values even for identical wheel loadings. It should also be recognized that differences in the stiffness of the support and the amount of play at the three places or locations where the instruments were placed will develop differences in values besides those caused by the changing "attitude" of the locomotive and its wheels in passing from one test location to another. Such variations are inevitable in railroad track and rolling stock,

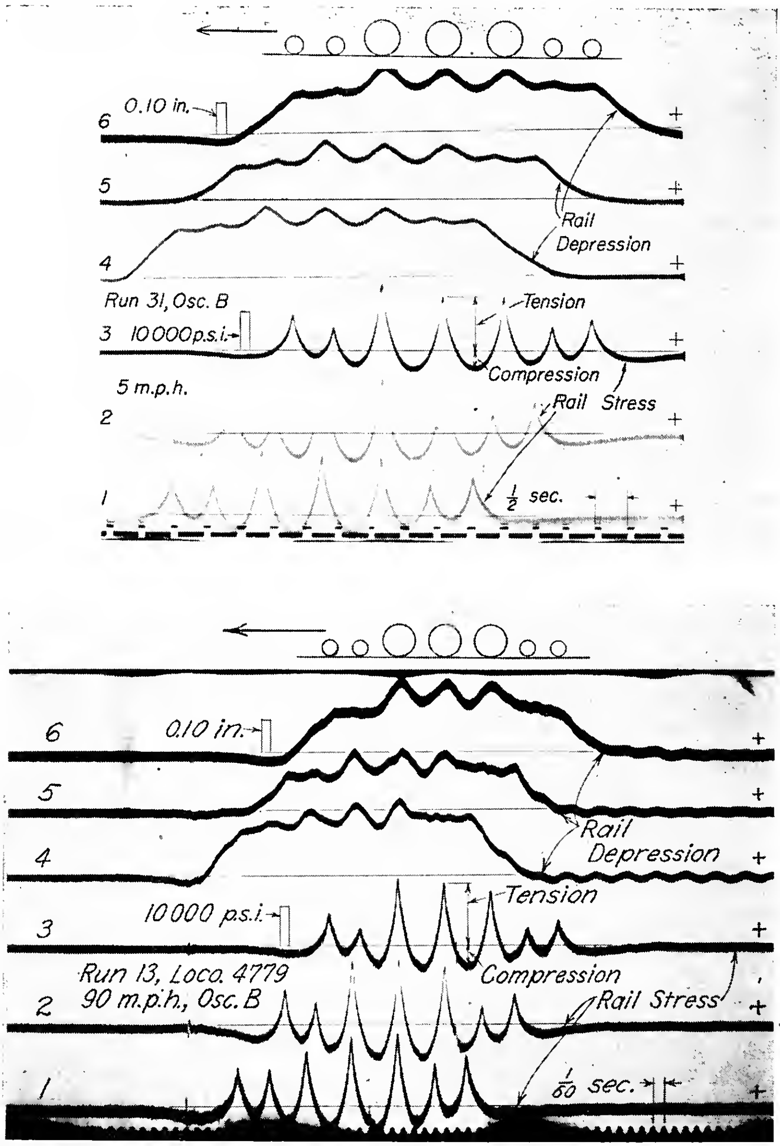

Fig. 11.—Typical Records of Rail Stress and Rail Depression at 5 and 90 Miles per Hour—Pennsylvania Railroad Electric Locomotive 4779—Elkton, Md.

even though the magnitudes of the variations will vary greatly with the quality and condition of both track and rolling stock.

Two typical films of stress and depression records are shown in Fig. 11. The upper record is for a speed of 5 miles per hour and the lower for 90 miles per hour, the highest speed run. These records are for right rail only. They are numbered 1 to 6 from bottom to top, the first, second and third representing stresses in the middle of the base of rail and the fourth, fifth and sixth depressions of the rail. The stress given by 1 and the depression by 4 are at the same gage location (Location 4 right rail). Similarly 2 and 5 are for the next location (Location 5 right rail) and 3 and 6 the last location (Location 6 right rail). A zero line of stress has been drawn on the film. Tensile stress is indicated above this line and compressive stress below it. The approximate scale of the records is indicated in the diagram. The film for 90 miles per hour has a timing wave of 60 cycle per second at the bottom edge; the 5 miles per hour film has half-second interval peaks. These two films were made by the six galvanometers of one of the oscillographs and are for the right rail. The other oscillograph running from a common driving shaft was simultaneously making similar records for the left rail.

The left end of the records is the head end of the locomotive, and the wheels pass over the instrument in the order represented above the diagram. The stress and depression records are thus made from left to right as the wheels move to the left. For those

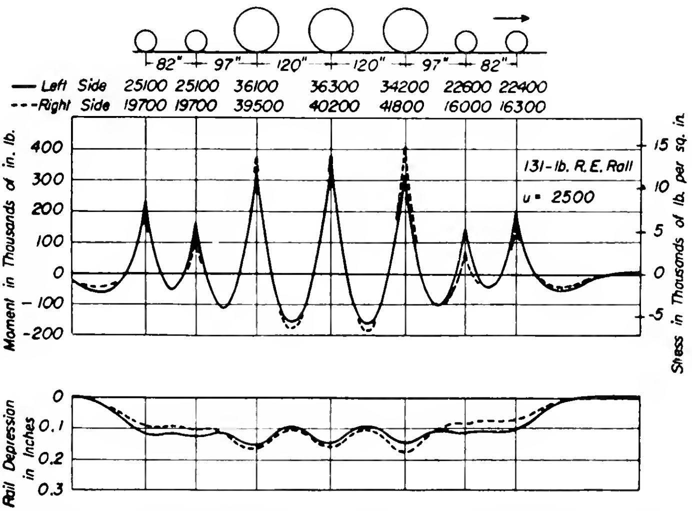

Fig. 12.—Calculated Moments and Stresses and Depressions in Rail for Wheel Scale Weights—Electric Locomotive 4779.

not familiar with interpretation of such records, it may be said that the peaks of the records are taken to be formed when a wheel is directly over the instrument. For the peak and immediately on each side the stresses in base of rail are tensile stresses. For the middle part of the space between wheels the stress is compressive and the record has a rounded form. For the spacing of the driving wheels of this locomotive the maximum compressive stress in base of rail at a point halfway between two driving wheels is about one-half of the maximum tensile stress, which occurs directly under the wheel. It may be remarked that the oscillograph records of stresses in rail were remarkably smooth and definite. As the scale of the record was perhaps three times that of Fig. 11, measurement of the magnitude of the stresses was a comparatively easy task.

In Fig. 12 are given the calculated magnitude and distribution of the moments and stresses and depressions in the 131-lb. rail along the length of the electric locomotive used, as determined analytically with static loading using the wheel weights reported as existing two years before the tests were made. The full line represents values for the left rail; for the right rail a dotted line is shown for stresses and moments whenever it differs enough from the full line to differentiate it in a reproduction. The stresses in base of rail at the driving wheels so calculated are 14,700 and 11,600 lb. per sq. in. for the first driving wheel, 13,700 and 12,700 for the second driving wheel, and 13,500 and 12,000 for the third. The corresponding bending moments in the rail are 400,000 and 320,000, 380,000 and 350,000 and 370,000 and 330,000 in.-lb. for the several driving wheels. It will be seen that the stresses recorded in Fig. 11 and the calculated values in Fig. 12 are quite similar in the characteristics of their magnitude and distribution, though of course variations may be expected because of possible variations in rail support along the track and inaccurate knowledge of the wheel loads, as well as the effect of speed and the ever present changes in the way the locomotive weight is applied to the track.

Table 1 gives the average stresses in the base of each rail at each gage location for each driving wheel at speeds of 5, 60 and 90 miles per hour. The given values are the averages for 10 runs at 5 miles per hour, 7 runs at 60 miles per hour, and 5 runs at 90 miles per hour, making 30 stress observations for each rail at 5 miles per hour, 21 at 60 miles per hour, and 15 at 90 miles per hour. The number of observations for each rail and each wheel is sufficient to furnish reliable average values of stresses and also to permit a study of the variation in stress for the three gage locations and the three speeds.

From the values in Table 1 it is found that for all driving wheels and all speeds the average stress for the left and right rails at Location 4 is 15,000 lb. per sq. in., for Location 5, 13,500 lb. per sq. in., and for Location 6, 13,700 lb. per sq. in. The average values at Location 4 are then about 10 percent greater than those at locations 5 and 6.

Table 1

Values of Average Measured Stresses in the Left Rail and the Right Rail for All Runs at 5, 60 and 90 Miles per Hour at Each Driving Wheel at Each Gage Location.

Electric locomotive 4779 of Pennsylvania Railroad at Elkton, Md. Values are given in thousands of pounds per square inch.

Speed in Miles per Hour	Driver No.	Rail Location 4		5		6		Average	
		Left	Right	Left	Right	Left	Right	Left	Right
5	1	15.4	15.2	13.9	15.5	13.9	15.3	14.4	15.3
	2	13.8	15.1	12.1	14.2	12.3	14.4	12.7	14.6
	3	15.2	13.2	13.2	12.4	13.4	12.4	13.9	12.7
	Av.	14.8	14.5	13.1	14.0	13.2	14.0	13.7	14.2
	Av.	14.6		13.5		13.6		13.9	
60	1	16.1	15.5	15.3	15.5	15.0	14.4	15.5	15.1
	2	14.7	14.8	12.3	14.7	12.3	14.5	13.1	14.7
	3	15.1	13.4	14.4	13.6	15.0	11.6	14.8	12.9
	Av.	15.3	14.6	14.0	14.6	14.1	13.5	14.5	14.2
	Av.	14.9		14.3		13.8		14.3	
90	1	16.9	15.2	13.3	15.9	12.7	17.1	14.3	16.1
	2	13.5	17.5	7.5	15.9	10.7	15.2	10.6	16.2
	3	13.2	17.2	9.3	15.0	12.8	13.5	11.8	15.2
	Av.	14.5	16.6	10.0	15.6	12.1	15.3	12.2	15.8
	Av.	15.5		12.8		13.7		14.0	
Grand Average		15.0		13.5		13.7		14.1	

The play between rail and tie and tie support at gage location 5 was found to be less than at the other two locations. Differences in stress at the three locations may be due not only to variations in rail support but also to the general movement of the locomotive at the points of the three locations.

The average of all the stresses in the left rail for the three driving wheels and for the three speeds is 13,500 lb. per sq. in. and that in the right rail is 14,700 lb. per sq. in. As the weighed load at the driving wheels on the right side was about 10 percent greater than that on the left side and as the superelevation of 1½ in. on the left rail resulted in an application of greater load by the three driving wheels on the right rail at the low speed amounting to perhaps 5 percent, the difference in stress in the two rails is less than might be anticipated. With the lack of information on the actual wheel loads at the time of tests definite discussion on the source of the variation is not possible.

Stresses in base of rail with a modulus *u* of 2,500 lb. per in. per in. have been computed on the basis of the reported scale weights on the wheels of the locomotive and have been multiplied by 14/13ths to give the same grand average as the stresses measured at five miles per hour and thus permit a comparison in the distributions of stress. The values for the nominal wheel loads have been computed in the same way.

Table 2

Measured Stress-s and Adjusted Computed Stresses in Base of Rail for Reported Scale Weights and for Nominal Weights

Electric locomotive 4779 of Pennsylvania Railroad at Elkton, Md. Values are given in thousands of pounds per square inch.

	Left Rail			Right Rail		
Location	6	5	4	6	5	4
Driver	1	2	3	1	2	3
Measured stress (5 m.p.h.)	13.2	14.2	15.3	15.2	12.1	13.9
Calculated from scale weights	14.5	14.8	15.8	12.9	13.7	12.4
Calculated from nominal weights	14.0	14.2	13.9	14.0	14.2	13.9

Table 3

Values of Averaged Measured Stresses in the Left Rail and the Right Rail for All Runs at 5, 60 and 90 Miles per Hour at Each Driving Wheel — Average of Three Gage Locations

Electric locomotive 4779 of Pennsylvania Railroad at Elkton, Md. Values are given in thousands of pounds per square inch.

Speed	Driver Number						Average			Average of Three Drivers
	Left			Right			Left and Right			
	1	2	3	1	2	3	1	2	3	
5	14.4	12.7	13.9	15.3	14.6	13.0	14.9	13.7	12.7	13.8
60	15 5	13.1	14.8	15.1	14.7	12.9	15.3	13.9	13.9	14.4
90	13.1	10.6	11.8	16.1	16.3	15.2	14.6	13.4	13.5	13.8
Av.	13.3	12.1	13.5	15.5	15.2	13.7	14.9	13.7	13.4	14.0

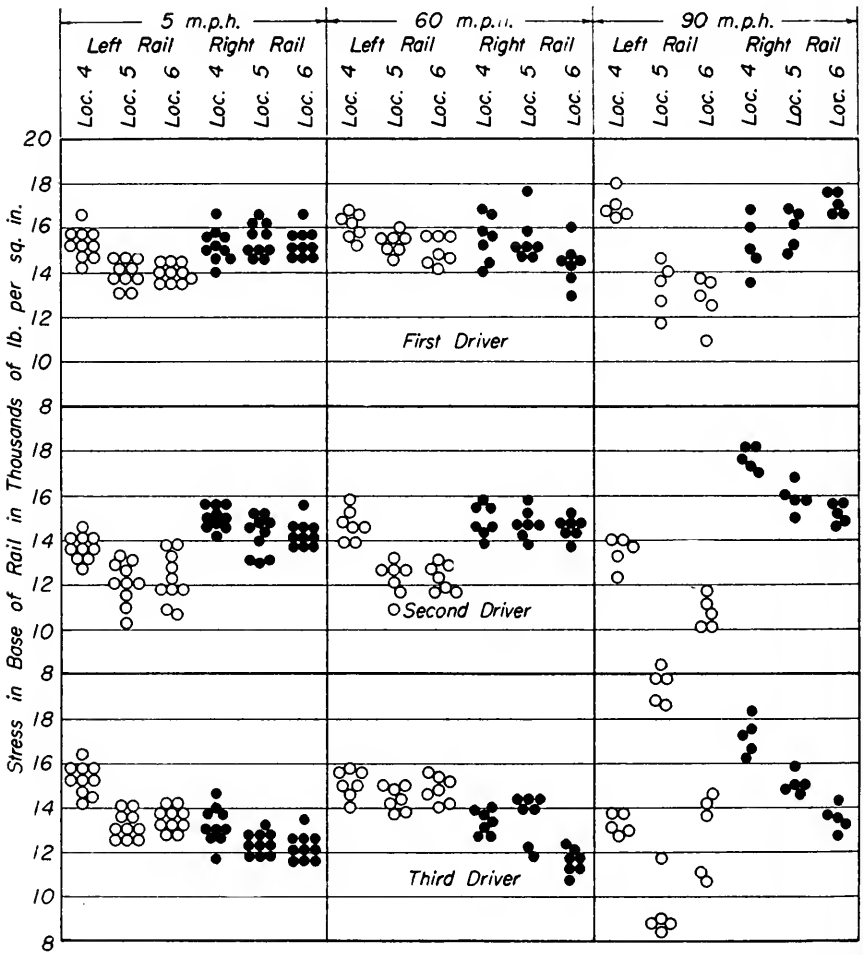

Fig. 13.—Individual Values of Measured Stresses in Left and Right Rail for Each Run and Each Driver of Electric Locomotive 4779 at Gage Locations 4, 5 and 6 at 5, 60 and 90 Miles per Hour.

The results are given in Table 2. A comparison with the corresponding averages for the measured stresses for each pair of driving wheels at five miles per hour shows that the average of the measured stresses is somewhat greater than the calculated ones at the first and third pairs of driving wheels and somewhat less at the second pair of wheels. A comparison of the average of the stresses for the left and right wheels on the same axle (Table 3) shows that the variations for the speeds of 5, 60 and 90 miles per hour are slight, the three speeds differing for each axle not more than 700 lb. per sq. in. from the average for the given axle. The uniformity is in the average of the stresses for two companion wheels; marked variations for the individual wheels of an axle are apparent, as is brought out more fully farther on.

In Fig. 13 are plotted individual points representing the stress in base of rail for each run for each driving wheel at each gage location for each of three speeds. The diagram gives a general idea of the distribution and spread of the individual values. It will be noted that each group of points has a similar variation; except for a few scattered points the values in a group in general come within a range of 2,000 lb. per sq. in. or less. Each group however occupies an individual position. The points for each gage location have a position and value that depend upon the driving wheel and the speed producing the recorded value. The six driving wheels show dissimilarity in the position of the plotted points. Notwithstanding the uniformity in the values of the averages and grand averages of the stresses at a given driving wheel, there are variations of some magnitude in the individual values at the six gage locations. Especially at the speed of 90 miles per hour are the wider variations noticeable at the different wheels and for the different locations.

At 90 miles per hour one of the largest ranges in stress for the three gage locations is found under the second driving wheel, which has a total range of about 3,000 lb. per sq. in. above and below the average. At 90 miles per hour it is apparent from the values shown in the figure that some action is taking place that makes substantial changes in the forces applied to the track during the time the locomotive travels the distance of 10 ft. from Location 4 to Location 5, and a further 10 ft. to Location 6. With the locomotive traveling at 90 miles per hour only about 1/7 sec. is required to cover the total distance of 20 ft. As an example, at 90 miles per hour, for the second driving wheel on the left rail the stresses average 13,500 lb. per sq. in. at Location 4. When the wheel gets to Location 5 the stresses are only 7,500 lb. per sq. in. but rise to 10,700 lb. per sq. in. with the wheel at Location 6. At the same time for the second driving wheel on the other rail (right rail) the stresses shown average about 17,500, 15,900 and 15,200 lb. per sq. in. for locations 4, 5 and 6 successively, all values being high with respect to the other rail. These stresses indicate not only a rapid variation at a given wheel but also some transfer of load from one side to the other.

The rapidity with which these changes take place would indicate that it is doubtful that the changes can be caused by movements of the locomotive as a whole. Any forces from movements involving such heavy masses as the whole locomotive could hardly be expected to change so quickly. A possible source of these variations is in the action of the running gear itself.

Three individual runs were selected that represent the general range of all the individual values shown in Fig. 13; these are plotted in Fig. 14. The sequence of values of stress for a given run may there be followed as the locomotive passes each of the three locations. Values for a given run and driving wheel have been connected by lines.

It is definitely shown by the figure that on a given run there are in some cases marked changes in the stress or moment developed by a driving wheel within the distance of ten feet between instrument locations. The greatest changes from place to place are found for runs at 90 miles per hour; it can be seen that on a given run the driver that gives the highest stress of the group at one gage location may give the lowest stress at the next location. Some variation in the trends of the several runs is seen but in general the stress changes in the same manner for a given driver at a given speed. This similarity indicates the probability that the changes from place to place are governed mostly by the action of some parts of the locomotive, which in turn is influenced by the variations of the track as the instrument locations are approached. The locomotive apparently has the same action for each run at a given location and speed, but this action varies widely at the several locations.

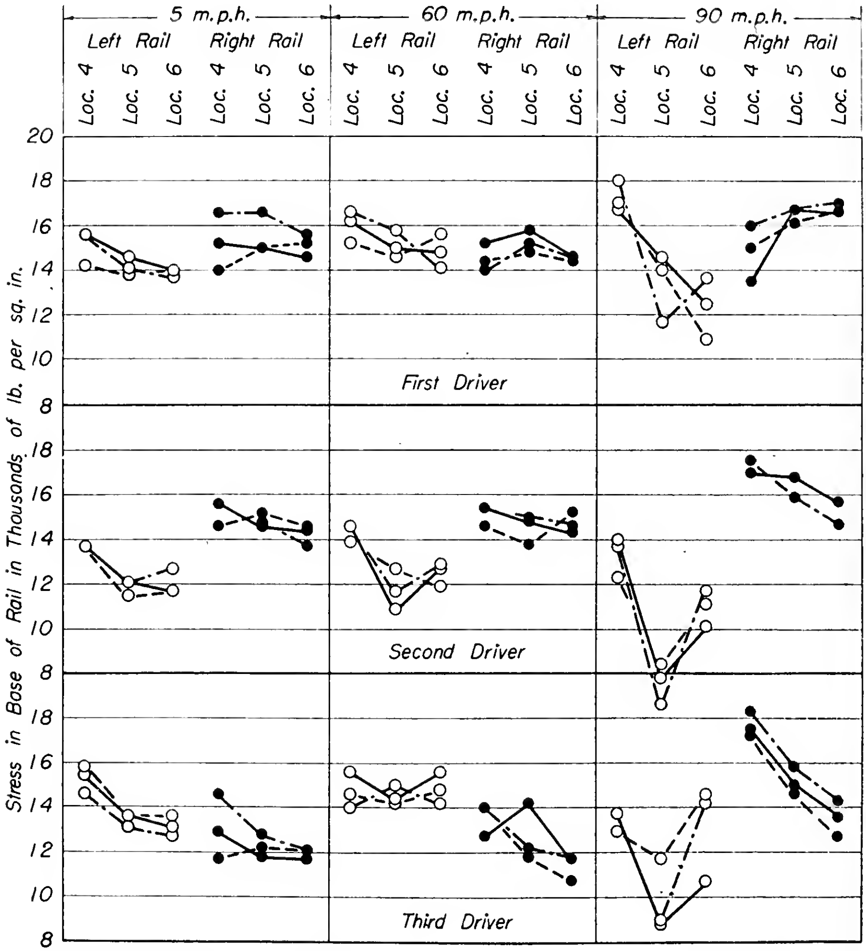

Fig. 14.—Stresses in Rail in Sequence at Gage Locations 4, 5 and 6 for Each Driver on Given Runs—Electric Locomotive 4779.

The test setup permitted a measurement of the stresses and depressions developed simultaneously by each of the six driving wheels at the six gages. The spacing and number of the instruments for measuring stresses and depressions corresponded with the spacing and number of the driving wheels. Thus, at one certain instant as the locomotive passed over the test setup all the driving wheels were recording simultaneous values with the wheels directly over the gages. The stresses and depressions then represent the effects at this one instant of all vertical loads or forces from the driving wheels. Fig. 15 gives these simultaneous values of moment obtained from the measured stresses for three runs that represent the range of values for each speed. Of course, the differences in support at the several locations and the inequalities in the loads on the wheels caused variations in the moments developed, but it is apparent that in at least one case there is some action that causes a greater variation than the differences referred to

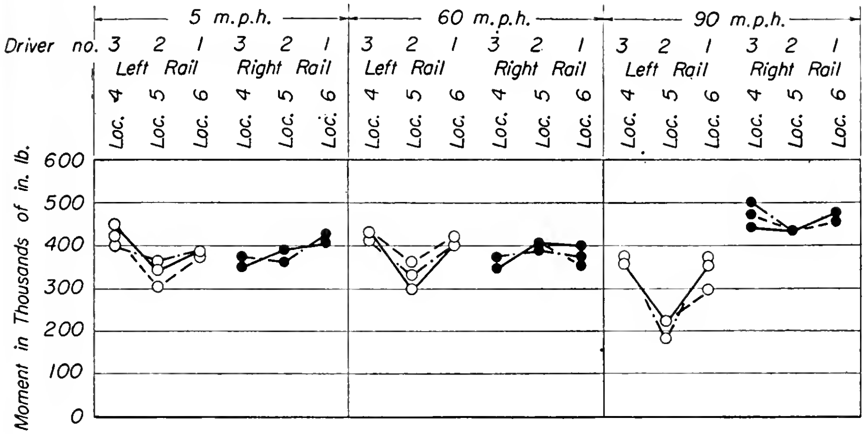

Fig. 15.—Simultaneous Moments in Rail at Each Driver at 5, 60 and 90 Miles per Hour—Electric Locomotive 4779.

produce. Between 5 and 60 miles per hour there are only minor changes in the magnitude of the moments for any wheel at a given gage location. At 90 miles per hour, however, the moment in the left rail under the second driving wheel is markedly lower at gage Location 5 than elsewhere. The moment values at the other locations (4 and 6) over which the third and first driving wheels are passing at the instant are also lower at 90 miles per hour than at 5 and 60 miles per hour, but they have not decreased so greatly as at Location 5. All moment values on the right rail have risen at 90 miles per hour but it is seen that the increases have been approximately equal at the three locations.

From Fig. 13 and Fig. 14, showing individual stresses and sequence of values for selected runs on each driver, it is seen that the same decrease in moment (or in stress) was shown by each driving wheel at 90 miles per hour in passing Location 5 on the left rail. The moments in the right rail at 90 miles per hour were in general higher than those for the runs at the lower speeds, though generally there were not the marked variations between gage locations found in the left rail. The fact that the several drivers on the left rail exhibit the same or similar characteristics on passing Location 5 would indicate that there is probably some peculiarity of support or alinement that influences the behavior of the locomotive action at that point. It is possible the peculiarity is not at Location 5, but some action may be initiated before reaching Location 5 and attain a somewhat increased state of development at that location.

The three locations had varying amounts of play between the rail and its support. Location 5 had the least play, the amount being about half that found at the other two locations. Location 5 in general showed lesser magnitudes of stresses and moments.

In Fig. 16 are plotted the moments in the left and right rail at each driving wheel for various speeds and all gage locations. The values given are averages of all runs. The diagram shows that at a speed of five miles per hour the moments in the two rails for a given driving wheel and location are similar or not greatly different. For the first and second driving wheels the moment for the right side is somewhat the greater, as is to be expected from the weighed loads previously given, but the third driving wheel on the left side gives the larger moment contrary to the relation expected. The moments

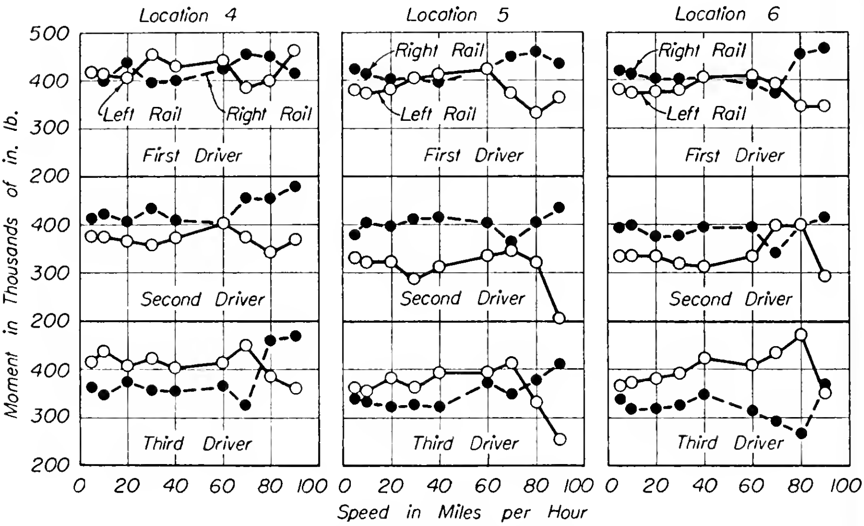

Fig. 16.—Moments in Left and Right Rail at Each Driver for Various Speeds—Electric Locomotive 4779.

in the rails at the higher speeds are seen to maintain their similarity to those at 5 miles per hour in most cases, with only small changes up to a speed of 60 miles per hour. Above 60 miles per hour greater changes take place in the moments; some of the largest differences between the two rails occur at 90 miles per hour. As an example the second driving wheel at Location 5 for 90 miles per hour developed 205,000 in.-lb. in the left rail and 435,000 in.-lb. in the right rail. The moments shown at 90 miles per hour are the average of five runs and most of the values for individual runs have as small variation as could be reasonably expected. It should be stated that for runs other than at 5, 60 and 90 miles per hour the values shown include only one or two runs at each given speed. However, the agreement with the general trend of the values for 5, 60 and 90 miles per hour was reasonable enough to include them with the averages.

It may be noted in Fig. 16 that changes of moment in one rail are generally matched by approximately equal and opposite changes in the other rail so that, whatever the action, a transfer of load from one rail to the other occurs. If the values for the two rails are averaged the points lie close to a horizontal line. The changes in either side are evidently a result of the transfer of load from one rail to the other, with a negligible speed or impact effect even at 90 miles per hour. The excellent condition of the track and the use of an electric locomotive probably were important factors in this lack of speed effect.

It may be well at this point to review in part the mechanics involved in the transfer of vertical load from one rail to the other.[3] The purpose of an analysis is to show the possibility of what in effect may be considered a transfer of load from one wheel to the other on the same axle when lateral forces are applied to the wheels or the axle. The lateral forces may be applied by the locomotive or car, or the corresponding lateral

[3] A discussion of the possible transfers of load from one side to the other on curved track was given by Dr. S. Timoshenko in Volume 26, 1925, Proceedings of American Railway Engineering Association in connection with the Fourth Progress Report of the committee.

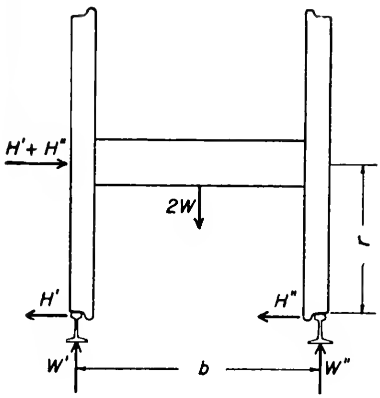

Fig. 17.—Vertical and Lateral Forces Applied to a Pair of Locomotive Wheels or Car Wheels.

reaction forces may be applied by the rails through such a source as poor alinement. In Fig. 17 vertical and lateral forces and reaction forces are shown as acting on a pair of locomotive wheels or car wheels. b is the assumed horizontal distance between centers of bearing of the wheels on the rails. The total vertical load transmitted to the axle is given as $2W$, and the actual individual vertical loads applied at the two rails are given as W' and W''. $H' + H''$ is the sum of the lateral (horizontal) forces applied to the axle and wheels by the bearings of the locomotive or car, considered to be applied at the level of the axle. The position of the points of application of $H' + H''$ is uncertain but for purposes of the demonstration the distance above the rail may be taken as equal to r, the radius of the wheel. At the top of the rail are corresponding lateral reaction forces (H' and H'') transmitted from rail to wheel through friction, or for one wheel possibly partly by a wheel flange.

Taking moments about the right rail bearing, for equilibrium,

$$Wb - W'b - (H' + H'')r = 0$$

whence

$$W' = W - (H' + H'')\frac{r}{b} \qquad (68)$$

Similarly, taking moments about the left rail bearing,

$$W'' = W + (H' + H'')\frac{r}{b} \qquad (69)$$

It is apparent from these two equations that the application of a lateral force to the axle or pair of wheels may change the relative pressures on the two rails from equal magnitudes to unequal amounts. Regardless of the relative values of the lateral forces H' and H'', the vertical reaction forces acting on the rail (W' and W'') will depend on the magnitude of the lateral force $H' + H''$ applied at the level of the axle, and an increase in the vertical pressure on one rail beyond one-half of the vertical load $2W$ will be accompanied by a corresponding decrease in the pressure on the other rail.

As an example assume the following conditions: $2W = 80{,}000$ lb., $H' + H'' = 20{,}000$ lb., $r = 36$ in., and $b = 58.5$ in. For these assumptions, $W' = 27{,}700$ lb. and $W'' = 52{,}300$ lb. With no laterally applied load the vertical reaction forces W' and W'' would, of course, have equal magnitudes and each would be equal to one-half of the applied load $2W$, or 40,000 lb. each. It is seen then that the lateral force of 20,000 lb. applied at the axle will decrease the vertical left rail reaction (W') approximately 31 percent and increase the right rail reaction (W'') by the same amount. The transfer of load between rails for these assumed conditions has about the same proportions as the measured moments in the two rails under the second driving wheel at Location 5 for the speed of 90 miles per hour, as given in the preceding discussion of Fig. 16. The moment developed in the left rail was 205,000 in.-lb. and the simultaneous moment developed in the right rail was 435,000 in-lb., indicating a change of about 36 percent from an equal division of load on the left and right rail.

The magnitude of possible transfer of load or pressure on rail from one wheel to the other on the same axle may be judged from consideration of possible limiting values of the frictional and other forces that may be developed between wheel and rail. For certain conditions it may be assumed that the lateral force is transmitted laterally at the top of the rail wholly by friction between wheel and rail and that the coefficient of friction developed is the same at the left wheel and rail as at the right wheel and rail. Call f the value of the coefficient of friction developed laterally between wheel and rail at any instant. Then

$$2fW = H' + H''$$

Substituting this expression in equations (68) and (69),

$$W' = W\left(1 - f\frac{2r}{b}\right) \quad (70)$$

$$W'' = W\left(1 + f\frac{2r}{b}\right) \quad (71)$$

Also, $$H' = fW' = W\left(f - \frac{2rf^2}{b}\right) \quad (72)$$

$$H'' = fW'' = W\left(f + \frac{2rf^2}{b}\right) \quad (73)$$

The foregoing equations take into account only the lateral frictional forces developable between wheel and rail. Worn treads and also contour and flange contacts against the rail may add to the developable lateral forces. Still other conditions may increase the magnitudes. How large a lateral force may be brought into action under conditions of traffic is of course not known, but the presence of lateral forces applied at the rail provides an explanation of the large variation in the stresses and bending moments developed in the two rails in the runs above 60 miles per hour.

From the data presented and the preceding discussions it is apparent that the electric locomotive develops some action at the higher speeds that causes substantial transfers of load between wheels on the same axle. Since the stresses were taken only at the middle of the base of the rail definite information on the presence or amount of any lateral moments developed in the rail is lacking. The locomotives of this class have been found in other tests to develop substantial lateral forces at the higher speeds. Changes of considerable magnitude in lateral forces applied to the track were found to occur in distances as small as 20 ft. It seems unlikely that such rapid changes in force can be the result of movements of the locomotive as a whole because of the large mass involved. The wheels and other unsprung parts would seem a more probable source of lateral forces capable of developing the rapid transfers of load evident in these tests.

It should be stated that the magnitude of the mean stresses measured in the rails was moderate. The small variation of the individual stresses of any run from the average value for a given wheel and location indicated that the locomotive is consistent in its variable action when all conditions are similar. It is quite possible that this action, whatever its nature, is started by some definite irregularity of the track not necessarily at the gage locations and occurs with a frequency mainly dependent on the characteristics of the locomotive parts affected so that as the test speed is varied the locomotive arrives at a gage location in different parts of its cycle of variation.

The data are of interest and value in giving information on the variability in rail stress and load with this electric locomotive, but must be regarded as insufficient for a complete understanding of the action of the locomotive. The variability shown by the several drivers at the three gage locations brings out one of the difficulties in using the data as a basis of comparison for the rail joint tests. The large range of stresses along

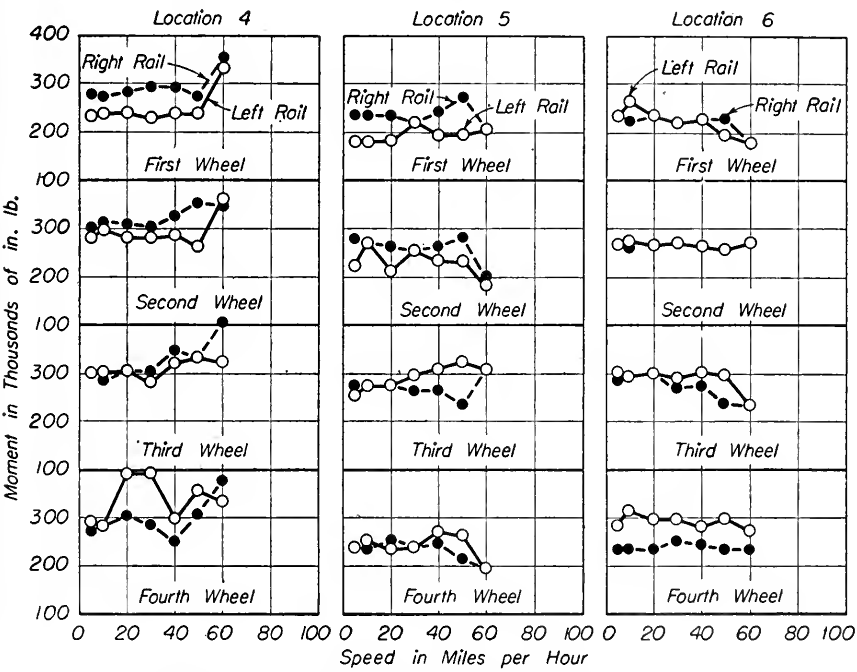

Fig. 18.—Moments in Left and Right Rail at the Wheels of the Heavy Car for Various Speeds.

the track given at the higher speeds by this electric locomotive with no unbalanced rotating or reciprocating parts suggests a reason for the apparently erratic distribution of stresses with respect to the counterweight position that has been found with steam locomotives at comparable speeds. The presence of lateral forces of similar magnitudes with the steam locomotives would cause changes in vertical loads comparable to the effects of counterbalance.

For the tests up to and including 60 miles per hour two cars were attached to the locomotive, one with an average load of 26,500 lb. per wheel and the other with an average load of 6,000 lb. per wheel. The moments developed in the two rails at the three locations with the heavier loading are shown in Fig. 18. As would be expected the moments are seen to be somewhat less than those developed by the locomotive.

There are no consistent or general increases in moment with increased speed and some wheels develop lower moments at some locations at 60 miles per hour than at the lower speeds. This fact would indicate that the car, like the locomotive, has some swaying or oscillation that results in changes in the load distribution among the wheels, though not to such an extent as was found with the electric locomotive at speeds higher than 60 miles per hour.

The heavy car at Location 4 developed moments of about 400,000 in.-lb. in several instances and moments of 300,000 in-lb. were found frequently at the three gage locations. The variations in moment as between the two wheels of an axle at the various speeds are not as great as found with the locomotive. In some cases simultaneous increases or decreases in moment for both the left and right rails occurred, indicating the load was not transferred between wheels of the same axle. It should be noted that the maximum speed of the car was 60 miles per hour rather than 90 miles per hour. A moment of 400,000 in.-lb. was used in the fifth and sixth progress reports of the committee as a design moment for joint bars and has also been used in the laboratory tests including the rolling load tests of rail joints now being conducted. It is of interest to find that such magnitudes of moment are at times actually developed in the rail at these speeds by a freight car and that the joints are called upon to carry stresses of the same order of magnitudes as those used for design purposes.

The values for the light car are not shown here but it may be stated that practically all moments under the light car were less than 150,000 in.-lb. and most of them were 100,000 in.-lb. or less. The records for the light car were quite ragged in form, indicating vibrations in the rail from some source. Although the amount of stresses produced in the rail by these vibrations was small, the effect of the vibrations on rolling stock or lading may be important. A possible source of this vibration is from rough wheels. However, records taken under traffic indicate similar effects from other light cars and it may be that the lesser mass of the car body when not loaded allows vibrations in the car parts to develop.

It may be noted that the first wheel of the heavy car developed lower moments at all locations. This low moment is probably due to a greater negative effect at the first wheel from the locomotive truck and adjacent car wheel than at any of the other wheels. None of the other wheels had a relatively heavy wheel load on both sides.

10. **Depression of Track.**—Immediately adjacent to the points where the magnetic strain gages were attached for measuring rail stresses six solenoid depression gages were placed to record the depression of the rail with respect to a support fixed in the roadbed. These instruments were described in Article 7 and views of them are shown in Fig. 8. Typical records of stresses and depressions taken at 5 and 90 miles per hour were shown in Fig. 11. These records are for the right rail. Values for the other rail were simultaneously recorded by the second oscillograph.

The rail depression records for five miles per hour shown in Fig. 11 may be compared as to general form and magnitude with the depressions shown in Fig. 12, which were calculated from the weighed wheel loads. At a speed of 90 miles per hour the load distribution among the several wheels was found to vary considerably. The long driver spacing (ten feet) permits the rail depression at points between wheels to vary to a greater extent than has been found with the usual wheel spacing. The general shape of the record along the length of the locomotive is markedly similar to the calculated curves and the magnitudes of the depressions at and between drivers are similar.

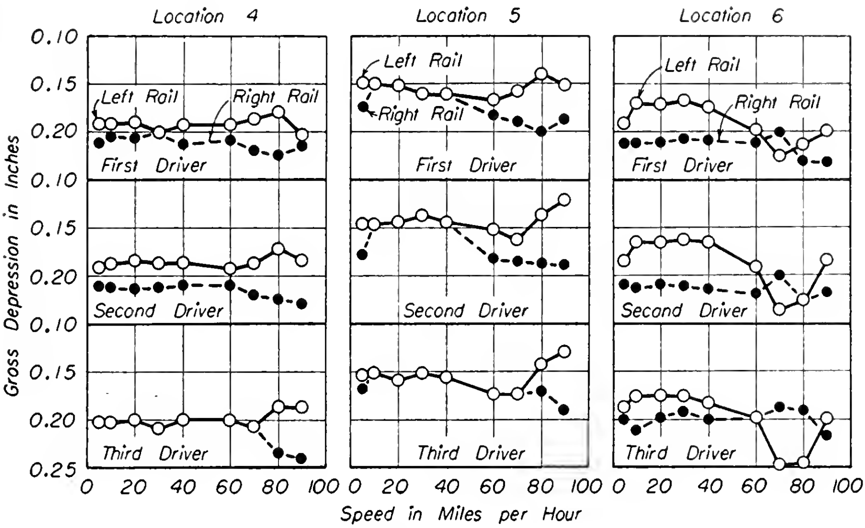

Fig. 19.—Gross Depression of Left and Right Rail at the Drivers of Electric Locomotive 4779 at Various Speeds.

The depression of the rear wheels of the truck are greater than those of the front wheels, both on the records and on the calculated curves.

The depression of the right and the left rail for each of the three driving wheels at the three gage locations is plotted in Fig. 19 with respect to speed. The values plotted are the average of 3 to 10 runs for the speeds of 5, 60 and 90 miles per hour and 1 or 2 runs for the other speeds. The depressions for 5 to 60 miles per hour are about 0.20 in. on locations 4 and 6 and 0.15 in. on Location 5. There is little difference between the two rails at locations 4 and 5; at Location 6 the right rail depresses about 0.04 in. more than the left rail. These depressions of course are gross depressions. The play between rail and ballast varied somewhat at the several locations, Location 5 having the least. As far as could be judged from the measurements, the play between the rail and its support was similar for the two rails at a given location. The play was about 0.14 in. for Location 4, 0.05 in. for Location 5 and 0.14 in. for Location 6.

The depressions are seen to vary little with speed up to about 60 miles per hour. Above 60 miles per hour the depressions for the two rails differ appreciably from each other in most instances. At these higher speeds an increase of depression of one rail relative to its depression at the lower speed generally is matched by an approximately equal decrease of depression of the other rail. Examples of this sort of change are seen in the case of the first driving wheel on locations 4 and 5 and the third driving wheel also on locations 4 and 5. In some instances the relative positions of the plotted points for right and left rails shift with respect to each other one or more times in the range of speed from 5 to 90 miles per hour.

The relative values of the depression in the two rails and the manner in which they change for the several speeds indicate that part of the wheel load may be transferred from one driver to another, generally to the wheel on the same axle, decreasing one driver load and increasing the other load. Further, there is no increase in the average depression for all the wheels as the speed increases—that is for the locomotive as a whole. This indicates a general lack of speed effect, or of impact effect, or increase of applied wheel pressures due to inertia forces. It would seem too, that the locomotive acts at a given location in a way that is governed by the speed at which the gage location is approached and acts similarly for each run at a given speed, since the individual runs showed good agreement with each other. The vertical bending moments shown in Fig. 16 also indicate the same similarity in action. Comparison of this figure for the bending moments with Fig. 19 for the depressions shows that an increase of moment is accompanied by an increase of depression.

So far as known, measurements have not been made previously that recorded rail depression at high speeds. It has been a question whether the rail and ties and ballast depress at high speeds in just the way they do at low speeds and static loading. Does the track behave elastically at high speeds and return immediately to an unloaded position? Possibly the action of the track at high speeds may be affected by the mass of its parts, frictional resistance, and relative movement of ballast particles. If the ballast does not return to the unloaded position as quickly as it is depressed, a lesser slope would be found in the depression records behind the locomotive wheels than ahead of them, if the loads and other factors do not differ. Another way of stating this is that if the rate of doing work in depressing the ballast were greater than the rate of recovery of the energy accumulated during the depression, the net result would be a loss of energy so far as the locomotive and cars are concerned and this loss would increase the power required for traction.

Careful examination of the depression records for the locomotive gave some evidence that there was a delay in the return of the track to an unloaded position. However, the delay was about the same for lower speeds as for the higher speeds, which gives reason to believe that the play in the track may have been a principal factor. Difficulty in judging this action was also caused by the transfers of load and some irregularities in the records. For these reasons definite conclusions on some of the questions on the action of the ballast must be deferred.

The runs at speeds up to and including 60 miles per hour were made with a heavy and a light car behind the locomotive. The rail depressions given by the wheels of the heavy car at all locations for both rails are shown in Fig. 20. The depressions at Location 5 are seen to be somewhat less than at the other locations. Location 5 had the least amount of play and the difference in depression there is probably due to the lesser play rather than to a higher value of the modulus of the support.

In general there is seen to be little increase with speed in the amount of the depressions under the car up to the highest speed used, and in some cases a decrease. The depression at Gage Location 4 shows the largest increase in depression with increase in speed. The larger increases and decreases in depression were generally accompanied by similar changes in the moments developed, as shown by a comparison of Fig. 20 with Fig. 18.

From the discussion and the diagrams it is evident that the recorded depressions were similar in form and magnitude to the calculated depressions for both the locomotive and the cars. There appears to be little if any increase in depression due to speed alone. The changes are apparently due to the action of the locomotive or car as influenced by the conditions of the track traversed prior to passing the instrument positions. The locomotive, especially at the higher speeds, has oscillations or lateral movements as a whole or in its parts that cause considerable variation in the load applied by the individual wheels and likewise transfers of load between the wheels on the same axle. Similar action by the locomotive was indicated by the stresses and moments discussed in Article 9 "Stresses and Moments in Rail."

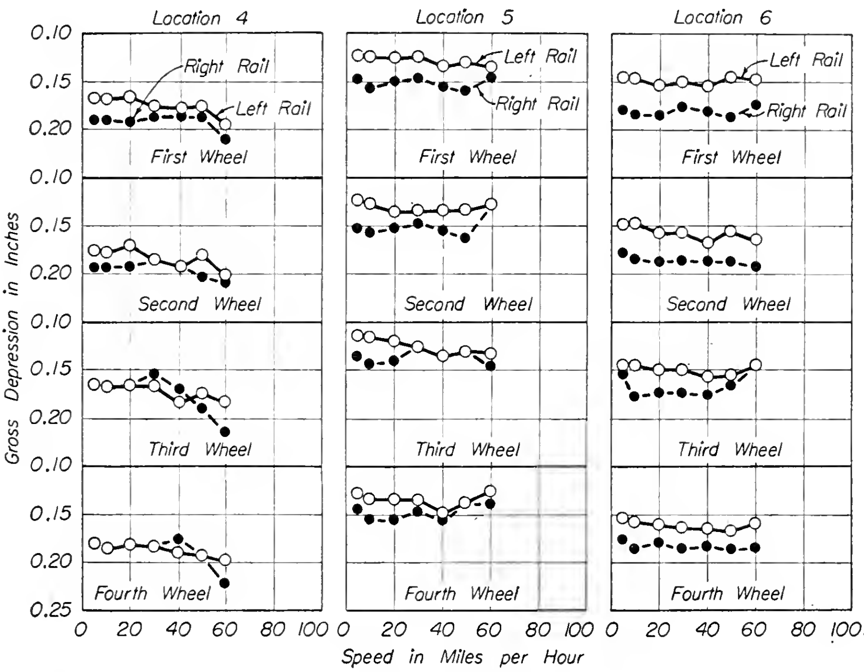

Fig. 20.—Gross Depression of Left and Right Rail at the Wheels of the Heavy Car at Various Speeds.

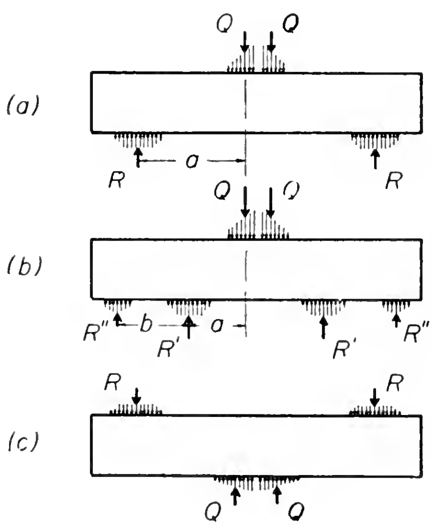

Fig. 21.—Diagram Showing Vertical Load Pressures and Reactions on Joint Bars. (a) Single Reaction Bearings for Positive Moment, (b) Double Reaction Bearings for Positive Moment, (c) Single Reaction Bearings for Negative Moment.

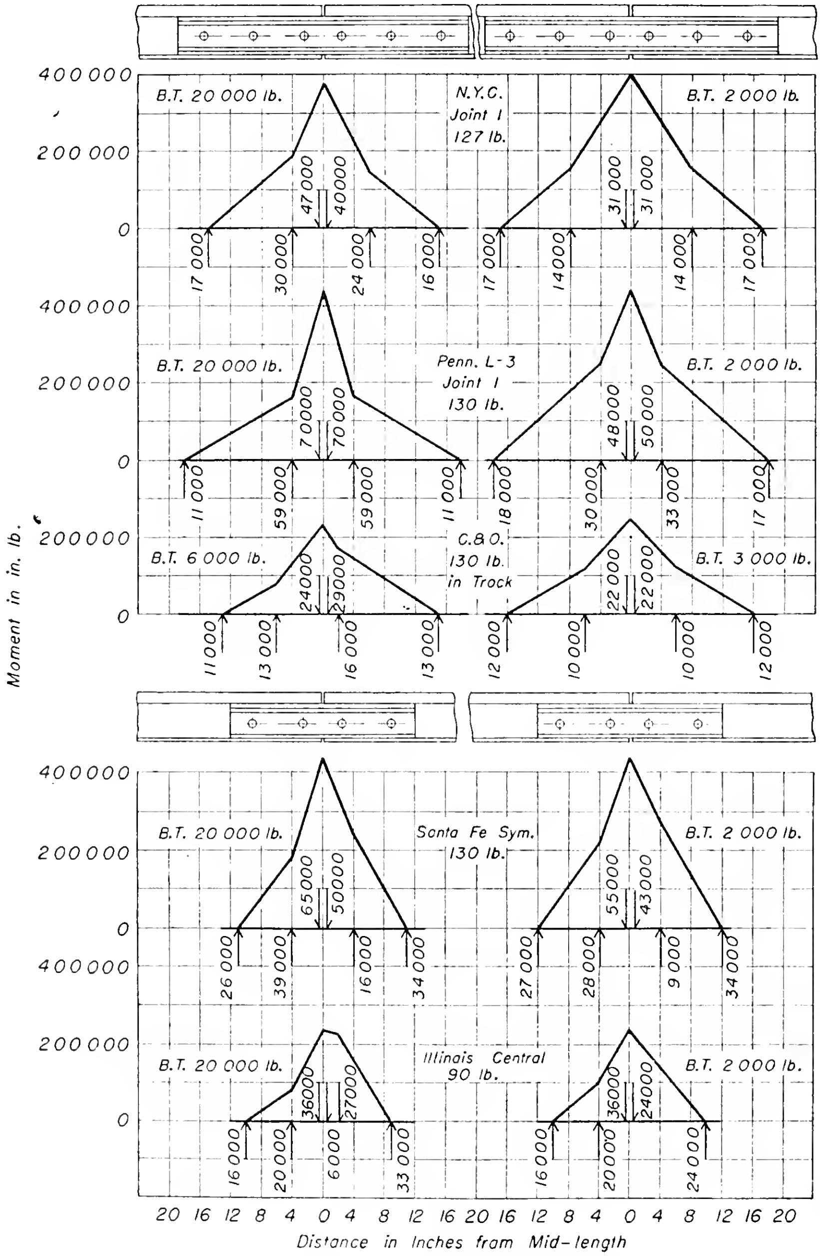

Fig. 22.—Typical Positions and Values of Bearing Loads and Reactions That Would Develop the Moments Observed in Two Bars at Sections along the Joint Bars.

By means of an engineer's level and a special leveling rod, measurements of the depression of the right rail with a light and a heavily loaded car were made for the determination of the modulus of elasticity of the rail support, *u*. The method used was similar to that described at page 197 of the Sixth Progress Report, AREA Proceedings, Vol. 35, 1934. The end wheels were spotted at gage Location 5. The wheel loads averaged 6,000 lb. and 26,500 lb., respectively. The heavy load gave a gross depression of 0.20 in. The play of the right rail at Location 5 was estimated from these measurements to be 0.05 in. The modulus was calculated to be 2,500 lb. per in. per in.

IV. Tests of Rail Joints

11. Rail Joints and Their Action.—The action of the joint bars in a joint is discussed at some length in the Fifth Progress Report under the title "II. General Structural Action of the Rail Joint" and in other places in that report and also in thé Sixth Progress Report. It will be of advantage here to review briefly some elementary matters regarding some of the principal forces developed in the rail joint between rail and bars and their probable position.

The forces and pressures and reactions developed in the interaction between rail and bars due to the wheel load and the bending action of the joint on the tie supports may be represented as in Fig. 21. For positive moment (downward deflection of joint), the bars will act as beams with loads or vertical forces applied to the top fishing surface of the bar by the under side of the rail head for short distances back from the rail ends as indicated at Q in (a), and with reactions applied by the rail base to the lower fishing surface of the bar at points toward the ends of the bar as indicated at R. In many or most cases with close fit there are two sets of the reactions, one set towards the ends of the bars at R'' and R'' and the other set R' and R' closer to the middle of the bar but outside of the position of the loads Q, as indicated in (b). The position of the loads and reactions and their centroids is dependent upon the length of the bar and particularly on the fit between bar and rail. The moment of resistance developed in the bars is the sum of the products of R' and R'' on one-half of the bars by their respective horizontal distances to the line of action of Q, and this resisting moment is equal to the bending moment applied or developed by the wheel loads, whatever that may be. For negative moment (upward bending), the positions of the loads and reactions applied to the bar are reversed, as indicated in (c).

It is apparent that all these loads and reactions applied to the bar exist in addition to the interactions between bar and rail produced by the existence of the tension in the bolts. In fact, the resultants of all the forces applied to a bar will increase or decrease the pressure between bar and rail at a given point materially and may in places even relieve contacts between surfaces.

To give a conception of the magnitude and position and variety of the vertical loads and reactions applied to the bars by the rails Fig. 22 is given, taken from Figs. 82 and 83 of the Sixth Progress Report. The values and positions of these loads and reactions were calculated from strain-gage measurements in laboratory tests and field tests and from the resulting magnitude and distribution of the moments calculated therefrom. It is apparent that the magnitude of the load applied to a bar by the rail (bearing pressure) depends not only on the wheel load but also on the fit between rail and bar, and especially on the positions of the centroids of the reaction forces as they may be developed in the joint. For example, if the horizontal distance from the centroid of bearing pressure on the top of a bar to the centroid of the reaction force R' is small and the magnitude of R' in Fig. 21 is relatively large with respect to that of R'', the bearing pressure Q will be relatively greater than otherwise, and if this bearing pressure is distributed over a small bearing area the intensity may be unduly great. It follows that the presence of a relatively small R' will result in a smaller Q and thus that the wear between bar and rail head will be decreased.

In Fig. 23 is given a diagrammatic division of moment between rail and joint bars for an assumed total moment produced by a wheel load applied at the mid-length of a joint; AB represents the part taken by the joint bars and BC that taken by the rail. In Fig. 24 are shown values of moments in the two bars at eleven sections along their length as a load is advanced across a joint.[4] It is apparent that bending moment is developed in sections all along the length of the bars well before a wheel load reaches a point over the bars and therefore curvature in the bars commences in advance. Thus, in case of worn or ill-fitting joints the vertical movement to give loading contact between bar and rail will take place before the joint is reached and the shock is minimized.

The foregoing discussion assumes known conditions of span and supports, as are obtained in a laboratory test. In track, the condition of the supports at a joint are more variable than along the rest of the rail. Even if originally the joint ties had as even bearing and as uniform supporting stiffness as may be found over the rest of the rail length, the lesser stiffness of the rail joint (resistance to rail deflection) will result in

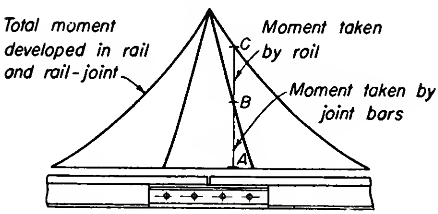

Fig. 23.—Division of Moment between Rail and Joint Bars.

higher loads being transmitted to the joint ties and ballast and therefore finally in greater permanent depression of the joint support. Furthermore, as play and uneven wear between rail and bars will permit downward movement of the joint without developing correspondingly greater bending resistance in the joint itself, the support at the joint will become still further depressed. These conditions and the smaller vertical stiffness of the rail joint as a whole will result of course in the joint giving the effect of a softer spot in the track as compared with the rest of the rail length. In tests of track, one of the ways by which this softness or reduction in stiffness may be judged is through the value of the ratio of the bending moment found to be developed at the joint to that ordinarily developed in the full rail. Obviously the more nearly this joint moment ratio approaches unity the less the opportunity for low joints and for rail batter.

A conception of the changes in moments and depressions of a rail joint having well-fitting bars and little play between rail and tie, as one of a group of wheels passes over the joint, may be obtained from the closely similar developments of moment and depression of the full rail as shown by analysis or by the oscillograph records of stresses and depressions for rail away from a joint. The changes will depend upon such matters as wheel spacing and stiffness of rail support. In a general way a wheel of a group may be expected to be 20 to 30 in. or more from the rail end when the positive bending in the bars begins and it will travel this distance before the wheel is at the rail gap and the bars are given their maximum moment. For electric locomotive No. 4779 this distance was probably about 24 in.

[4] See Article 8 "Action of a Rail Joint under an Advancing Load" in Sixth Progress Report, AREA Proceedings, Vol. 35, 1934, page 110.

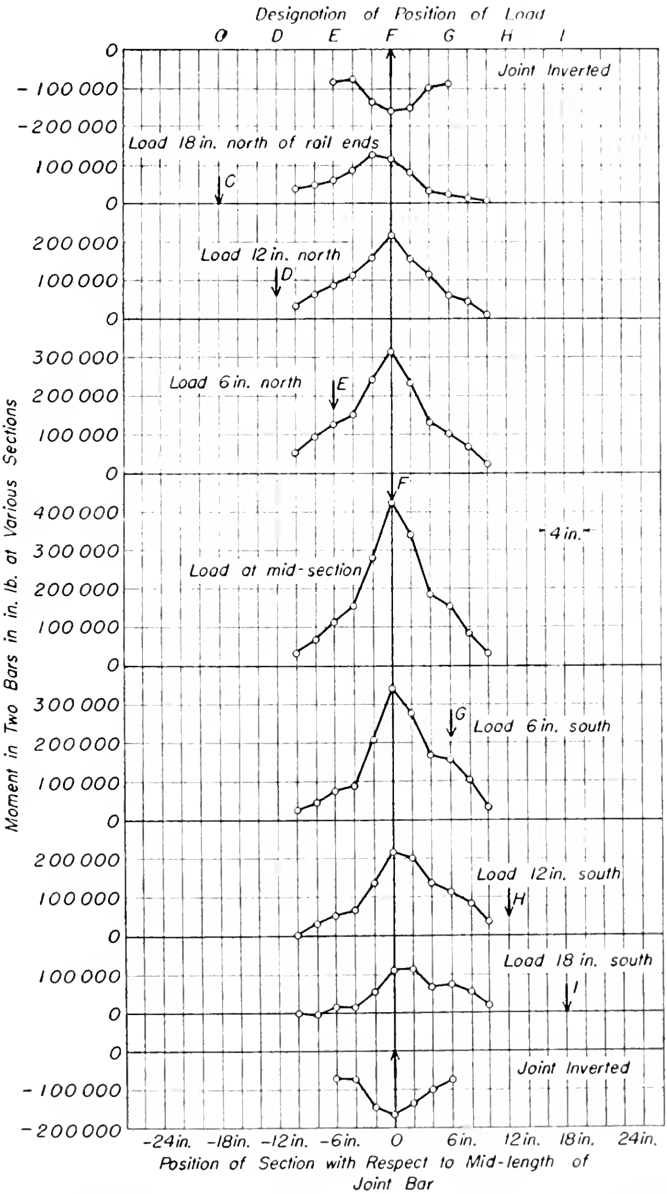

Fig. 24.—Moments in Two Bars at Various Sections on Applying a Load of 33,300 lb. at Middle of 48-in. Span with Rail Joint Advancing.

It should be understood that aside from being a connecting link between adjoining rails and acting to preserve continuous alinement and surface, it is highly desirable that the rail joint should approximate to uniform continuity of beam action over its supporting ties and ballast and should furnish to as great a degree as possible the same stiffness of beam as does the rail. This means that its construction should be such that it will apply as closely as possible the same loads and pressures to the ties as are given throughout the rest of the rail. The value of any particular form of rail joint is dependent, of course, upon its behavior in these respects and upon its resistance to wear and other deterioration throughout its life.

It is apparent that with the variations in support provided in track and with the differences in types and conditions of joint bars there will be wide variations in the magnitude of the bending moments developed in rail joints. For similar conditions of track the magnitude of the bending moment developed becomes a measure of the effectiveness of the joint. The stresses measured at two gage lines in the upper and lower part of a section at mid-length of the joint bars offer the best means for finding the magnitude of the bending moment developed in the joint bars at the rail gap.

In Articles 13 and 14 of the Fifth Progress Report (Proceedings American Railway Engineering Association, Volume 31, 1930, pages 99–112) analyses are given of the flexural action of both the symmetrical and the unsymmetrical types of joint bar. On the assumption that the strains measured in joint bars are representative of the bending stresses, the bending moment developed in a joint may be calculated by substituting in Equation (67)[5] of the Fifth Progress Report measured stresses s_1 and s_2 of any two gage lines used such as B and C in the tests under discussion. This equation takes into account any inclination of the neutral axis from the horizontal. As brought out in Article 13 "Laboratory Tests to Find Gage and Stress Relations and Conversion Ratios", various deformations of the bars due to forces other than the forces assumed in ordinary beam analysis introduce variations from the assumptions of the analysis. In Article 13 the empirical use of conversion ratios is presented for use in making calculations of the bending moments developed in the field tests.

Some readers may find interest in Articles 47–55 of "VII. Discussion of Tests of Rail-Joints" in the Sixth Progress Report (AREA Proceedings, Vol. 35, 1934, pages 244–277).

12. **The Joint Bars and the Test Schedules.**—The tests in track were made with bars of four different sections as follows: Pennsylvania Railroad F–4 symmetrical bar, Baltimore & Ohio Railroad B–19 symmetrical bar, Norfolk & Western Railway A–39 angle bar, and Chesapeake & Ohio Railway B–43 head-free bar. The sections of these bars and the location of the gage lines for the field tests are shown in Fig. 25. The position of the gage lines was the same on both inner and outer bar. Geometrical properties are given in Table 4. The last three bars may be termed heavy bars, the F–4 being somewhat lighter. The moment of inertia about the horizontal axis (I_x) ranges from 12.20 to 19.63. The product of inertia (J_{xy}) ranges from 0.75 to 4.17. By

[5] Equation (67) is

$$M_x = \frac{I_x x_2 - J_{xy} y_2}{y_1 x_2 - x_1 y_2} s_1 + \frac{J_{xy} y_1 - I_x x_1}{y_1 x_2 - x_1 y_2} s_2 \quad \dots\dots (67)$$

where M_x is the vertical moment (resisting moment in the vertical plane), x_1 and y_1 are the abscissa and the ordinate of the point in the section for gage line 1 taken with reference to the horizontal and vertical geometrical axes of the section, and x_2 and y_2 are similarly the coordinates for gage line 2, and s_1 and s_2 are the corresponding measured stresses, respectively, at the two gage lines. I_x and I_y are the moments of inertia of the section of the bar with respect to its horizontal and vertical gravity axis, respectively, and J_{xy} is the product of inertia with respect to the two axes.

Table 4

Description and Geometrical Properties of the Joint Bars

Units are inches and pounds. All values are for a single bar. Bars are for 131-lb. R.E. rail. The subscript denotes the axis to which the properties correspond.

Name	Type of Section	Length of Bar	I_x	I_y	J_{xy}	Section Modulus	Area
P.R.R., F-4	Symmetrical	36	12.20	0.80	0.75	4.81	5.20
B. & O., B-19	Symmetrical	24 and 36	16.69	1.85	1.06	6.52	6.58
N. & W., A-39	Angle bar	36	19.63	3.77	4.17	7.14	6.52
C. & O., B-43	Head-free	36	16.05	1.70	2.12	6.32	6.26

Table 5

Analytical Properties of the Joint Bars.

Values are based on analysis given in Fifth Progress Report, Article 13. M_x represents the vertical bending moment and M_y the lateral bending moment. α is the angle of inclination of the neutral axis from the horizontal.

Name and Section	Free Bending		Value of M_y/M_x required for Given Value of tan α		
	Tan α	α	0	0.3	0.75
P.R.R., F-4	.938	43°-10'	.061	.043	.013
B. & O., B-19	.572	29°-47'	.063	.030	...
N. & W., A-39	1.104	47°-50'	.212	.165	.081
C. & O., B-43	1.248	51°-18'	.132	.104	.058

the analyses for bending given in the Fifth Progress Report and the discussions and interpretations given in the Sixth Progress Report[6], the F-4 and B-19 may be considered for ordinary purposes to be symmetrical bars. Substitution of the values of I_x and J_{xy} in equations (47) and (51) of that report will indicate the extent to which the other two bars depart from symmetrical action.

The bars were generally used in the condition in which they came from the mill. The term full bearing (FB) is given to bars having continuous bearing fishing surfaces along their length. Bars having bearing restricted to certain portions of the length of fishing surfaces are termed controlled bearing bars (CB). Bars used in the condition received from the mill are termed "as is" (AI). Bars were machined to true and straight fishing surfaces along their length and these are termed machine fit bars (MF). After machine fit bars had been tested in track the top fishing surface through the middle portion was ground down 0.05 in. at mid-length and tapered uniformly to zero at a point 4 in. from the leaving rail end also to zero at a point 6 in. from the receiving rail end; these are termed simulated wear bars (SW). Two pairs of F-4 bars were selected from stock as representing greater than usual camber of bars as obtained from the mill and are termed high camber bars (HC). Two pairs with downward con-

[6] AREA Proceedings, Vol. 31, 1930, page 65; and Vol. 35, 1934, page 66.

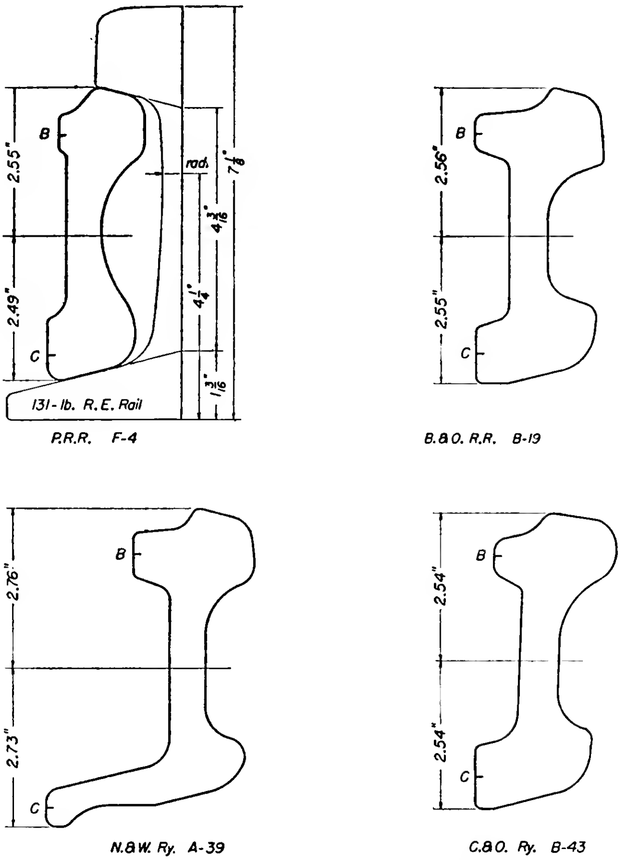

Fig. 25.—Sections of Joint Bars and the Positions and Designation of the Gage Lines Used.

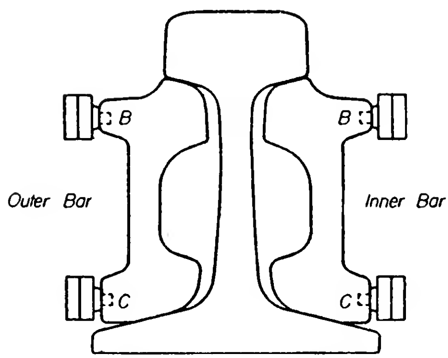

Fig. 26.—Position of Four 2¼-in. Magnetic Strain Gages at Mid-Length of Joint Bars.

Table 6

Schedules of Rail-Joint Tests

Stresses, vertical movements, and longitudinal movements were measured unless otherwise noted.

Schedule No.	Run No.	Condition	Bearing	Length of Bar Inches	Locations	Speeds
			Pennsylvania F-4 Bars			
5,6,7	78 - 116	AI	FB	36	1,2,3	5,40,60,90
33*	391 - 399	AI	FB	36	1	5,60,90
11,12,13	155 - 203	MF	FB	36	1,2,3	5,40,60,90
20,21,22	267 - 294	SW	FB	36	1,2,3	5,60,90
2,2a,3,4	35 - 77	AI	CB	36	1,2	5,40,60,90
8,9,10†	117 - 154	MF	CB	36	1,2	5,40,60,90
31*	372 - 380	SW	CB	36	1	5,60,90
34,35,36‡	400 - 431	W	CB	36	1,2,3	5,60,90
37‡	432 - 440	W	CB	36	1,2,3	5,60,90
31*	372 - 380	HC	CB	36	2,3	5,60,90
32,33°	381 - 399	HC	CB	36	2	5,60,90
39*	450 - 463	HC	CB	36	2,3	5,60,90
30*	363 - 371	NC	CB	36	2,3	5,60,90
			Baltimore & Ohio B-19 Bars			
17,18,19‡	240 - 266	AI	FB	36	1,2,3	5,60,90
38‡	441 - 449	AI	FB	36	1,2,3	5,60,90
14,15,16	204 - 239	MF	FB	36	1,2,3	5,40,60,90
23,24,25	295 - 326	MF	FB	24	1,2,3	5,60,90
26,27,28	327 - 353	SW	FB	36	1,2	5,60,90
26,27,28	327 - 353	SW	FB	24	3	5,60,90
29*	354 - 362	MF	CB	36	1	5,60,90
30*	363 - 371	MF	CB	24	1	5,60,90
			Norfolk & Western A-39 Bars			
29*	354 - 362	AI	FB	36	2,3	5,60,90
			Chesapeake & Ohio B-43 Bars			
2,2a,3,4	35 - 77	AI	HF	36	3	5,40,60,90
8,9,10†	117 - 154	AI	HF	36	3	5,40,60,90

* Stresses only measured.
† Electric locomotive 4790 used instead of 4779.
‡ Rail stresses measured 18 in. from mid-length of the joint.
° Joint depressions measured.

vexity are termed negative camber bars (NC). Three pairs of F–4 bars originally installed in 1933 were selected from main line track under heavy traffic to be representative of worn condition (W). The corresponding original rails were also brought to the test track and the rails and bars were laid in their original relation. However, the wear on these bars was not very great as compared with conditions in track with lower standards of maintenance. The joint bars were all 36 in. in length with the exception that four pairs of B–19 bars had a length of 24 in. For convenience and brevity the conditions and variations named above will be referred to by the short names or the abbreviations here given.

Fig. 26 shows a cross-section of an assembly of B–19 bars and 131-lb. R.E. rail and four magnetic strain gages for measuring longitudinal stresses in the bars. The effect of the offset of the gages from the surface of the bar shown in the figure has been considered in the calculation of moments from the measured stresses.

As determined by the use of thickness gages all the bars except the simulated wear and the worn bars fitted the rail quite closely. This fit between bar and rail probably was considerably better than is usually found with the ordinary run of joint bars.

In the tests it was found necessary to apply a relatively high bolt tension, 20,000 to 30,000 lb., because of the need of preventing movement of ends of rails by changes in temperature during the hours of the test.

The schedules of the tests on the rail joints in track are given in Table 6. Runs, speeds, joint locations, and kind and condition of bar are tabulated. Study of this table will give a good comprehension of the scope and variety of the tests. The column "Joint Location" indicates whether one, two, or three joints of a given kind and condition were tested.

13. **Laboratory Tests to Find Gage and Stress Relations and Conversion Ratios.**—In Article 13 "Flexural Action of the Unsymmetrical Type of Joint Bar" in the Fifth Progress Report of the Committee on Stresses in Railroad Track[7] are given analytical methods for finding the relation between bending moments and stresses which apply to both symmetrical and unsymmetrical types of bar. These analyses consider only the bending action of the joint bars with the usual assumptions of proportionality of stress to distance from a neutral axis. The analyses do not consider the effect of bearing pressures on the magnitude of longitudinal strains and the presence of other conditions that affect longitudinal strains. When the wheel load is applied to the rail joint, the bearing pressure of rail on bar developed at certain points along the fishing surfaces and the Poisson-ratio action sets up longitudinal strains not considered in the analyses. The eccentricity of loading by the forces applied by the rail head to the joint bar at points on the upper fishing surface and the reactions taken by the rail base also introduce conditions not taken into account in the analyses. Another influence not considered is the tension in the bolts, which in effect has produced longitudinal strains in the bars by lateral bending and concentrations of pressure on the fishing surface. Also the change in the relative position of rail and bars at certain points, upon the application of wheel load (although seemingly small), results in a variation in these longitudinal strains that has an appreciable effect upon the measured longitudinal strains. Altogether the action of the rail joint is very complex and the stresses in the bars are the results of numerous forces.[8] Some method of estimating the effect of the additional strains set up in the joint is needed before a satisfactory interpretation of the data of the track tests may be made.

No analytical method for taking into account actions of such complexity has been found. In the absence of a rational method experimental determinations in the laboratory were made of the ratio between the bending moment applied to the rail joint and that calculated from the measured longitudinal strains developed in the joint bars. From these data empirical conversion ratios were found for the various types and conditions of rail joints used in the track tests. This experimental method has given values for the conversion method that insure reasonable accuracy for the calculation of the magnitude of the moments developed in the track from the stresses measured.

Laboratory tests were made on joints having the identical bars used in the track tests, together with two pieces of rail cut from rails also used in the track. The joints were loaded as a simple beam with a single load at the middle of a 48-in. span. The two loads used in the laboratory were 25,000 lb. and 33,300 lb., which developed

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[7] AREA Proceedings, Vol. 31, 1930, page 100.

[8] Reference may be made to a discussion on variations from proportionality of stress to distance from neutral axis and effect of bearing pressure in Article 19 "Inclination of the Neutral Axis of the Joint Bars at Various Sections Along Their Length", page 138 of the Fifth Progress Report of the Committee on Stresses in Railroad Track, AREA Proceedings, Vol. 31, 1930, and also to Article 26, "Miscellaneous Experimental Data", page 189 of the same report. Reference may also be made to Article 19, "Moments in Rail Joints", page 146 of the Sixth Progress Report, AREA Proceedings, Vol. 35, 1934, for a discussion of methods of conversion previously used in determining magnitude of bending moments from measured stresses.

moments at mid-span of 300,000 in.-lb and 400,000 in.-lb., respectively, loads and moments being comparable to those of the field tests. The stresses were measured with a 2¼-in. strain gage, the gage length used in the field tests. As the magnetic strain gage used in the field tests was offset from the surface of the bar and the effective point of measurement of the stress had been found by the Test department of the Pennsylvania Railroad to be 0.45 in. from the surface (a distance equal to the distance between the surface of the bar and the geometrical axis of the gage coil) this condition was simulated for gage lines B and C in the laboratory tests (see Fig. 25 for position of gage lines B and C) by screwing studs into the holes used for mounting the magnetic strain gages and reading the stresses in gage lines in the heads of these studs 0.45 in. out from the surface of the bars. Readings were also taken with studs of such length that the gage points were at the surface of the bars. All tests were made with the high bolt tension used in the field tests, (25,000 lb. or more) a condition which had been found necessary in the track to control the rail gap as the temperature of the rail changed during the day. It had been found in the field tests that any large change of gap was detrimental to the interpretation of the indications given by the magnetic strain gages used to measure the longitudinal movement between the outer bar and the rail head near its end, besides possibly damaging the instruments. It can be seen from this discussion that the conditions of the joints in the laboratory tests closely simulated the conditions of the joints for the field tests.

A typical stress distribution over a vertical section of the bars at mid-length is shown in Fig. 27 for a test of the B–19 joint bars, a symmetrical bar of heavy cross section. The position of the gage lines on the section is indicated by the numbered points on the side of the section. Gage lines B and C correspond to gage lines used in the field tests; these two positions are as near the top and bottom of the bar as the gages could be placed in the track. In the figure the magnitude of the measured stress is plotted with respect to its vertical distance from a horizontal axis through the center of gravity of the section. The full lines are for the 33,300-lb. load and the broken lines for the 25,000-lb. load. The straight full lines passing through the intersection of the center-of-gravity axis and the axis of zero stress indicate the theoretical variation of stress over the section for the two loads. The effect of the bearing pressures and various other forces, as well as possibly some inclination of the neutral axis from

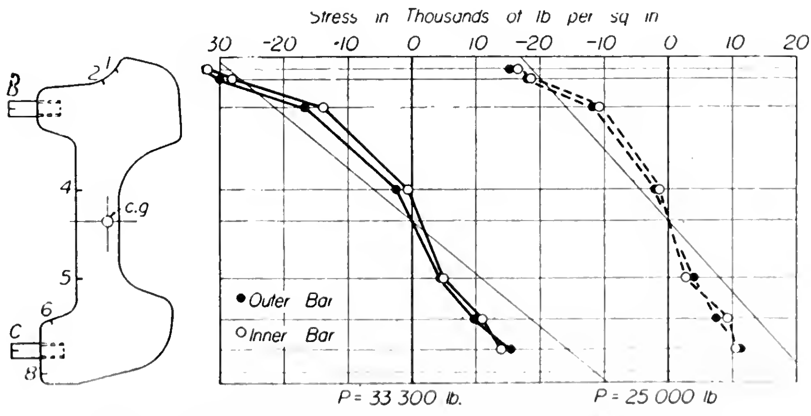


Fig. 27.—Observed Stresses in Various Gage Lines at Mid-Length of B–19 Joint Bars.

horizontal, can be plainly seen in the curving of the lines of stress distribution making the stresses at B smaller than the theoretical stress and those at the higher gage lines either higher than the theoretical value or close to it. A calculation of the vertical moment in the joint from the stresses in gage lines B and C by Equation (67)[9] gives 265,000 in.-lb. for the load of 33,300 lb. which is only 66 percent of the applied moment. For the load of 25,000 lb. the calculated moment is 65 percent of the applied moment, a closely similar value. It may be well to call attention to the impracticability of measuring the stresses on the side of the bar next to the rail; obviously their magnitude will be different from those at the gage lines used.

From the tests outlined above values of the conversion ratio were obtained for the individual joints by dividing the applied bending moment by the moment calculated by substituting in Equation (67) the measured stresses at gage lines B and C. It was found that the values of the conversion ratio obtained for the two loads of 25,000 and 33,300 lb. are so nearly the same that for the range in load between these amounts the variation is not important, and hence averages for the two loads have been used in establishing values for the conversion ratios. As the conversion ratios found with the B–19 bars were nearly the same for 24-in. and 36-in. bars, it was assumed without testing that this similarity applied also to the other forms having the two lengths. As it was found that similar ratios held with the B–19 section for bars with full bearing and controlled bearing with machine fit, it was assumed that these conditions do not affect the conversion ratios in the other sections.

Values of the conversion ratio for various conditions of the joint bars of a given kind ("as is", machine fit, high camber, negative camber, etc., not including worn bars and bars simulating wear) were so nearly the same—perhaps within two or three percent of an average value—that it was thought best to use average or group values, especially as the accuracy of readings did not permit great refinement.

Table 7 gives the values of the conversion ratios found in this way for the various forms and conditions of joint bars used in the tests in track. These conversion ratios are applicable to the section at mid-length of bar and not to other sections. The magnitude of the bending moment developed in the rail joint is then taken to be the product of the given conversion ratio and the moment calculated by Equation (67) through the substitution of the measured stresses in gage lines B and C. This equation takes into account the position of the neutral axis and any inclination from the horizontal it may have.

It will be noted that these conversion ratios range from 1.00 to 1.67. For good fit (both "as is" and machine fit) the value is 1.49 for F-4 and B-19 bars, including full bearing and controlled bearing. On the other hand it was found that the condition of wear through the middle part of the length of the top fishing surface had a marked effect on the conversion ratio. For the F-4 worn bars the conversion ratio is 1.23 instead of 1.49 found with new F-4 bars. An even more marked effect was found with bars ground to simulate a condition of considerable wear; the ratio was found to be 1.00 with the 36-in. B-19 bars instead of 1.49 given by the unused bars. This means that the moments calculated from the measured stresses at B and C give the full amount of moment developed in the bars with simulated wear. The same conversion ratios were assumed to be applicable to the other bars having simulated wear condition.

It may be remarked that the smallness of the ratios for worn bars is due presumably to relief from heavy bearing pressure on the top of the worn bars near the rail ends and its transfer to points away from the mid-section. With the simulated wear bars, the bearing pressure is applied still further away from the rail end and the con-

[9] For equation (67) see Article 11 "Rail Joints and Their Action".

Table 7

Conversion Ratios for Calculation of Bending Moments with Field Test Data

Ratios were determined for use with stresses at gage lines B and C.

Joint Bar	Condition	Length of Bar Inches	Conversion Ratio
P.R.R. F-4 Controlled Bearing	As is	36	1.49
	Machine fit	36	1.49
	High camber	36	1.49
	Negative camber	36	1.49
	Worn	36	1.23
	Simulated wear	36	1.00
P.R.R. F-4 Full Bearing	As is	36	1.49
	Machine fit	36	1.49
	Simulated wear	36	1.00
B & O B-19 Full Bearing	As is	36	1.49
	Machine fit	24 and 36	1.49
	Simulated wear	24 and 36	1.00
B & O B-19 Controlled Bearing	Machine fit	24 and 36	1.49
N & W A-39 Full Bearing	As is	36	1.67
C & O B-43 Headfree	As is	36	1.41

version ratio approaches unity. The tests described in Article 26, "Miscellaneous Experimental Data" of the Fifth Progress Report, previously referred to, show clearly that the distribution of longitudinal stress over a vertical section is quite different a short distance away from the vertical sections that have the heavy vertical loads applied to them, and that a vertical section that is free from nearby bearing pressure gives a stress distribution more nearly like that assumed in beam analysis. It may be well to add that the load (bearing pressure of rail on bar) here referred to is the force Q shown in Fig. 21 which is developed when the joint is loaded.

All the laboratory tests discussed above were made with loadings applied vertically so that the joint carried bending moments in the vertical plane only. Since the stresses observed in the track tests showed that in some cases considerable lateral bending moment was present, it was thought desirable to ascertain what effect this combined bending would have on the conversion ratio. Accordingly a joint with B-19 bars of 36-in. length previously tested in vertical bending was supported in a manner such that a ratio of lateral load to vertical load of approximately one to four was applied to the joint. This test setup is shown in Fig. 28. The resulting conversion ratios were found to be closely similar to the values obtained for vertical loading, so it was judged that the lateral load had a negligible effect in this respect. The small differences found were about the order of magnitude of the accuracy of the observations and the conditions of the setup.

In the laboratory tests just described measurements were made of the deflection of the joints in the 48-in. span under the given loads. As the information thus incidentally found may serve as an indication of the relative stiffness of the various joints and as the stiffness in a way may be some measure of the ability of the joint to distribute the load along the track as compared with full rail, the results have been shown graphically in Fig. 29.

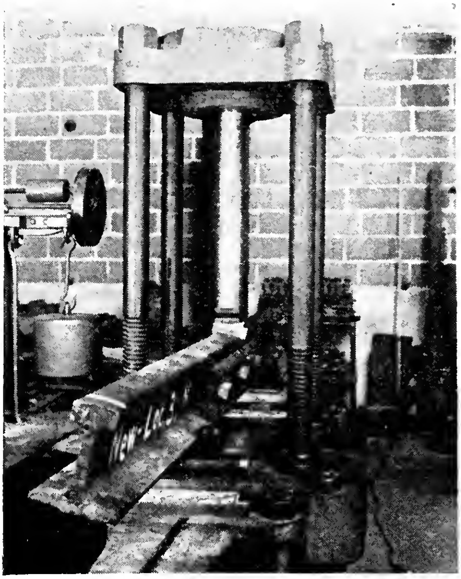


Fig. 28.—View of Test Setup Giving Combined Vertical and Lateral Bending Load.

Except for the B-19 "as is" full bearing bars the tests were made with only one joint of a kind, and the results may not be fully representative. The F-4 "as is" joints give somewhat larger deflection than the B-19. Machine fit joints are slightly stiffer than "as is". The "as is" head-free joint and the F-4 worn joint have similar deflection. The heavy angle bars (having tight bolts as have the other joints) deflect about the same as the B-19 machine fit joint. The worn bars give greater deflection than the "as is"

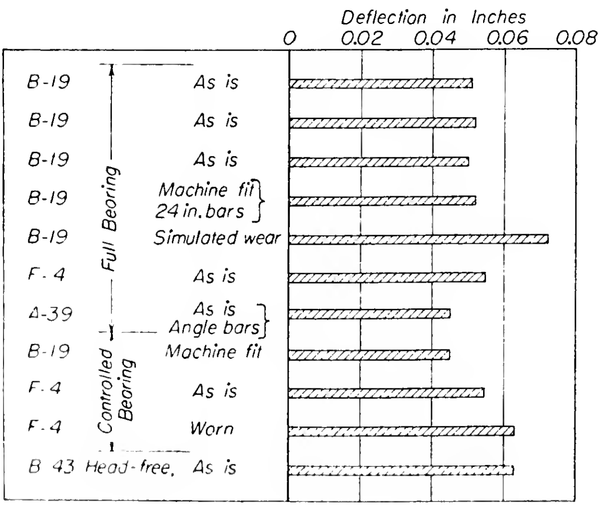


Fig. 29.—Deflection of Rail Joints in Laboratory Tests—Load 33,300 lb. Span 48 in.

joints, and the simulated wear joints have still greater deflection. It may be added that the deflection of a full rail under the same load and span would be about 0.029 in.

14. **Stresses in Rail Joints in Track.**—In the track tests stresses were measured in the inner and outer bars of the joints at the four positions shown in Fig. 26 of Article 12 "The Joint Bars and the Test Schedules". All gages for measuring stress were placed at mid-length of the joint. As can be seen from the figure a magnetic strain gage B was attached on the top flange of the bar (gage line B), and a second strain gage C on the bottom flange (gage line C). A view of two gages mounted on the outer bar of a joint with F-4 bars is shown in Fig. 6 of Article 7 "Testing Equipment". As the gages were offset laterally from the surface of the bars the gage readings will be different from the actual surface stress when there is marked lateral bending of the joint or of individual bars.

Representative records of the stresses in a B-19 joint at 5 and 90 miles per hour for gage lines C and B of the outer bar and B of the inner bar may be seen in Fig. 39, designated as records 4B, 5B and 6B, respectively. The stress at C for the inner bar was recorded by the other oscillograph and is not shown.

It may be noted that the stress records for the runs at 90 miles per hour show a notch in the peaks at most of the wheels. The stress record at the notch drops sharply and then quickly rises as the wheel passes over the rail gap at the mid-length of the joint where the gages are attached. It is judged that this notch is caused by the wheel passing over the rail gap. This effect is generally present to a lesser degree in the records for five miles per hour. The depth of the notch was found to be related to the speed in many instances.

Because of complicating conditions, the stresses themselves cannot be readily interpreted for the discussion of some of the purposes of the tests. However, the recorded stresses will be of direct value for showing variations in individual runs under comparable conditions, for indicating the presence of lateral bending, and for estimating the maximum stresses in the various bar sections. Representative data will be shown for these purposes.

As lack of space on the bars for application of all gages simultaneously prevented recording all the measurements taken on the joint bars in one given run, it was necessary to make three sets of runs, changing the gages for each set (5, 60, and 90 miles per hour, with several runs at each speed) to obtain all desired data at the three joint locations. See Article 8 "Operation of the Tests and Reduction of the Data".

Representative sets of stresses (s_B and s_C) measured in three types of joint bars are given in Table 8; these tests were all made at one joint location with the same speeds of the same locomotive and with similar bolt tension. Stresses are given for individual runs at speeds of 5 to 90 miles per hour, all for Location 3. The joint bars were 36-in. in length, with full bearing fishing surface and "as is" condition. The first set of data gives stresses for the B-19 bar, a heavy symmetrical section. The second set is for the A-39 bar, a heavy angle section. The third set is for the F-4 bar, a symmetrical section of somewhat less cross-sectional area. These three sections cover a considerable range of design in joint bars. The properties of these bars may be referred to in Table 4 and cross sections in Fig. 25. Also reference may be made to Table 6, in Article 12, which gives a list of the joints tested, the joint locations, conditions of the bars, and other data of the tests.

The stresses (s_B and s_C) given in Table 8 are the values measured at the two gage positions on the outer and the inner bar at mid-length as each of the three drivers passed the instruments. The moments given in one column are the vertical bending

Table 8

Representative Measured Stresses at Mid-length of Joint Bars at Joint Location 3

s_B and s_C are the values measured by the magnetic strain gages and s_{max} is the estimated maximum stress in the bar. Stresses are given in thousands of pounds per square inch. Moments are given in thousands of inch pounds.

Run No.	Speed (m.p.h.)	Driver No.	Outer Bar				Inner Bar			
			s_B	s_C	s_{max}	Moment	s_B	s_C	s_{max}	Moment
			B & O B-19 Joint Bar, 36 in., Full Bearing, As Is							
246	5	1	11.2	15.6	27.1	177	15.3	12.7	30.4	182
		2	11.2	13.5	25.6	162	9.6	10.3	20.8	130
		3	10.0	12.7	23.3	149	11.2	13.3	25.4	161
247	5	1	11.2	15.0	27.0	173	14.3	12.9	29.2	178
		2	11.0	12.9	24.7	156	10.4	10.1	21.9	134
		3	10.0	12.0	22.9	145	10.8	11.7	23.7	148
248	5	1	11.2	14.6	26.6	170	13.7	12.7	27.9	171
		2	11.2	13.1	25.1	159	9.8	9.9	20.8	128
		3	10.8	12.1	23.7	149	....	....	....	...
241	60	1	11.6	12.7	25.3	158	12.0	11.3	25.0	152
		2	11.2	15.6	27.4	177	12.6	9.4	24.4	142
		3	10.2	11.7	22.9	144	10.8	9.7	21.7	133
243	60	1	11.2	12.9	25.1	158	11.8	10.1	23.4	142
		2	10.6	16.0	27.2	177	13.5	9.2	25.4	146
		3	11.4	12.7	25.3	158	....	....	....	...
240	90	1	12.6	14.6	28.5	179	14.3	11.5	28.1	167
		2	11.4	15.6	28.0	179	12.4	10.1	24.6	146
		3	10.4	10.9	22.7	140	11.0	9.0	21.8	130
242	90	1	11.2	15.2	27.0	174	15.7	9.4	28.7	161
		2	11.0	17.0	28.3	186	14.3	10.3	27.2	158
		3	10.4	12.3	23.5	149	11.6	9.2	22.6	134
245	90	1	12.4	16.6	28.5	186	16.3	11.9	31.3	182
		2	10.2	16.6	27.2	179	13.3	9.7	25.3	148
		3	10.2	13.5	24.3	156	13.1	8.8	24.9	142
			N & W A-39 Joint Bar, 36 in., Full Bearing, As Is							
357	5	1	9.0	16.4	26.6	184	14.9	4.9	27.2	162
		2	8.4	14.8	24.5	169	11.6	4.1	21.1	127
		3	7.5	12.9	21.8	149	11.2	5.1	21.1	130
358	5	1	9.0	15.8	26.1	180	14.5	5.3	26.8	160
		2	8.2	14.4	24.0	165	11.2	4.1	20.6	124
		3	7.3	13.3	21.7	150	11.6	4.9	22.0	134
362	5	1	9.7	15.8	27.3	187	15.3	7.9	29.5	184
		2	8.7	14.7	24.8	170	12.0	5.9	23.3	144
		3	7.8	13.2	22.5	154	12.0	6.3	23.2	145
354	60	1	9.6	14.6	25.8	177	13.1	5.3	24.4	149
		2	8.8	15.4	25.5	175	13.5	3.3	23.9	139
		3	8.0	12.7	22.2	152	11.2	3.9	20.9	125

moments calculated from the strain gage records in the manner described in Article 13, "Laboratory Tests to Find Gage and Stress Relations and Conversion Ratios".

The estimated maximum stress (s_{max}) in a bar given in the column headed s_{max} is that found for the remotest fiber by calculation from the given moment and the stress s_C in the lower flange on the assumption that this stress is unaffected by bearing pressure and other factors discussed previously. The calculation indirectly involves finding the position of the neutral axis and finally the stress at the remotest point from this neutral axis, usually a compressive stress at the top part of the bar. The calculation was ex-

Table 8 (Continued)

Run No.	Speed (m.p.h.)	Driver No.	Outer Bar				Inner Bar			
			s_B	s_C	s_{max}	Moment	s_B	s_C	s_{max}	Moment
N & W A-39 Joint Bar, 36 in., Full Bearing, As Is (Cont.)										
355	60	1	9.6	14.8	26.2	179	13.5	4.3	24.4	145
		2	9.2	16.6	27.2	187	15.3	2.9	26.5	152
		3	8.0	14.0	23.2	160	12.6	4.3	22.9	137
359	60	1	9.5	13.6	25.0	170	12.8	5.1	23.6	144
		2	8.7	17.0	26.6	185	14.3	3.9	25.5	150
		3	7.2	12.9	21.3	147	12.2	3.3	21.6	127
356	90	1	10.4	17.6	29.3	206	16.7	5.3	30.3	180
		2	7.8	18.6	27.2	189	15.9	3.3	27.7	159
		3	8.6	12.9	23.2	159	11.6	5.8	22.4	139
360	90	1	10.1	15.7	27.8	190	16.5	7.0	31.0	189
		2	8.4	18.3	27.8	193	18.0	3.7	31.2	180
		3	8.4	12.8	22.9	157	13.3	5.1	24.6	149
361	90	1	10.6	15.3	27.6	190	15.7	6.7	29.4	180
		2	9.5	16.2	27.3	187	14.9	6.0	27.9	169
		3	8.9	13.0	23.6	162	13.3	5.8	25.1	154
P.R.R. F-4 Joint Bar, 36 in., Full Bearing, As Is										
88	5	1	13.0	15.0	28.6	133	12.8	16.6	29.6	139
		2	11.0	19.3	31.0	146	18.1	13.1	33.4	148
		3	11.5	14.0	25.9	121	11.8	14.2	26.5	124
89	5	1	13.0	15.4	28.7	134	13.0	16.3	30.0	140
		2	11.2	18.6	30.3	143	12.4	13.1	26.1	121
		3	11.2	13.8	25.5	119	11.6	13.6	25.6	119
90	5	1	12.8	14.6	28.1	130	12.8	16.3	29.7	139
		2	10.8	18.8	30.2	142	13.0	12.9	26.6	122
		3	11.2	13.6	25.3	118	11.4	13.8	25.5	119
81	62	1	11.6	14.6	26.8	125	12.4	13.8	26.8	124
		2	12.2	21.4	34.1	161	16.3	12.2	30.0	134
		3	10.2	14.4	25.0	118	14.7	11.3	27.8	124
82	61	1	13.2	15.6	29.3	137	13.8	14.6	29.0	134
		2	12.2	20.0	32.4	153	15.2	12.1	29.1	130
		3	11.2	14.6	26.6	124	13.2	11.7	26.1	118
83	61	1	12.2	14.6	27.6	128	11.4	13.6	25.5	119
		2	12.2	20.0	32.4	153	15.2	12.7	29.7	133
		3	10.4	14.6	25.2	119	13.0	11.7	25.5	116
78	90	1	15.7	21.8	38.0	179	18.8	17.3	37.6	171
		2	13.3	22.5	36.3	171	17.5	13.6	32.4	146
		3	11.2	15.6	27.1	128	15.3	12.4	29.3	131
79	89	1	13.5	19.1	32.9	155	17.3	15.3	34.3	155
		2	13.3	23.5	37.3	176	18.4	14.6	35.2	157
		3	11.0	17.0	28.4	134	15.5	12.0	29.1	130
80	90	1	15.3	21.8	37.5	177	19.4	16.8	37.8	171
		2	12.4	22.5	35.4	167	17.7	13.1	32.6	145
		3	11.6	16.4	28.4	134	16.3	12.6	30.7	137

pedited by the use of graphical methods. These estimated maximum stresses, while not exact values, may be expected to approximate the actual values.

A comparison of the measured stresses in the several joints may well be made for a given driver and location to determine how closely one run checks another at the same speed. It is important that variations should be small in any three sets of runs making up the data on a given joint. For this purpose compare the stresses (s_B or s_C) in Table 8 for different runs at a given speed and joint location. As an example, in the first group of data, the joint with B-19 bars, the stresses s_B on the outer bar at joint Location 3 for a speed of 5 miles per hour are 11,200, 11,200 and 11,200 lb. per sq. in. for runs 246, 247, and 248, respectively. Even at 90 miles per hour the stresses for three runs are in close agreement, being 12,600, 11,200 and 12,400 lb. per sq. in. for runs 240, 242, and 245, respectively. The maximum variation from the average for these three stresses is 900 lb. per sq. in., which is representative of the larger variations to be found in the rest of the data. The stress s_C and those in the two gage lines of the inner bar have similar agreement in the three runs. Few stresses for the several runs at a given speed vary more than 1,000 lb. per sq. in. from the average value for comparable conditions, and most of them have less variation. In this connection it may be stated that the limiting accuracy set in the reduction of data from the records was ±500 lb. per sq. in. It appears then that the agreement between individual runs for comparable conditions is good for most cases, especially considering the limits of accuracy in other respects. The assumption that the repetition of the runs three times will give comparable data for the purpose is justified within reasonable limits.

The magnitude of the calculated maximum stresses (s_{max}) can be studied in this table as related to the type of bar. The values of the stresses at a speed of five miles per hour are best suited for comparison because of the lesser variability in the action of the locomotive at this speed. In comparing the stresses, consideration must also be given to the bending moment developed in the joint, which always depends on the individual characteristics of the joint. It may be noted in the table that in general the bending moment developed is somewhat less for the F-4 bar than for the B-19 or the A-39 bar. The sections named are in order the lighter symmetrical bar, the heavy symmetrical bar, and the heavy angle bar. The B-19 and the A-39 bars generally developed moments of approximately the same magnitude.

Bearing in mind what has been said in regard to the relative bending moments developed in the three joints, the estimated maximum stresses (s_{max}) may be compared. The maximum stresses for the B-19 and A-39 bars from Table 8 with few exceptions are below 30,000 lb. per sq. in. and are usually about 25,000 lb. per sq. in., whereas in many cases the maximum stresses in the F-4 bar are 30,000 lb. per sq. in. or greater, even though the moments in the F-4 bars are generally less than in the other two types. Three runs where the moments happen to be the same (179,000 in.-lb.) in the outer bar for driving wheel No. 1 may be cited for comparison. The B-19 bar had a maximum stress of 28,500 lb. per sq. in. (run 240), the A-39 bar a stress of 26,200 lb. per sq. in. (run 355), and the F-4 bar a stress of 38,000 lb. per sq. in. (run 78). The stress in the lighter bar is thus seen to be more than 10,000 lb. per sq. in. higher than the stress in the other two bars for an identical moment.

The stresses in Table 8 will also give some indication of the presence of lateral bending in the joint. The stresses at corresponding gage locations on the outer and inner bars may be compared for this purpose. If there is general lateral bending of the joint, the stress for one bar will be high and the corresponding stress for the other bar low. The relation of the magnitudes of stresses in the outer and the inner bars at their top will be the opposite of that at their bottom. The stresses for driving wheel No. 1, run 245, at 90 miles per hour may be taken as an example to illustrate the presence of lateral bending. The stress s_B for the outer bar is 12,400 lb. per sq. in. and for the inner bar 16,300 lb. per sq. in. while s_C for the outer bar is 16,600 lb. per sq. in. and for the inner bar 11,900 lb. per sq. in. Thus for the outer bar the lateral bending has decreased the compressive stress at s_B due to vertical bending and increased the tensile stress at s_C. This would indicate lateral bending of such nature as to produce tension in the outer bar or an outward bending with respect to the joint. An opposite relation of the stresses in the inner bar also indicates a general outward bending of the joint.

For the lower speeds the stresses in corresponding gage lines in the outer and the inner bar are seen to be quite similar in magnitude for both the F-4 and the B-19 joints; for the higher speeds they become dissimilar indicating the presence of lateral bending due doubtless to lateral forces developed by the locomotive. The A-39 angle bar joint shows considerable dissimilarity in stresses at corresponding gage lines on outer and inner bars for all speeds. The stress s_C for the angle bar at the gage location at the edge of the projecting lower flange would be more affected by lateral bending than would the symmetrical bar.

It is seen then that the data of Table 8 show relatively small variations in the stresses in any bar from run to run for a given wheel at a given speed and location. The presence of general lateral bending of the joint is indicated in some cases, and this lateral bending is generally greater for the higher speeds. Appreciably larger stresses were found in the lighter section, F-4 bars, than in the B-19 or A-39 bars.

Because of the great amount of data obtained, it is not feasible to publish even a table of the average stresses for all the tests.

15. **Values of Moments in Rail Joints in Track.**—Many of the comparisons to be made from the data of the tests can best be taken from the values of the vertical bending moments developed at mid-length of the joint as calculated from the measured stresses in the bars with the aid of the conversion ratios. Because of variations in design of bar, the position of gage lines, the action of the locomotive laterally, and the opportunity for averaging runs, bending moments have been found most satisfactory for the purpose of comparing the various types of joint bars and their effectiveness in approaching continuity in rail.

As a first step in the determination of the vertical bending moment developed at mid-length of a joint, the measured stresses were substituted in Equation (67) (see Article 11). As various deformations of the bars due to forces other than the forces assumed in ordinary beam analysis introduce variations from the assumptions of the analysis it is necessary to multiply the result by the conversion ratio established for the given type and condition of bar, as described in Article 13 "Laboratory Tests to Find Gage and Stress Relations and Conversion Ratios". Equation (67) takes into account any inclination of the neutral axis from the horizontal. As may be seen in Fig. 26 the magnetic strain gages at gage lines B and C were offset from the surface of the bars. The effective amount of this offset has been found to be 0.45 in. This value has been used in determining the coordinates of the positions of the gage lines for the calculation of the moment from the measured stresses, s_B and s_C, which correspond to s_1 and s_2 of Equation (67). It is believed that the method here used in reducing the data of the tests obtains values for the vertical bending moments with a reasonable degree of accuracy.

In Table 9 are given the values of the vertical bending moment in the joint bars at mid-length for the three joint locations and the several types and conditions of the bars as the three driving wheels passed the joint at speeds from 5 to 90 miles per hour. Each value is the average of three or more runs.

Reference may be made to Table 6, which lists the bar sections, length of the bars, condition of the bars, type of bearing, speeds used and other information for all the rail joints tested. This table will give a good understanding of the scope and variety of the tests.

Table 9

Vertical Bending Moments at Mid-length of Rail Joints

Moments are given in thousands of inch pounds. In the calculation of moments from the measured stresses the conversion ratios were used.

Speed	Location	Driver No. 3	Driver No. 2	Driver No. 1	Av.	Speed	Location	Driver No. 3	Driver No. 2	Driver No. 1	Av.
P.R.R. F-4, 36 in., Controlled Bearing, As Is											
5	1	251	293	289	278	60	1	246	297	264	269
	2	290	280	345	305		2	267	269	321	286
	Av.	271	287	317	292		Av.	257	283	293	278
40	1	243	288	279	270	90	1	251	196	172	206
	2	252	260	336	283		2	205	248	357	270
	Av.	248	274	308	277		Av.	228	222	265	238
P.R.R. F-4, 36 in., Controlled Bearing, Machine Fit (loco. 4790)											
5	1	286	278	269	278	60	1	320	289	279	296
	2	223	241	239	234		2	180	244	250	225
	Av.	255	260	254	256		Av.	250	267	265	261
40	1	321	265	289	292	90	1	314	256	169	246
	2	172	267	261	233		2	145	231	301	226
	Av.	247	266	275	263		Av.	230	244	235	236
P.R.R. F-4, 36 in., Controlled Bearing, Simulated Wear											
5	1	181	155	157	164	60	1	150	147	136	144
						90	1	133	108	63	101
P.R.R. F-4, 36 in., Controlled Bearing, Worn											
5	1	...	342	...	...	60	1	...	...	340	...
	2	247	246	249	247		2	254	270	276	267
	3	280	282	...	...		3	300	302	279	294
	Av.	263	290	...	...		Av.	277	286	298	281
						90	1	...	...	280	...
							2	247	206	268	240
							3	262	277	283	274
							Av.	255	242	277	257
P.R.R. F-4, 36 in., Controlled Bearing, High Camber											
5	2	359	368	402	376	60	2	369	385	400	385
	3	389	376	366	377		3	409	388	338	378
	Av.	374	372	384	377		Av.	389	387	369	382
						90	2	273	359	...	...
							3	463	425	410	433
							Av.	368	392	...	...
P.R.R. F-4, 36 in., Controlled Bearing, High Camber											
5	2	234	255	292	263	60	2	247	281	286	271
	3	345	336	370	350		3	354	357	370	360
	Av.	290	296	331	307		Av.	300	319	328	316
5*	2	188	196	230	205	60*	2	181	201	218	200
	3	197	200	264	220		3	228	213	241	228
	Av.	193	198	247	213		Av.	205	207	230	214
						90*	2	137	151	240	176
							3	208	228	268	235
							Av.	173	190	254	206

* Shims inserted between rail and tie-plate.

Table 9 (Continued)

Speed	Location	Driver No. 3	Driver No. 2	Driver No. 1	Av.	Speed	Location	Driver No. 3	Driver No. 2	Driver No. 1	Av.
P.R.R. F-4, 36 in., Controlled Bearing, Negative Camber											
5	2	175	203	229	202	60	2	185	212	240	212
	3	148	137	130	138		3	161	167	160	163
	Av.	162	170	180	170		Av.	173	190	200	188
						90	2	135	198	269	199
							3	...	...	...	...
P.R.R. F-4, 36 in., Full Bearing, As Is											
5	1	269	275	293	279	60	1	233	296	234	254
	2	297	294	357	315		2	298	304	336	313
	3	242	272	275	263		3	240	290	256	262
	Av.	269	280	308	286		Av.	257	297	275	276
40	1	230	275	299	268	90	1	237	200	160	199
	2	237	289	345	290		2	232	257	347	249
	3	225	275	294	265		3	266	321	339	309
	Av.	231	280	313	274		Av.	245	259	282	262
P.R.R. F-4, 36 in., Full Bearing, Machine Fit											
5	1	275	296	328	300	60	1	250	314	302	289
	2	249	245	283	259		2	248	261	279	263
	3	227	238	298	254		3	245	268	266	260
	Av.	250	260	303	271		Av.	248	281	282	271
40	1	255	272	308	278	90	1	276	232	232	247
	2	221	220	308	250		2	171	186	289	215
	3	223	244	281	249		3	241	285	306	277
	Av.	233	245	299	259		Av.	229	234	276	246
P.R.R. F-4, 36 in., Full Bearing, Simulated Wear											
5	1	201	208	226	212	60	1	162	200	201	188
	2	165	182	195	181		2	144	163	181	163
	3	157	163	189	170		3	144	156	161	154
	Av.	174	184	203	188		Av.	150	173	181	168
						90	1	173	159	142	158
							2	107	116	176	133
							3	125	151	174	150
							Av.	135	142	164	147
B & O B-19, 36 in., Full Bearing, As Is											
5	1	339	368	395	367	60	1	294	383	368	348
	2	302	321	365	329		2	286	322	357	322
	3	300	292	351	314		3	285	323	306	305
	Av.	314	327	370	337		Av.	288	343	344	325
						90	1	350	298	274	307
							2	234	255	404	296
							3	285	334	350	323
							Av.	290	296	342	309
B & O B-19, 36 in., Full Bearing, Machine Fit											
5	1	305	308	351	321	60	1	265	327	325	306
	2	231	248	303	261		2	216	250	297	254
	3	228	242	300	258		3	242	274	275	264
	Av.	255	266	318	280		Av.	241	284	299	275
40	1	270	273	362	302	90	1	294	251	248	264
	2	219	223	315	252		2	187	183	291	220
	3	223	244	303	257		3	217	297	341	285
	Av.	237	247	327	270		Av.	233	244	293	257

Table 9 (Continued)

Speed	Location	Driver No. 3	Driver No. 2	Driver No. 1	Av.	Speed	Location	Driver No. 3	Driver No. 2	Driver No. 1	Av.
				B & O B-19, 24 in., Full Bearing, Machine Fit							
5	1	184	190	215	196	60	1	169	217	205	197
	2	151	160	190	167		2	157	173	205	178
	3	162	166	188	172		3	238	266	256	253
	Av.	166	172	198	178		Av.	188	219	222	209
						90	1	199	171	140	170
							2	139	131	200	157
							3	255	315	311	294
							Av.	198	206	217	207
				B & O B-19, 36 in., Full Bearing, Simulated Wear							
5	1	245	241	269	252	60	1	200	242	248	230
	2	168	191	225	195		2	151	166	191	169
	Av.	207	216	247	223		Av.	176	204	220	200
						90	1	220	194	145	186
							2	126	112	185	141
							Av.	173	153	165	164
				B & O B-19, 24 in., Full Bearing, Simulated Wear							
5	3	154	145	169	156	60	3	150	171	170	164
						90	3	150	174	190	171
				B & O B-19, 36 in., Controlled Bearing, Machine Fit							
5	1	230	232	263	242	60	1	211	233	245	230
						90	1	...	227	204	...
				B & O B-19, 24 in., Controlled Bearing, Machine Fit							
5	1	191	181	169	180	60	1	208	187	172	189
						90	1	...	...	...	...
				N & W A-39, 36 in., Full Bearing, As Is							
5	2	293	304	338	312	60	2	300	317	372	330
	3	286	300	351	312		3	284	329	320	311
	Av.	290	302	345	312		Av.	292	323	346	321
						90	2	238	257	366	287
							3	306	356	378	347
							Av.	272	307	372	317
				C & O B-43, 36 in., Headfree, As Is							
5	3	254	255	282	264	60	3	248	273	266	262
	3	220	206	207	211		3	244	225	220	230
40	3	238	248	290	259	90	3	284	328	316	309
	3	220	232	237	230		3	302	266	257	275

16. **Effect of Camber in Joint with No Re-tamping.**—As the track was not touched during the time of the tests except to insert five new rails just before the test and as the condition of the tie support was not changed from test to test (no re-tamping), it is apparent that a rail joint will have different relations to the tie support according to the relative straightness of the bar and to the fit between bar and rail given by the several types of bar used or even by different bars of the same type. One indication of such differences of tie support is the camber or lack of camber of the rail joint itself as related to the level of the tie plate and ties immediately under it. If the two rails at the joint have no camber, as compared with the original position of the supporting surfaces, there will be what may be termed a normal distribution of load

among the ties at and near the joint. If there is negative camber in the rail joint as compared with the original position of the supports these ties will take more than their normal share of load and the bending moment developed in the joint will be less than what may be considered normal. If there is positive camber, these ties will take less than their normal load and the bending moment in the joint will be greater than the normal amount. All of this must be taken with relation to an original normal or level position of the tie support. Although the magnitude of the camber appears small, with the stiff rail the effect on the support given by the ties runs back several tie spaces each way from the joint. Obviously, too, if joints with high camber had been tamped to give uniform supporting conditions from tie to tie, this condition of camber or no camber may not be expected to affect the magnitude of the bending moment developed in the joint—at least not until traffic has acted to change the supporting conditions. Because of the variation in supporting conditions in the tests when different sets of bars are inserted at a given joint location without re-tamping, it is deemed advisable here to discuss some of the data relating to amount of camber of a joint and magnitude of bending moment developed in the belief that this will help to avoid misinterpretation of data in the further discussion of the tests.

The rail joint camber used was the average measured ordinate of the unloaded joint at the rail surface at points 4 in. each way from the rail ends on a chord of 32 in. The ordinates were taken from the plotted profile of the rail surface. In effect the chord used ended in the rail surface 16 in. each way from the rail gap. In Fig. 30 the measured vertical bending moment developed in the joint at five miles per hour is plotted against the measured camber. As little distinctive difference was found in different types of bars the points in the figure are plotted with respect to condition of bar rather than type. Each point is the average of the moments developed in two joint bars by the three driving wheels on one rail for three runs or more. Four principal conditions of bar are given, "as is", machine fit, worn bar and simulated wear. The data include the results from the three joint locations. A given pair of bars was tested at one given joint location only, and other joints of the same kind were tested at the other joint locations, except that both pairs of B-43 head-free bars were tested at joint Location 3. The vertical spread of the points is due to differences in tie support at the three joint locations and to other variable conditions. In general, as would be expected with joints not re-tamped, there is a definite trend for the amount of the camber to govern the magnitude of the bending moment developed.

The camber of the joint in general corresponds to the camber of the bars. The machining of the machine fit bars produced a bar with straight fishing surfaces, which in turn gave approximately a straight rail surface in the joints, as is seen by the grouping of the machine fit joints near the line of zero camber. The joints with "as is" bars are mainly grouped around a line for camber of +0.010 in. It was found that joints provided with bars selected as having high camber and having a joint camber of around +0.030 in. developed high bending moments even though the bars were the lighter F-4 section. Two joints with bars of the same F-4 section selected as having large negative camber developed low bending moments. The joints with bars ground to simulate wear fall in the negative camber class and developed a relatively low bending moment and obviously placed a relatively larger bearing load on the joint ties. To show this effect in another way, shims 0.15 and 0.20 in. thick were placed on the two joint ties at joint Location 2, and shims 0.09 and 0.12 in. thick at joint Location 3, using the F-4 high camber bars. For the ties adjoining the two joint ties there would be little or no bearing until the joint ties had been depressed somewhat. The insertion of the shims decreased the moment developed in the joints with high camber bars from an average of 310,000

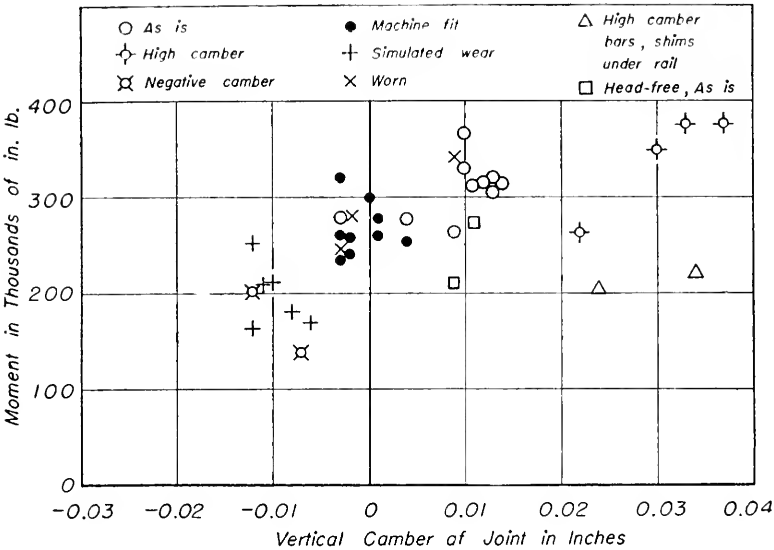


Fig. 30.—Relation between Joint Camber and Bending Moment Developed in Rail Joints under Drivers of Locomotive at Speed of 5 Miles per Hour.

in.-lb. to 220,000 in.-lb. With the shims present, it is evident that bearing load on the ties at the joint will be greatly increased and that such ties cannot maintain their original level.

In Fig. 30 the general scope of the joint camber ranges from +0.009 to +0.014 in. for the group of "as is" bars of the different types, from —0.004 to +0.004 in. for the group of machine fit bars, and from —0.006 to —0.012 in. for the simulated wear bars. The camber of the joints with high camber bars ranged from +0.022 to nearly +0.040 in. That small changes in camber should change the magnitude of the moment developed in the joint so much when ties are not re-tamped may seem strange. However, the deflection at the middle of a 32-in. simple span of 131-lb. rail loaded with a single wheel load of 40,000 lb. is about 0.010 in., with a corresponding bending moment of 320,000 in.-lb. Although the arrangement of the tie supports is much more complicated than the simple beam span, the smallness of this rail deflection shows that small changes may make marked differences.

Altogether the tests show that changes in joint camber without re-tamping of ties modifies the load carried by the ties at the joint and affects the magnitude of the moment developed in the joint bars and that this effect must be considered in the interpretation of the tests. Again, it should be noted that this discussion refers to joints with bars having varying camber inserted in track without re-tamping to make the surface position of the ties fit the camber of the joints. The results should not be taken to determine whether joints should or should not be made with camber and tamped to make the bearing on the ties fit the conditions of joint camber.

17. Discussion of Type and Condition of Bar.—In order to facilitate a comparison of the bending moments developed in the several types of bar in their several conditions of fit and camber in detail, the values of the bending moments taken from

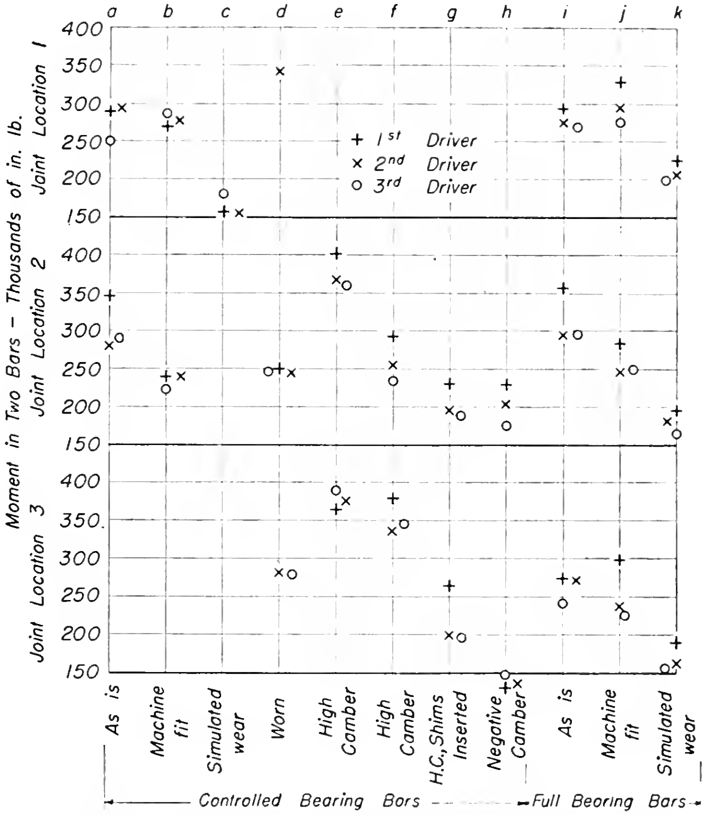


Fig. 31.—Bending Moments in F–4 Rail Joints for Several Conditions of Fit and Camber at Speed of 5 Miles per Hour.

Table 9 have been plotted in Figs. 31 and 32. The figures give the bending moment in the joint at the three joint locations for each driving wheel at a speed of five miles per hour. Values are plotted for the several conditions of bar ("as is", machine fit, simulated wear, etc.). Each point is the average of values obtained from three or more runs at five miles per hour. These values then show the variation in the moments developed under the individual driving wheels as well as the variation in the three joint locations. Joint locations 1 and 3 were on the right rail, and 2 was on the left rail. As was shown in Fig. 3 the weighed loads on the several drivers varied considerably. The weight on the right driving wheels was considerably greater than that on the left driving wheels when the engine was weighed, but it may be pointed out in advance that this relation apparently does not always hold in the tests. The plotted points for the moments for the several wheels in some instances are closely grouped (similar values of bending moment) and in others the moments differ by considerable amounts.

Fig. 31 gives the bending moments for the 36-in. P.R.R. F-4 bars with controlled bearing and full bearing for the several conditions of the bars. Points for joints having bars in a given condition for a given test are plotted on the same vertical line. Beginning at the left vertical line (a) moments for controlled bearing F-4 bars in "as is"

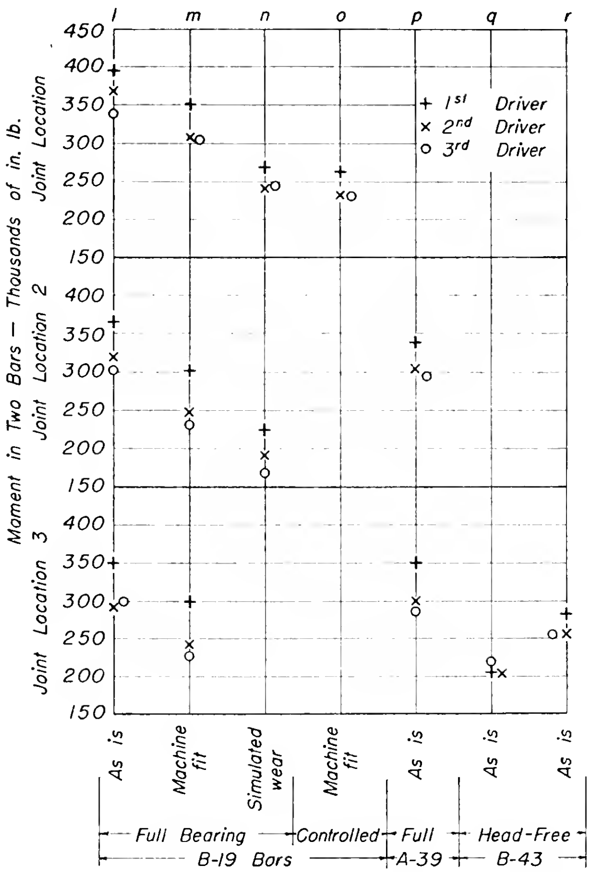


Fig. 32.—Bending Moments in Several Types and Conditions of Rail Joints at Speed of 5 Miles per Hour.

condition at joint location 1 and 2 are shown. It is seen that the moment at joint Location 2 under the first driver is greater by more than 50,000 in.-lb. than that under the second and third drivers. The average for three wheels is 280,000 in.-lb. for joint Location 1 and 305,000 in.-lb. for joint Location 2. Substitution of machine fit bars in the same joint locations (line b) gives a moment of similar magnitude in joint Location 1, but the moment at joint Location 2 becomes 235,000 in.-lb. As the camber of the two joints at joint Location 1 was almost identical in the two cases, while the camber at joint Location 2 changed from +0.013 in. for the "as is" bars to —0.003 in. for the machine fit bars, the cause of the lower moment is doubtless due to differences in camber, which for joints not re-tamped has been shown to modify the magnitude of the moment developed in a given joint location.

The simulated wear bars (ground from machine fit with 0.05 in. of metal cut from the top fishing surface at mid-length, tapering 4 and 6 in. each way) gave a joint camber of —0.012 in., which of itself would decrease the moment developable in the bars. The moment with the simulated wear bars (line c) at joint Location 1 averaged 165,000 in.-lb., in place of 280,000 in.-lb. developed with the original machine fit bars. The smaller moment in the joints with simulated wear bars means here that a greater load or pressure is applied to the joint ties than was applied with the bars in machine fit condition. Necessarily, with an increase in tie loads, these joint ties would be pressed downward more under traffic and would soon require added maintenance. The effect of such wear in the bars then would be to decrease the moment-carrying capacity of the joint and to force the ties at the joint downward and thus produce a low joint. Nor could re-surfacing of this worn joint anew give more than a temporary normal bending moment for the joint. In such cases tightening the bolts anew will increase the droop of the joint, which itself produces unfavorable joint conditions.

The three joints with worn bars taken from track and tested with their original rails (line d) were not sufficiently worn to cause the joint to droop downward, and the moments developed are similar to "as is" and machine fit bars having like joint camber.

As was noted in Article 16 "Effect of Camber in Joint with No Re-tamping", the two joints with bars selected for more than usual camber (lines e and f) develop abnormally high moments in two separate sets of tests. The average of the moments for the three wheels shown at line e for joint Location 2 is 375,000 in.-lb. as compared with 305,000 in.-lb. for the "as is" bars. When shims were placed on the joint ties to take up the play between rail and tie and to give full support from the beginning of loading of the tie, as a wheel rolls along, (line g), the moment developed was materially decreased. Also, the joint with bars selected for negative camber (line h) developed at joint Location 2 a relatively low bending moment, 200,000 in.-lb. as compared with 305,000 in.-lb. for the "as is" bars.

The three vertical lines at the right side of Fig. 31 have F-4 bars with full bearing along their length. With consideration given to the amounts of the joint camber, it is found that the moments developed in "as is" bars (line i) at joint locations 1 and 2 correspond in magnitude with the moment developed in the machine fit bars. At joint Location 3, regardless of a higher camber in the "as is" joint, the moment (260,000 in.-lb.) is unexpectedly small for a camber of +0.009 in. No reason is known for this. For joint locations 1 and 2, taking into account the joint cambers, the moments in both "as is" and machine fit bars (lines i and j) correspond fairly closely with values found with the F-4 controlled bearing bars on lines a and b. It may be said then that there is little difference in moment caused by the two kinds of bearing under the conditions of these tests.

The moments for three full bearing 36-in. F-4 joints in a simulated wear condition are plotted on line k. There is seen to be a marked decrease in moment, the average of all values being less than 200,000 in.-lb. The camber of the joints was reduced greatly by the simulated wear condition and is doubtless the source of the low moment.

Fig. 32 gives the bending moments for the B. & O. B-19 bars, the N. & W. A-39 angle bars, and the C. & O. B-43 head-free bars for the several conditions of the bars. All of these bars had a length of 36 in. Beginning at the left vertical line l the moments for joints with B-19 bars with full bearing in "as is" condition are given for the three joint locations. All the plotted points are above 300,000 in.-lb. except one which is slightly below. These values are in general somewhat higher than those found with the lighter F-4 "as is" bars just discussed. The camber of the joints of the two types was similar in amount, although at Location 1 the camber is somewhat less with the F-4 bars and the corresponding moment is likewise somewhat smaller. On the second vertical line (m), with B-19 bars having full bearing in the machine fit condition, the moments are lower by an average of more than 55,000 in.-lb. from the "as is" bars at the same three joint locations. This decrease in moment accompanies a decrease in camber, which doubtless is the source of the decrease in moment, since with both conditions the fit, bolt tension, and other test conditions were quite similar.

On line n joints with B–19 bars ground to simulate wear show moments markedly less than the joints with "as is" and machine fit bars in joint locations 1 and 2, averaging 125,000 in.-lb. less than the average moment of 350,000 in.-lb. for the "as is" condition for the same two locations. Although these simulated wear B–19 joints show the most marked negative camber of any of the joints tested, including the F–4 bars with negative camber, the moments developed are greater than in the simulated wear F–4 joints, due doubtless to the stiffer section of the B–19 bars.

A single 36-in. B–19 controlled bearing machine fit joint (line o) was tested at joint Location 1. The moment in this joint was low with respect to the other joints tested at this location, even somewhat lower than the simulated wear joints (see lines l, m and n). This joint was one of the few 36-in. joints that had the rail ends butting together and probably most of the reduction in moment developed in the joint was due to this condition. The camber for this joint (–0.002 in.) was similar to that for the other machine fit bars.

On line p the joints with 36-in. A–39 angle bars in "as is" condition have moments averaging 310,000 and 310,000 in.-lb. at joint locations 2 and 3, values which are closely similar to those found with similar tests with B–19 bars. The relatively large values developed with this heavy angle bar may be attributed to the high bolt tension maintained during the tests, about 30,000 lb. This high bolt tension would act to hold the neutral axis fairly close to horizontal and thus would avoid a decrease in stiffness and in bending moment which has been found in angle bars when tested with moderate and low bolt tension.

The moments developed by the two joints with 36-in. B–43 head-free bars are plotted on lines q and r. Both joints were tested at joint Location 3. The moments developed (210,000 and 265,000 in.-lb.) are rather low, being somewhat less than those developed by the F–4 joints in the "as is" condition and materially lower than those found with B–19 and A–39 bars. As will be discussed later these joints in some instances showed greater movements between bar and rail (vertical and longitudinal) than did the other joints, even at the high bolt tension used, (about 30,000 lb.). These larger movements are probably the cause of the smaller moments developed.

The values of the bending moments developed in the various types of bars are also plotted in Fig. 33 according to the camber measured in the joint. General increase in bending moment with increase in camber will be noted, as was discussed in the last article. In general, too, for the same type of bar and for similar cambers, joint Location 1 gives higher moments than do joint locations 2 and 3. For similar cambers joints with B–19 bars show higher bending moments than those with F–4 bars. The B–43 head-free bars have somewhat lower values. In general the values for the same or similar conditions are in as close agreement as can be expected with all the chances for variation that exist in track tests of this kind.

It is apparent that some of the peculiarities found in comparing values of the bending moments developed in the joints are due to such matters as the camber of the joint and the characteristics of the rail supports at the given joint locations. A few examples may be cited. With the B–19 bars in both "as is" and machine fit conditions, the moment developed at joint Location 1 is 50,000 in.-lb. greater than at joint locations 2 and 3, even though the amount of the camber for a given condition is nearly the same for the three joint locations. For the B–19 controlled bearing bar with machine fit, the moment at joint Location 1 is only 240,000 in.-lb. as compared with 320,000 in.-lb. found with the full bearing bars of the same type and condition of bar

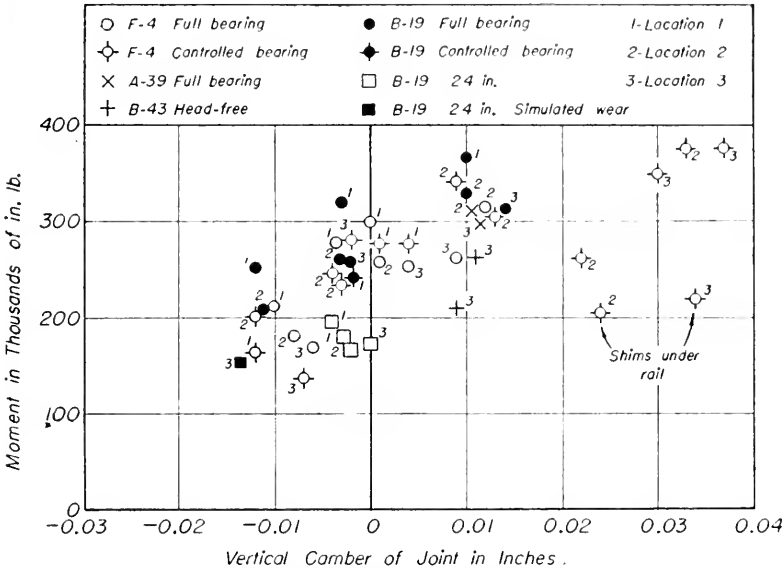


Fig. 33.—Relation between Joint Camber and Bending Moment Developed in Rail Joints under Drivers of Locomotive at Speed of 5 Miles per Hour.

at the same joint location. The camber in the two cases is quite similar. However, in the former case the rail gap was closed by the high rail temperature existing at the time of the test. Comparing joints with both full bearing and controlled bearing F–4 "as is" bars at joint locations 1 and 2, the relatively small value of the moment at Location 1 in both cases accompanies a small camber and the relatively large value at Location 2 is found with a camber of + 0.012 in. or more.

Three pairs of 24-in. B–19 full bearing bars in machine fit condition were tested at joint locations 1, 2 and 3, one pair of 24-in. B–19 controlled bearing bars also in machine fit condition at joint Location 1, and one pair of 24-in. B–19 full bearing bars in simulated wear condition at Location 3. These joints all gave bending moments materially smaller than did the joints with 36-in. bars having the same conditions (see Table 9 and Fig. 33). The average of the moments developed in the four joints with 24-in. machine fit bars was 180,000 in.-lb. The average of the moments developed with the corresponding 36-in. B–19 bars was 280,000 in.-lb. The moment developed in the one joint tested with 24-in. simulated wear bars was 155,000 in.-lb. and that with 36-in. simulated wear bars was 225,000 in.-lb. Previous tests in both laboratory and track have shown little differences in deflection, stress, and moment for joints with bar lengths of 24 and 36 in. In the present case fit, joint camber, and other conditions were apparently approximately the same. The one known difference in condition of test was that in these tests in track with 24-in. bars, in spite of the high bolt tension used, the high temperature in the rail at the time of test forced the rails together in a way that gave lower values to the flexural compressive stresses developed in the bars when loaded, and likewise possibly lowered the tensile stresses also.

In an effort to learn something of the effect of the closure of the gap on the stresses and moments developed in the joint bars, a study was made of the data of the field tests of joints with 36-in. bars in which the rail gaps had been closed by the high temperatures, but it was found that the conditions were not generally sufficiently similar to warrant drawing a conclusion. However, one joint with 36-in. B–19 bars (controlled bearings) had no gap and gave a markedly low moment in comparison with a joint of the same type with full bearing bars at the same joint location—thus pointing to a definite probability of a reduction of moment in bars through closing of the gap. A laboratory test was made in the rolling load testing machine on a joint having 24-in. B–19 joint bars by rolling the load of 45,000 lb. along the span of 36 in., first with a rail gap of about ⅛ in. and second with a wedge driven into the rail gap between the heads of the two rails. The bending moments developed in the joint bars at mid-span were calculated from the measured stresses. The moment in the bars was found to be about 12 percent less in the second test than in the first. After giving consideration to the analysis of possible conditions it is thought that with the gap closed by an increase in temperature in the rails, as a result of the high compression developed in the head and other parts of the rails, the beam action of the joint is modified in a way that causes a decrease in the stresses in the bars and likewise a decrease in the moment that would otherwise be taken by the bars.

Table 10

Average Joint Moment Ratios at 5 Miles per Hour

The base of the joint moment ratio is taken as 370,000 in. lb.

Joint Bars	Condition	Bending Moment (inch pounds)	Joint Moment Ratio
F-4	As is	285,000	.77
F-4	Machine fit	270,000	.73
F-4	Simulated wear	190,000	.51
B-19	As is	335,000	.91
B-19	Mechine fit	280,000	.76
B-19	Simulated wear	225,000	.61
A-39*	As is	310,000	.84
B-43†	As is	240,000	.65

* Two joints tested at Locations 2 and 3
† Two joints tested at Location 3

In view of these considerations and with the evidence of previous tests, the development of a smaller moment in the joints with 24-in. bars should not be taken as establishing a superiority in the 36-in. length over the 24-in. length in respect to ability to carry bending moment. The results indicate, however, the need for adequate tests to be made on joints in track with 24-in. and 36-in. bars.

The effectiveness of a rail joint in track may be judged by its ability to develop and carry bending moment under normal conditions of tie support and to approach, as closely as may be, the stiffness and the moment carrying capacity of the full rail. In earlier reports of the committee the term "joint moment ratio" has been used as the ratio of the bending moment developed in the joint to the bending moment developed in the full rail under similar supporting conditions. The general average value of the bending moment in the rail under the load of the six driving wheels of the locomotive used in the tests was taken as 370,000 in.-lb. This value is approximately the average of the calculated and measured moments for the six driving wheels at a speed of five miles per hour, which were given in Article 9 "Stresses and Moments in Rail". Using this value as a base, the joint moment ratios obtained with the bending moments found in the tests of the joint at five miles per hour, calculated from the values given in Table 9, are given in Table 10. Since the camber of the joints as they stood originally in the track before the new rails and joint bars were put in is not known, the actual relation of the tie supports to the camber found for the various joints during the tests is uncertain, but it is very likely true that the camber in these original joints lay between that found with the machine fit and the "as is" conditions, say between zero and + 0.010 in. In other words, if the tie supports had been fitted to the camber of the "as is" joints by re-tamping the moments developed in these joints would probably have been smaller than those given in Table 10, and likewise with tamping to conform to the camber of the joint the moments developed in the machine fit bars would have been greater than those given in the table. Also under these conditions there would have been little difference between the moments for the "as is" and those for the machine fit bars. Possibly the joint moment ratio for the F–4 bars would then be about 0.75 and for the B–19 bars about 0.85. The difference between these two values may be taken to mean that the stiffer B–19 bars have advantages over the F–4 bars, though the difference in effectiveness throughout the lifetime of the joints may be expected to be greater than shown by the difference in these numerical values.

The comparison has been made between F–4 and B–19 bars because of the number of tests and of joint locations used. For the same two joint locations there is little difference in the joint moment ratio for the B–19 bars and the A–39 bars. For the B–43 bars, however, the joint moment ratio is less than for the B–19 bars.

The comparisons have been made on the data taken at five miles per hour because at this speed the loads applied by the individual wheels of the locomotive are evidently more nearly the same throughout the many runs than could be expected at the higher speeds. Lateral loads and forces and transfers of load from one wheel to another were more marked and more frequent, as will be noted in a study of the data of the higher speeds.

18. **Relation of Speed to Type and Condition of Bar.**—In Figs. 34 and 35 the values of the moments developed in the joints at speeds from 5 to 90 miles per hour are plotted with respect to speed. The values shown are generally the average of three or more runs at a given speed; they are given for each of the three driving wheels and for the three joint locations. A line has been drawn through the average moment for the three driving wheels at each of the several speeds. The type of joint, their condition, and other pertinent data are given with each set of points.

The tests were made in an effort to learn what influence type of bar, condition, and other variations had on the action of the joint when the locomotive was operated at high speed. As in the tests of stress in rail previously discussed the action of the locomotive at the higher speeds was found to be quite different at one location from that at another and much more variable at high speed than at five miles per hour. This variety of action on the part of the locomotive made it impracticable to determine the effect of joint type or condition in relation to speed. Since no two of the three joint locations were opposite each other on right and left rails, it is not desirable to average the results at the higher speeds for the two rails, as was done for the stresses measured in the rails. It will be recalled that the average of the rail moments for the two wheels of an axle was found to be approximately constant for all speeds for a given location along the track despite the large variation in the individual values for one rail. This would indicate that the variations were mostly transfers of load from one wheel to the other on the same axle. However, it was found that the individual

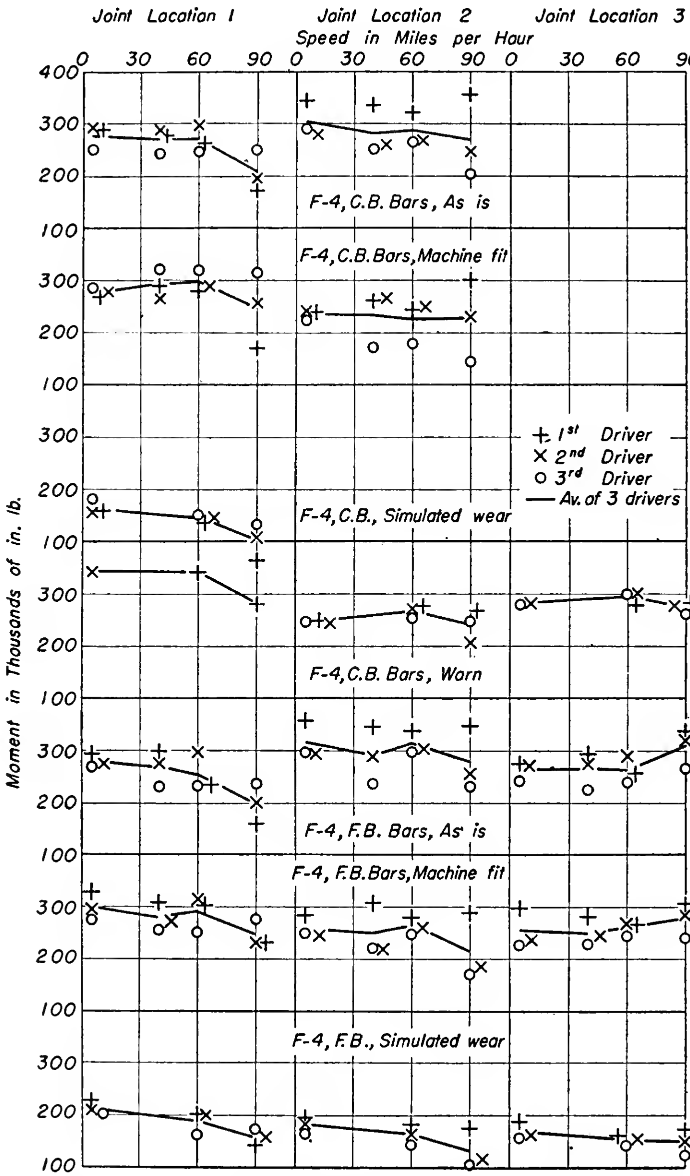


Fig. 34.—Relation between Speed and Bending Moment Developed with F–4 Rail Joints.

runs at a given location and given speed showed little variation, which indicates that the locomotive produced similar results under given conditions.

The new, unworn condition of the bars and rails, the excellence of surface, and the high quality of the support were undoubtedly a factor in minimizing effects of

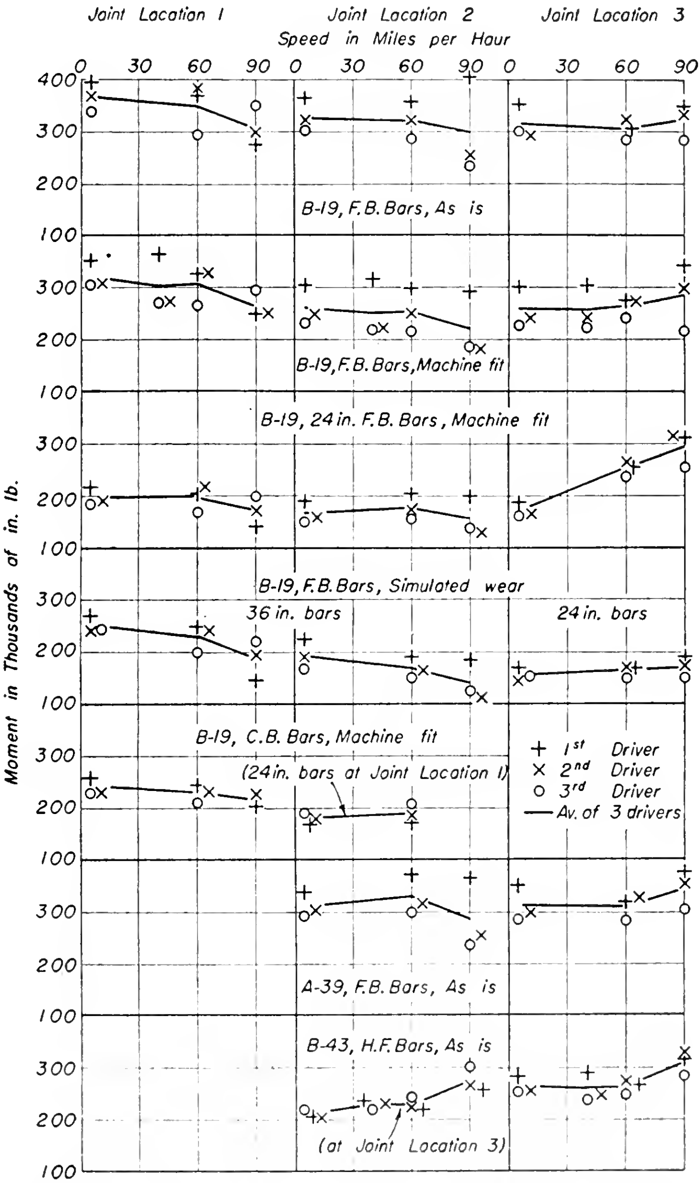


Fig. 35.—Relation between Speed and Bending Moment Developed with Several Types of Rail Joints.

speed, as was also the high bolt tension required in the joints to give satisfactory operation of some of the instruments.

Because of the conditions discussed above, the results for the higher speeds will be discussed only in a general way and comments will be made on illustrative examples.

A

An inspection of Figs. 34 and 35 shows that at joint locations 1 and 2 the average of the moments for the three wheels has a downward trend with increase of speed. At Joint Location 3 the average moment increases or shows little change. Joint Location 1 is the first test location the locomotive passed over and is on the right rail and Joint Location 2 is one-half rail length ahead on the left rail. Joint Location 3 is the last test location passed by the locomotive one rail length beyond Joint Location 1 and is also on the right rail. This decrease of moment at joint locations 1 and 2 with increase of speed should not be taken to indicate that a low value of moment exists all along the track. At places along the track other than the test locations the locomotive probably will act in a somewhat different manner, and the moments will have different relations to the speed. These other places may be some distance away, for at high speeds a complete oscillation or other movement of the locomotive or one of its parts will cover a considerable distance.

Some further comments may be made. The joint moments developed by the individual driving wheels at the higher speeds show a wide spread of magnitudes and a variety of manner of action even at one given joint location and with a given set of bars. There are some few high values of joint moment at the high speeds, about 400,000 in.-lb. Very frequently the first driving wheel develops the highest moment, and in such cases this occurs at all three of the joint locations. The variations in values at the higher speeds are doubtless due principally to the variations in the action of the locomotive. Conditions of the track along its length also enter into the variations, for different runs at a given speed usually give similar moments at one wheel. No systematic increase in stress or moment at the high speeds with the locomotive used was found, though the wide spread of values is an indication that values still higher than those recorded may be developed with more or less frequency. The outstanding result is the marked variation in the magnitude of the moments developed in the joints at the high speeds.

It should again be called to mind that in the case of the moments in the right and the left rail, the averages for the two rails at opposite points showed little effect of speed, yet some individual values in one rail or the other were considerably in excess of the average, as high as 500,000 in.-lb. An unduly low moment developed by a wheel at one location probably means an unduly high moment at some other location and the joint may thus be subject frequently to higher moments than the values shown in Figs. 34 and 35.

The moments shown for the several joints may be said to be moderate in magnitude in most instances, due probably to the very excellent condition of the joints and the support. Less favorable conditions, such as battered rail ends, were found to add appreciably to the moments developed and the variety of action shown may be expected to give increases of moment that will further tax the strength of the joint.

19. **Vertical and Longitudinal Movements Between Joint Bars and Rails.**— A purpose of the tests was to measure some of the vertical and longitudinal movements between the bars and the rail and learn how they change as the locomotive passes. The small movements that take place between the fishing surfaces are undoubtedly the cause of much of the wear, especially when the movements are accompanied by high bearing pressures. Movements between the rail and the bar also decrease the effectiveness of the joint in the track. The effect of speed on the magnitude of these movements and on the manner in which they varied has also been a subject of speculation. It has been felt that the higher speeds cause greater damage to the rail joints and that some of this damage might be through wear or impact effects from sudden movements in the joint.

The measurements that could be taken were limited by the number of gages available and the clearances. Four gages recorded the relative vertical movements between head of rail and top of bar at the rail ends and at each end of the bar, all for the outer bar. Two gages, one at each rail end, measured the relative longitudinal movement between the rail head and the mid-length of the outer bar. Views of these gages mounted on a joint bar in track are shown in Fig. 7. No gages were placed on the inner bar because of lack of clearance for the wheel flanges. It was not possible to mount gages for both vertical and longitudinal movement on the same joint, so the gages were alternated and additional sets of runs made to obtain values for all the test joints.

Unfortunately it was necessary to use a high bolt tension to restrain the rails from moving in the joint and thus to prevent damage to instruments and uncertainty in the records. This high bolt tension decreased the movements greatly and probably eliminated some of the speed effects that may be present, especially in badly worn or poorly fitting joints.

Typical records of the vertical movements for run No. 247 at five miles per hour are shown in Fig. 36. The joint had B–19 bars in "as is" condition at Joint Location 1 on the right rail. The records were made by oscillograph A and are numbered 1A to 6A from the bottom of the record. The square peaks at the extreme lower edge of the film made by the timing galvanometer are spaced at half-second intervals. The four gage positions (see Fig. 7) are designated as V_1, V_2, V_3 and V_4 and they are respectively the end of the bar on the leaving rail, the middle of the bar on the leaving rail, the middle of the bar on the receiving rail, and the end of the bar on the receiving rail. All positions are on the outer bar only, and V_1 is the first position passed by the locomotive. Record 1A is for position V_1, 2A for V_2, 3A for V_3 and 4A for V_4. The fifth record, 5A, is the stress at gage line C of the outer bar and its peaks locate the position of the wheels with respect to the mid-length of the joint. Since the three driving wheels were spaced exactly ten feet apart, distances may readily be scaled off along the record. The sixth record is the stress at gage line C on the inner bar at joint location 3; this is a rail length farther along the track than the joint on which the rest of the records were taken and is also on the right rail. Similar records for run No. 245 on the same joint at 90 miles per hour are shown in Fig. 36. The timing record at the bottom gives one-sixtieth second intervals.

Some comments may be made on the shape and characteristics of the records. The two films shown in Fig. 36 were taken on runs for the same joint at 5 miles per hour and at 90 miles per hour. Some of the records for the movements at the various gage positions are seen to be somewhat similar in shape to the stress records, indicating that generally these movements begin to take place as the wheel approaches the gage and is yet some distance away. The maximum or peak values occur with the wheel over the gage and then the movement decreases as the wheel leaves the gage position. The wheel position along the records may be determined by record 5A whose peaks show when the wheel is at mid-length of the joint.

In some cases part of the vertical movement takes place with considerable rapidity. An example of this may be seen at gage position V_3 (record 3A in Fig. 36) at 90 miles per hour. At this gage the movement at the receiving rail end shows a very quick increase in magnitude as the wheels pass the mid-length of the joint. This sudden increase probably takes place as the wheel strikes the receiving rail end. The time interval over which this rapid change in the movement magnitude takes place is very small at 90 miles per hour, probably approaching 0.001 of a second. The decrease in magnitude as the wheel leaves the mid-length of the joint is at a relatively slower rate. The rapid rate of increase of movement at the receiving rail end may be equivalent to an impact effect that possibly is a cause of the increased wear generally observed at the receiving rail end on both rail surface and bar fishing surface. The whole cycle of the vertical movement changes from a zero magnitude to a maximum magnitude and again to zero in 0.01 to 0.02 sec. while the locomotive is covering a distance of about 15 to 30 in. when running at 90 miles per hour.

The algebraic signs on the records at the right side of the figures indicate the kind of movement or stress. A plus sign means an increase in distance or a tensile stress and a

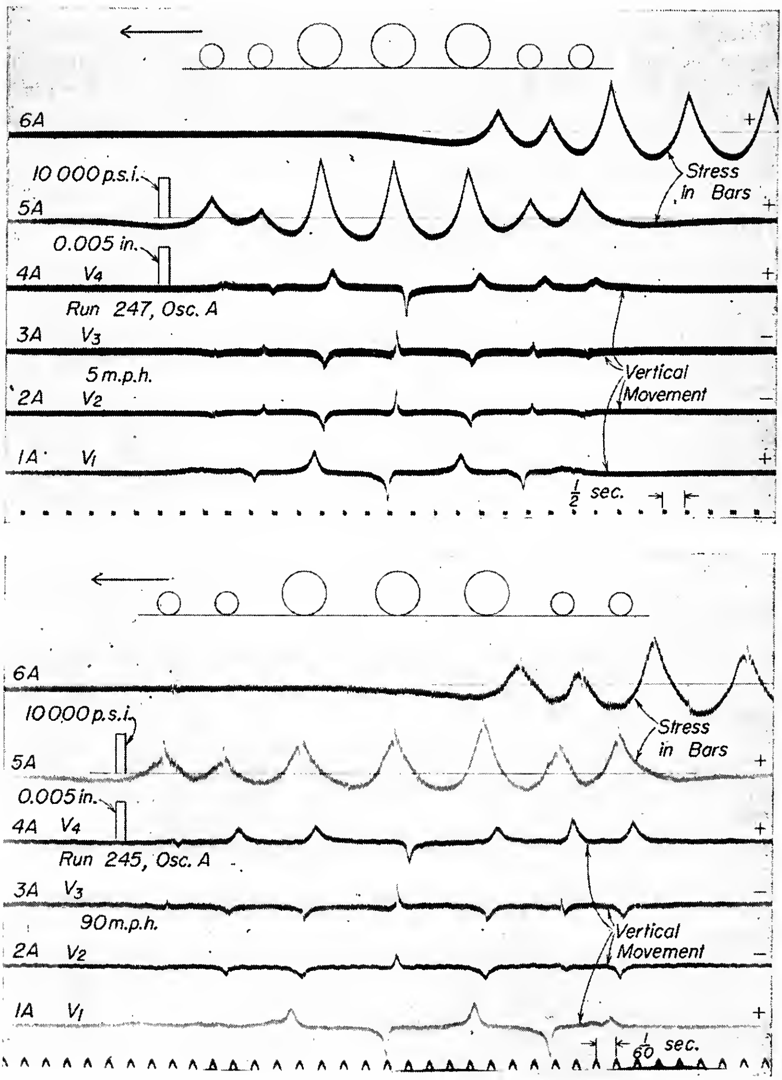


Fig. 36.—Typical Records of Vertical Movement between Bar and Rail Head at 5 and 90 Miles per Hour—Also Stress in Bars.

negative sign the opposite. Previous experience in static field tests and laboratory tests had indicated that with the load at the mid-length of the joint there should be a decrease in the distance or space between the top of the bar and the rail head at the rail end and an increase at the ends of the bars. The application of load at the bar ends with well fitting bars in these previous tests did not produce much movement at the point of application of the load.

Inspection of the records shows several points at variance with this previous experience. An outstanding difference is the direction of the vertical movement under the middle driving wheel as compared to the other wheels, given in Fig. 36. In most cases in these records and in the other records taken, the middle driving wheel produces a movement opposite in direction to that of the other wheels. There are some exceptions to this statement but in general the middle driving wheel produces a negative movement or decrease in distance for all gage positions whether at the bar ends or the rail ends at the time the wheel is over the gage and the other wheels cause a positive movement or increase of distance between bar and rail. It can also be noted from the records that there is little if any movement at the ends of the bar when the wheel is at the middle of the joint. The vertical movements shown in the records are of the order of 0.002 in. or less, as can be seen from the scales given. The high bolt tension and good fit of most of the bars tested tended to minimize the movements.

The movement produced by the second or middle driving wheel, though at variance with most of the other wheels is more nearly in agreement with the results expected. A number of possibilities as to the cause of these differences between the movements at the various wheels were investigated both at the time of the tests and in correlating the results but no definite factor has been proven to cause them. The instrumental equipment was checked at the time of the tests for direction of deflection and possible electrical or magnetic differences and static tests were also made. A difficulty encountered in correlating these differences in the results was that only vertical movements were measured on a given joint for a given set of runs, except the one stress recorded for location of wheel position.

A possible explanation that may be offered but has not been proved is that the differences referred to above are caused by the difference in the bearing of the wheel on the top of rail. The tire of the middle driving wheel was flangeless and all other tires were flanged and coned. The blind tire will tend to give bearing at the middle of the rail head or possibly outside the middle with the rail canted, and the coned tires generally have a bearing somewhat inside the middle of the head even with the cant of the rail of 1 in 40. This eccentricity of bearing may produce enough tilting and twisting of the rail head to cause a movement comparable to or even greater than the small movements resulting from the action of the joint. There was no way of checking this possibility from the data of the tests. It would have been especially desirable to have readings also on the inner bar to determine whether the rail head did tilt but clearance did not permit the application of gages on the inner bar.

The vertical movements showed little or no change with increase of speed, and so it is not deemed necessary to show the results for all speeds. The values of vertical movement for the three wheels at the four gage lines for a speed of five miles per hour and for the various kinds and conditions of joints are shown in Fig. 37. The values are the average of all the runs and the three joint locations. It was found that, with a few exceptions, there was little difference at the several locations.

The values plotted are the maximum movements regardless of the position of the wheel rather than values when the wheel was over the middle of the joint. The maximum values normally occurred when the wheel was over the gage. Thus the peaks of the values for V_1 and V_4 are seen in Fig. 36 to be displaced along the record by the length of the joint to the scale of the figure. Since the scale in this direction is relatively small this displacement is not very noticeable.

It may be noted from Fig. 37 that the values shown are small in magnitude, few being over 0.003 in., except with the simulated wear joints and one of the head-free joints. These values are similar in amount to movements measured in static tests previously reported with tight bolts and well fitting bars. Attention should again be called however, to the manner of the movements as shown by the sign of the plotted values. As discussed for the records shown in Fig. 36 the middle or second driver is seen to give a closing movement in almost all tests and the first and third drivers generally give

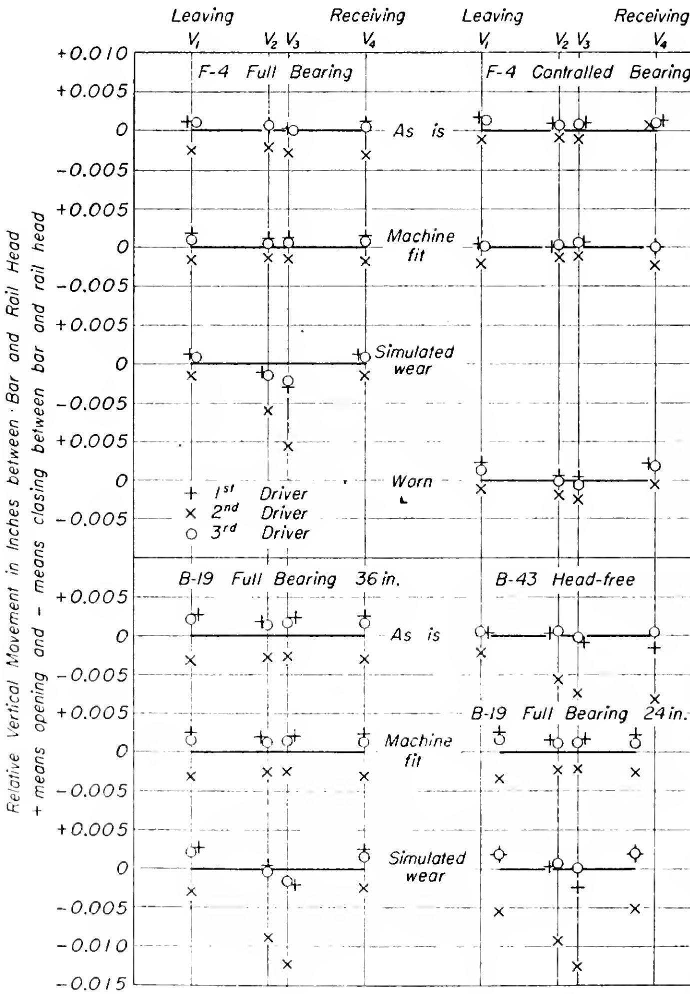


Fig. 37.—Relative Vertical Movement between Bar and Rail Head for Various Types and Conditions of Rail Joints at 5 Miles per Hour.

either a small opening movement or a negligible movement. Some few values are at variance with those statements but not in any large amount and in some cases it was difficult to determine the way in which the records should be interpreted.

The joints having bars simulating wear are seen to have considerably larger closing (negative) movements under the second driver at the middle of the bar length (positions V_2 and V_3) and smaller closing movements under the first and third drivers. The movements at the ends of the bars do not appear to be changed much by the simulated wear condition, as might be expected because no change was made in the fit at the ends. The movements are also greater at the receiving rail end than at the leaving rail end, probably the result of the longer slope on the ground-out portion of the bar at the receiving rail end.

The F–4 bars with controlled bearing in the worn condition are seen to have small vertical movements showing that the wear on these bars was not large.

Two B–43 joints were tested at Joint Location 3 and the average of the results is plotted in Fig. 37. The vertical movements measured for the two joints differed somewhat from each other at corresponding gage lines. These differences were possibly due to the fact that a locomotive other than the regular locomotive was used for the tests on one of the joints. The second driving wheel of the regular locomotive produced markedly large movements (about 0.010 in.) similar in magnitude to those found with the simulated wear joints.

The necessity for using high bolt tension in the joints and the excellence of fit of the test joints available for test detracted from the value of the results as a basis for judging the effects of some of the factors entering into the action of joint bars. Tests on some of the types and conditions of bars after a portion of their service life had been passed would probably be more informative and show results more characteristic of the several factors.

Little evidence was found of any effect of speed, though the form of the records showed that at the higher speeds some of the movements take place with great rapidity.

The relative longitudinal movement of the two rail ends with respect to the upper fishing surface of the outer joint bar at mid-length was measured by two specially designed magnetic strain gages. The two gages were attached to the rail ends and the middle portion of the outer joint bars as shown in Fig. 7 to indicate the relative longitudinal movement that took place between the rail ends and the mid-length of the joint bar. Lack of clearance would not permit gages to be applied to the inner bar so all measurements were on the outer bar.

The longitudinal movements take place between the fishing surfaces of the bar and rail because of the differences in the flexural curvature of the rail and the bars along the length of the joint when under load and the differences in magnitude of the longitudinal strains developed at the fishing surfaces of the bars and the rails. The friction between the surfaces is insufficient to prevent slip from occurring. At the rail ends where this slip is a maximum there are high bearing pressures due to the development of moment in the joint. It has been demonstrated by Gough and Clenshaw[10] that even a very minute slip will produce wear when accompanied by high bearing pressures. Since the rail flexural stress at the rail ends is zero and that in the bars is a maximum, we may expect a relatively large slip at the mid-length of the joint for this reason alone. The effect of speed on this action was unknown and a purpose of the tests was to see

[10] "The Testing of Engineering Materials" by H. J. Gough, M.B.E., D.Sc., F.R.S. and W. J. Clenshaw, B.Sc., of the Engineering Department, National Physical Laboratory, Teddington, England. (Reprinted from the Transactions of the Institute of Marine Engineers)

if there were any differences in the action at the higher speeds that would produce increased wear or deterioration of the joint.

The picture of the action of the longitudinal movement or slip in the joint as a whole cannot be obtained from the results from two gages at the rail ends, but a number of laboratory tests made previously show that the slip takes place along the fishing surfaces of the bars. Coincidence of the larger values of slip with the locations where high bearing pressures have been found to occur should determine areas of greatest wear. The slip measured along the top fishing surface of a 36-in. 105-lb. New York Central rail joint and a 24-in. 90-lb. Illinois Central rail joint is shown in Fig. 38. These joints were tested in the laboratory. The New York Central joint was loaded with

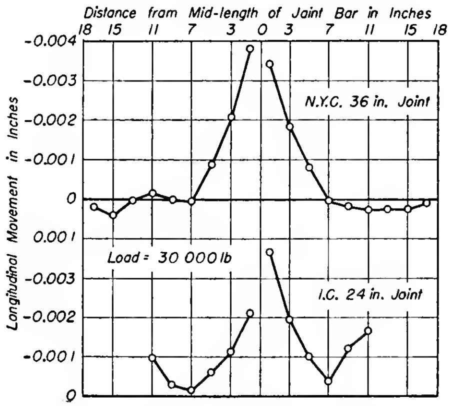


Fig. 38.—Relative Longitudinal Movement between Bar and Rail Head at Various Distances along a Joint in Laboratory Tests.

30,000 lb. applied at the middle of a 32-in. span. The Illinois Central joint had two loads of 30,000 lb. applied at a distance of 16 in. from the supports of a 68-in. span. The ordinates for these diagrams are slip (longitudinal movement) for a point on the rail fishing surface with respect to a point on the bar fishing surface immediately below. The abscissas are distance along the length of the joint. Values of the slip are shown at every two-inch interval. A negative value of slip indicates movement of the rail end toward the mid-length of the bar and a positive value indicates movement away from mid-length of the bar.

It is seen from Fig. 38 that the slip or relative longitudinal movement at the top fishing surfaces at the mid-length of the joint approached a value of 0.004 in. and is negative for both rail ends and for both tests. This location is the approximate location of the magnetic strain gages in the field tests. At four or five inches back from mid-length the slip has decreased considerably and in some cases it reverses direction. The Illinois Central bars were well worn and the fit was apparently not as uniform as that of the New York Central bars and the results are not as uniform along the length of the joint.

Two representative films with records of longitudinal movement taken at 5 and 90 miles are shown in Fig. 39. Both are for a B–19, full bearing, "as is", 36-in. joint. The records from bottom to top are numbered 1B to 6B inclusive. The record at the extreme bottom edge of the film is the timing record and the peaks come at half-second intervals for the run at 5 miles per hour and at 1/60-sec. intervals for the run at 90 miles per hour. Record 1B is for gage position L5, the longitudinal movement gage on the receiving rail end, and record 2B is for gage position L6, the longitudinal movement gage on the leaving rail. Thus the wheels pass over position L6 (record 2B) before passing L5 (record 1B). Record 3B is the stress at the mid-length of the same joint on the bottom flange of the outer bar and its peaks indicate the position of the wheel with respect to the mid-length. As spacing between driving wheels is ten feet, this distance gives a

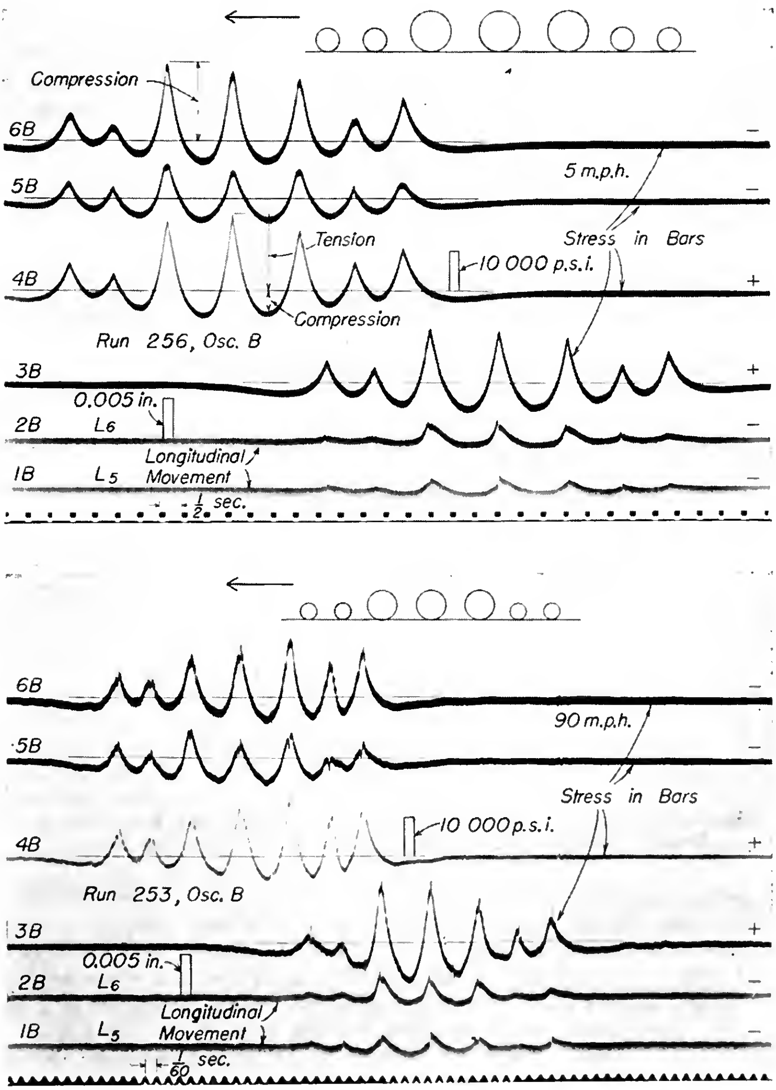
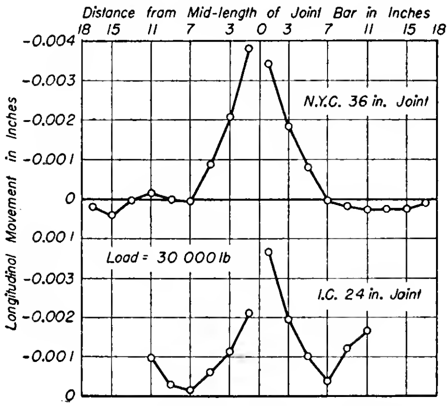


Fig. 39.—Typical Records of Longitudinal Movement between Bar and Rail Head at 5 and 90 Miles per Hour—Also Stress in Bars.

if there were any differences in the action at the higher speeds that would produce increased wear or deterioration of the joint.

The picture of the action of the longitudinal movement or slip in the joint as a whole cannot be obtained from the results from two gages at the rail ends, but a number of laboratory tests made previously show that the slip takes place along the fishing surfaces of the bars. Coincidence of the larger values of slip with the locations where high bearing pressures have been found to occur should determine areas of greatest wear. The slip measured along the top fishing surface of a 36-in. 105-lb. New York Central rail joint and a 24-in. 90-lb. Illinois Central rail joint is shown in Fig. 38. These joints were tested in the laboratory. The New York Central joint was loaded with



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Two representative films with records of longitudinal movement taken at 5 and 90 miles are shown in Fig. 39. Both are for a B–19, full bearing, "as is", 36-in. joint. The records from bottom to top are numbered 1B to 6B inclusive. The record at the extreme bottom edge of the film is the timing record and the peaks come at half-second intervals for the run at 5 miles per hour and at 1/60-sec. intervals for the run at 90 miles per hour. Record 1B is for gage position L5, the longitudinal movement gage on the receiving rail end, and record 2B is for gage position L6, the longitudinal movement gage on the leaving rail. Thus the wheels pass over position L6 (record 2B) before passing L5 (record 1B). Record 3B is the stress at the mid-length of the same joint on the bottom flange of the outer bar and its peaks indicate the position of the wheel with respect to the mid-length. As spacing between driving wheels is ten feet, this distance gives a

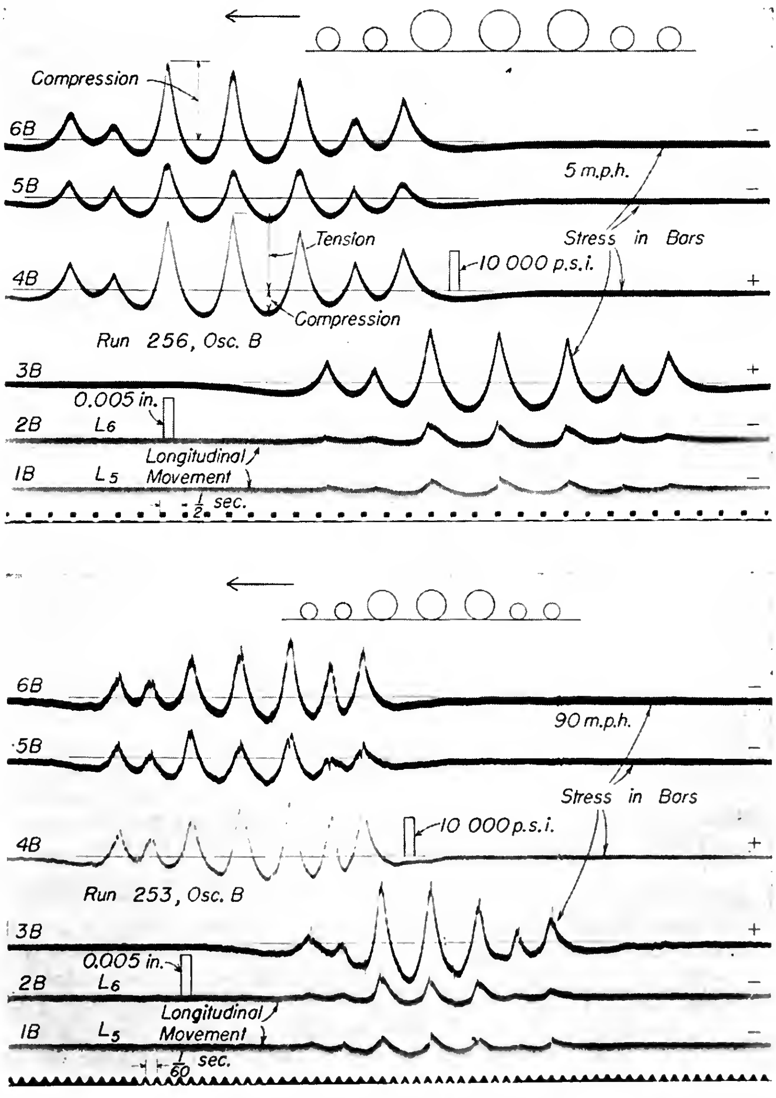

Fig. 39.—Typical Records of Longitudinal Movement between Bar and Rail Head at 5 and 90 Miles per Hour—Also Stress in Bars.

means of obtaining the scale of distance along the film. The other records (4B, 5B and 6B) are stresses on a joint on the same rail one rail length east. The vertical scales of the records are given on the left and the directions or signs on the right. A negative sign denotes movement of the rail end toward the mid-length of the bar and compressive stress and a positive sign the opposite.

The records of longitudinal movement or slip between fishing surfaces of rail and bar are similar in shape to the stress records; they show sharp peaks under the wheel load and reversals in direction of movement at points between the wheels and have a rounded form. The movement begins at the time the joint starts to take stress, even when the wheel is some distance from the joint, and it reaches a peak value when the wheel is over the mid-length of the joint. At this time there is a sudden change in the magnitude of the movement that is somewhat similar to the very rapid change found

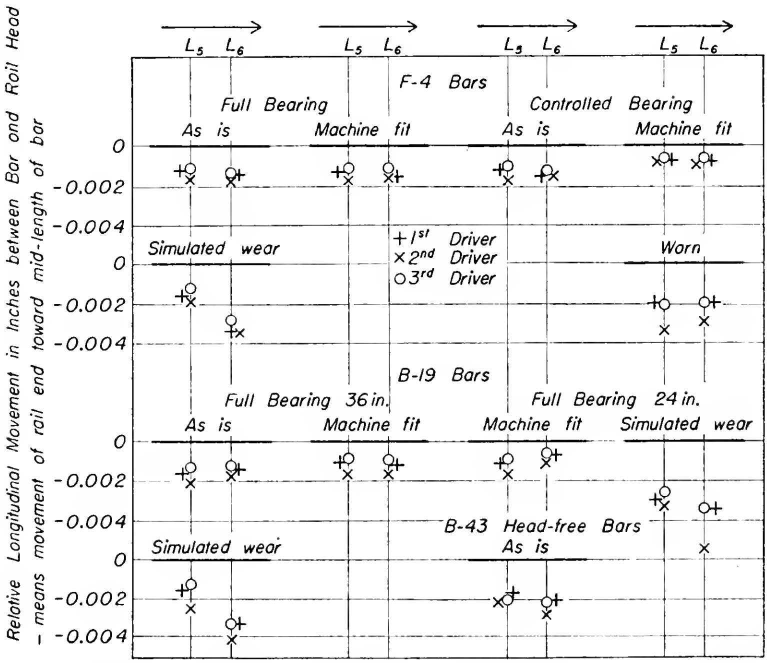

Fig. 40.—Relative Longitudinal Movement between Bar and Rail Head for Various Types and Conditions of Rail Joints at 5 Miles per Hour.

in the vertical movement records. On the leaving rail the record (record 2B) rises to a peak value, drops sharply, and then rises again to a lower peak value. The drop probably occurs as the rail gap is crossed. The record on the receiving rail (record 1B) has a similar form except that the rise after the sharp drop-off goes to a greater height than the initial rise. Also the sharp drop in the movement records corresponds to a similar drop in the stress record (record 3B). This variation in the stress record is not very definite in the reproduction but is very definite in the original record for the run at 90 miles per hour.

The average longitudinal movements for a speed of five miles per hour for all the tests and for three driving wheels are shown in Fig. 40. The results for the higher speeds are not shown for the reason that little variation with speed was found. As the values at the three locations differ little, the average value is plotted in the figure.

From the figure it may be seen that the magnitude of all the longitudinal movements is relatively small. The negative sign indicates a movement of the rail ends toward the mid-length of the joint. Most of the values are 0.002 in. or less except in the case of the worn bars and those with simulated wear. The latter two reach a maximum value of about 0.004 in. The worn joints also show somewhat greater movement than the "as is" or the machine fit joints. A characteristic of the data shown is that the second driving wheel (flangeless) again is at variance with the other two wheels. In this case the second wheel gives somewhat greater movement but not markedly so. The magnitudes of all the longitudinal movements are small and the variation for the several driving wheels is probably of little importance. The variation was nearly uniform for all joint locations. The values are somewhat smaller than were found in the laboratory tests. This difference is probably a result of the higher bolt tension and excellent fit in the tests in track. The higher bolt tension may be expected to develop greater frictional resistance to longitudinal movement.

The results show the presence of an appreciable amount of movement between bar and rail at the rail ends, which of course are positions of high bearing pressure. The movement is sufficient to produce wear and the amount of the movement will increase as the bolt tension drops off and the bars wear. Movements of this nature are undoubtedly the source of much of the wear that produces poor fit and low joints. Even extremely minute amounts of tangential slip were found by Gough to cause contact corrosion and formation of oxide debris. This action occurs even when the surfaces are clean or oiled. No corrosion or much wear took place unless slip was present. The tests of Gough used rather small contact pressures compared with what may be expected in rail joints.

The excellent fit and the high bolt tension may have partially defeated one purpose of the tests in that the effects of speed were minimized. The form of the records and their magnitude showed little change with the higher speeds. As in the case of the vertical movements a part of the longitudinal movement was observed to occur in a very short time. Just what effect this rapidity of movement may have on the wear is not known.

20. **Recapitulation and General Discussion.**—Comments and discussion will now be made in an effort to bring together some of the meanings and findings in the tests of the rail joints in track.

It is well to visualize the position of the principal forces acting between the rail and the joint bars. For positive moment (downward bending) (see Fig. 21) the head of the rail presses downward upon the top fishing surface of the bar for a short distance near the ends of both rails, perhaps 1 to 2 in. just back of the rail end for both rails, with the centroid of the loads applied at perhaps 0.5 in. to 1.5 in. either way from mid-length of bar, and with the area of the pressure contact dependent upon fit between bar and rail. In acting as a beam a closely fitting bar has two or generally four vertical bearing reactions between its bottom fishing surface and the top of the rail base of the two rails. One reaction always extends for some distance along the bar near the end, and the second reaction for each half of a bar is developed for a short distance outside of the position of the vertical load applied by the head of the rail. For a given wheel load and given tie supports (the magnitude of the bending moment developed depending in a complex manner upon the wheel load and the tie supports and upon the action of the rail joint), the magnitude of the two reactions for each half-length of bar will depend upon fit and stiffness of bar and particularly upon the position of the interior reactions. Likewise the load applied by the rail head is largely influenced by the magnitude of this interior reaction. As shown in Article 11 "Rail Joints and Their Action" the magnitude of this pressure applied to the bar by each rail head may have as great a calculated pressure as 70,000 lb. for a wheel load of 33,000 lb. For the negative bending moment generally developed in front of and behind a wheel the position of the loads and reactions developed between rail and bar will be reversed. The values of the negative bending moment, as found in tests of track, may vary say from 30 to 60 percent of the amount of the positive moment developed by the given wheel, depending upon the wheel spacing and conditions of the track.

The bearing pressures and reaction forces applied to the joint bars by the rail when the joint carries load introduce complications into the measurement of the structural action of the bars. The bearing forces and reactions applied at certain positions on the fishing surfaces and their variable concentration produce deformations in the metal other than the longitudinal strains considered in the analysis of ordinary bending action of beams, particularly interfering with the assumption that the bending stress varies directly with the distance from the neutral axis. The effect or influence of the additional forces on the deformation of the bars at gage lines near the rail ends was so indeterminate as to make it impracticable to attack the problem by theoretical analysis. Instead, laboratory tests were made on joints with the different types and conditions of bar by applying known loads and bending moments and then determining by calculation from the analytical formula and the stresses measured at the gage lines the value of the empirical constant by which the moment so calculated should be multiplied to get the moment actually applied. This constant, called the conversion ratio, was determined for each type and condition of bar for use with the particular position of the gage lines used in the field tests. Although the method is empirical, it is believed that as applied to the track tests the resulting values of the moment so found are sufficiently close to actual values to warrant their use in making comparison of the action of the various types of joint bars.

The effectiveness of a rail joint may be said to depend upon (a) the excellence of fit between bar and rail at critical points along the length of bar; (b) the stiffness of the bars as governed by the moment of inertia of the section of the bar with reference to the neutral axis actually obtained in track service; (c) a sufficiently low maximum stress to keep below an allowable working stress chosen with respect to fatigue resistance for the frequencies of driving wheel loads, heavy truck wheel loads, and ordinary truck wheel loads, respectively; and (d) the deflection of the rail joint as a whole as compared with the full rail. Any comparison of rail joints will necessarily assume similar bearing resistances to depression when the track is tamped and fitted to the actual camber of the joints.

For these track tests the relative magnitudes of the moments developed in the joint bars at mid-length, as compared with the moment developed in the full rail away from the joint (for convenience called the joint moment ratio) will make a good measure of the effectiveness of the joint including its relative stiffness. As in the tests no re-tamping was done after installation of different pairs of joint bars it will be necessary to consider the camber of the joint in making comparisons of the various joints, and this can be done only in a general way.

First, it should be stated that the new bars used in the track tests (F–4, B–19, A–39 and B–43) were all well-fitting bars. Probably all bars fitted the rails more closely than do the usual run of joint bars when new. Nearly all these bars gave a joint camber in the neighborhood of + 0.010 in. in 32 in., which was probably more than the camber of the original joints when the track was tamped last. With the great stiffness of the rail supports in this track (high modulus of elasticity of rail support) higher camber in the new test joints added appreciably to the magnitude of the moment developed by the wheel loads.

It is evident from the data that for comparable conditions of tests the heavy and stiff symmetrical joint bar B–19 in "as is" condition develops a higher bending moment and a greater joint moment ratio than the somewhat lighter and less stiff symmetrical F–4 joint bar (also in "as is" condition), the two kinds of joints having joint moment ratios of essentially 0.90 and 0.80, respectively. Even with the development of a greater moment, the maximum stresses are less in the B–19 bar than in the F–4 bar, comparatively about 25,000 and 35,000 lb. per sq. in. Thus the heavier section develops a greater moment with a smaller stress and also distributes the load better among the ties because of its greater stiffness. As the joint camber with both types of bars was presumably greater than that for which the track was last tamped, the ratios given (0.90 and 0.80) are obviously higher than if the track had been re-tamped. For well tamped track in regular condition the values of the joint moment ratio for these two types of joint may be expected to be, say, 0.85 and 0.75, respectively. The values 0.90 and 0.80 however, may be used for comparison under comparable conditions.

The machine fit bars doubtless gave even better fit than the "as is" bars and would be expected to give smaller depression and greater moments. However, as the straighter bars gave decreased joint camber and thus applied greater pressure to the joint ties, the advantages of better fit were necessarily nullified, at least in part, and no show of gain over "as is" bars could be expected in the tests.

The heavy A–39 angle bars used with the same high bolt tension maintained in all the joints (about 30,000 lb.) and having about the same joint camber as the B–19 joints show a joint moment ratio of 0.85. Obviously the high bolt tension required for protection of the gages was useful in holding the neutral axis close to a horizontal position. Although this angle bar has a moment of inertia about a horizontal axis nearly 20 percent greater than the B–19 bars, its effectiveness will drop off considerably as wear progresses or bolt tension drops.

The joints with B–43 head-free bars with joint camber similar to other joints with bars in "as is" condition developed less moment and gave a joint moment ratio of 0.65. They gave somewhat greater vertical and longitudinal movements between bar and rail in these tests, as this type of joint had given in previous laboratory tests. The deflections of the B–43 joints in the laboratory tests were also greater than other joints.

A comparison of the tests with full bearing and with controlled bearing shows results that are similar with respect to moments and vertical movements. As made, the length of the bearing at the middle of the bars with controlled bearing, especially that at the bottom fishing surface, was greater than is desirable to secure decreased bearing pressures. Laboratory tests indicate that joints with controlled bearing are as stiff as those with full bearing. It is not known what difference in wear would occur.

The seven joints with bars ground to simulate wear (0.05 in. at top in middle, the depression running out at 4 and 6 in. away) developed markedly lower moments, and the joint moment ratios averaged about 0.50 and 0.60 for the F–4 and B–19 joints, respectively. The vertical camber of these joints ranged from –0.006 to –0.016 in. One of these joints in a laboratory test with a span of 48 in. gave a relatively high deflection. In the track a greater load was therefore transmitted directly to the joint ties. Re-tamping such joints has little effectiveness.

The moments developed in the three F–4 joints having worn bars taken from track are not particularly different from the joints with new bars and the same joint camber.

The large deflection in the one laboratory test indicates that in re-tamped track undue pressure would be transmitted to the ties at the joint and thus that the moment developed would be smaller than that developed with the new bars.

The smaller bending moments found in joints having bars of 24-in. length, as compared with similar bars of 36-in. length, are believed to be due to the effect of high compression developed in the rails at the time by high temperatures. In view of earlier tests on long and short joints, the differences in the bending moments should not be taken as establishing a superiority in the longer length in respect to ability of new bars to carry bending moment. Further tests on joints in track should be made under known uniform conditions. It should be kept in mind too that these tests are with new bars, and that little is known of relative wear with different lengths of bar. Service tests may be expected to give information of value on this point.

Due to the variability in the transfer of load from one rail to the other at the higher speeds, definite conclusions with respect to the effect of speed for the several types and conditions of joint bars can not be stated. With the variable load came occasional high stresses.

The vertical and longitudinal movements between bars and rail were generally small, being 0.002 to 0.003 in. for the joints with "as is" and machine fit bars. One type of joint, the B–43 head-free, had somewhat greater movement than the other joints. This result had been observed previously in laboratory tests of the same kind of joint.[11] The joints with simulated wear gave greatly increased longitudinal and vertical movements at mid-length where the top of the bar had been ground off. The joints worn in service (F–4 CB) gave vertical movements similar to the "as is" joints but the longitudinal movements were somewhat greater. These joints were only moderately worn.

Little or no increase in the vertical and longitudinal movements with increase in speed was found even with bars having simulated wear. This lack of increase was probably in part prevented by the general excellence of fit between bars and rail and the high bolt tension. However, in some cases, a considerable part of the total vertical and longitudinal movement was found to take place very quickly, probably an impact effect due to the wheel crossing the rail gap, which may be a source of joint wear. As shown by the records the vertical and longitudinal movements generally began to take place while the wheel was some distance from the rail ends thus preventing the occurrence of "slap" or "flip" of the joint that has been suggested as a possible cause of joint wear. A markedly worn joint possibly would have given different results in this respect and tests should be made on joints and track in deteriorated condition.

It is believed that even the small amounts of longitudinal movement measured are an important source of joint wear because of the high bearing pressures developed at the locations where the greatest movements take place. The tests of Gough and Clenshaw corroborate this conclusion.

It may also be suggested that any modification in the design of the joint that decreases the stress in the bar at its middle, like a heavier or stiffer bar or a greater fishing height accompanying the use of a higher rail, will decrease longitudinal movements between bar and rail and thus probably decrease joint wear.

All the measurements taken on joint bars and rail, except in the tests with rail batter and the flat spot on the wheel, showed an almost complete absence of general average speed effect such as had been observed in earlier tests of track and rolling stock.

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[11] Sixth Progress Report, AREA Proceedings, Vol. 35, 1934, Article 7e, "Norfolk & Western Continuous and Head-free Continuous Rail joints for 130-lb. P.S. Rail."

The larger variations in moment observed in the joints, as well as in the rail, were judged to be due to transfers of load between wheels on the same axle of the locomotive.

The deflection of the various rail joints obtained in the laboratory tests and shown in Fig. 29 may be considered to give an indication of the relative stiffness of the joints and their ability to distribute load to the ties.

V. Miscellaneous Tests

21. **Effect of Flat Wheels.**—Wheels of railway equipment develop flat spots in the tread from various causes that need not be discussed here. The presence of such flat spots is a source of expense, annoyance, and in some cases even danger. Writers have developed analyses on the effect of flat spots and variations in wheel and track surface upon depression and stress in rail, and some experimental work has been done. The assumptions used in analyses have not generally conformed closely to the physical conditions existing. In the experimental work the inability of the mechanical type of stress recorder to withstand the severe impact caused by a flat spot and to record clearly and accurately the rapid stress variation has retarded progress in the investigation of the problem. The magnetic strain gage used for the tests here reported overcame many of the instrumental difficulties encountered previously and gave records that in most respects may be considered satisfactory. Records of the depression of the rail were also obtained simultaneously with the stress records, and these add value to the data.

Because of lack of familiarity at the time of the tests with the form and magnitude of records obtainable, the test records are not as fully satisfactory as they could now be made. Higher film speeds and provision for more clear space would have shown more clearly the exact form of the record without interference with other records on the film.

A discussion and analysis of the effect of a low spot in a rail or a flat spot on a wheel on the depression may be found in Timoshenko's "Applied Elasticity", page 334, and in "Vibration Problems in Engineering" (second edition), page 107. This analysis has been used and discussed by H. R. Thomas and N. H. Roy in Appendix B of the "Fourth Progress Report of the Joint Investigation of Fissures in Railroad Rails".[12] A special method for calculating the effects of irregularities in wheel and track surfaces of shapes that cannot be expressed in convenient form analytically is included in this latter report. Various examples are calculated and there are discussions of applications of the methods of analysis and of the validity of the assumptions.

The analyses by Timoshenko and by Thomas and Roy determine the depression of the wheel and rail produced by the vertical movements of the mass (the wheel and the unsprung weight incidental to it) due to an assumed irregularity in the wheel or the rail surface. The rail and its support are considered as equivalent to an elastic spring. The wheel is assumed to maintain contact with the rail at all times and the inertia of the rail and its support is neglected. The solutions require that the track act as a spring in tension at times, but the effect of the superimposed static wheel load will generally be sufficient so that the track will not actually rise above its unloaded position.

A modification of the analysis of Timoshenko was made, for the purposes of this report, to determine the effect which the car spring will have on the action of the vibrating system and to learn whether this effect is of importance. Because of limitations of space the derivation of the modified solution will not be given; it follows standard methods conforming to the assumptions of the problem. The upper end of the spring was assumed to be fixed, an assumption not greatly in error as long as oscillations

[12] AREA Proceedings, Vol. 39, 1938, page 807.

of the car body do not develop. The shape of the flat spot is the form used by Timoshenko. This shape is not greatly different from the usual irregularities present in wheels and track. The applicability of all these analyses is limited and while the one here reported probably offers a closer approach to the true conditions for certain cases it still has some of the defects of the others.

The shape of the flat spot or the low spot is assumed in the analysis to have the form given by the expression, $h \sin^2 \frac{\pi}{T_1} t$, where h is the maximum depth of the spot, $T_1 = \frac{l}{v}$ where v is the velocity of the car and l the length of the spot, and t is the elapsed time at any instant from the initial contact with the flat or low spot. The ratio $\frac{t}{T_1}$ corresponds to the distance the wheel has traveled along the flat spot at any instant expressed in terms of the full length of the spot. This curve is horizontal at the two ends, a condition likely to occur in track.

By the modified analysis the deflection or depression of the rail, Δ, due to the flat spot or low spot (or high spot) of the assumed form was found to be

$$\Delta = \frac{h}{2}\left[\left(\frac{T^2}{T_2^2} - 1\right) - \left(\frac{T^2}{T_2^2} + \frac{T_1^2 T^2}{T_2^2(T^2 - T_1^2)}\right)\cos\frac{2\pi t}{T} + \left(1 + \frac{T_1^2 T^2}{T_2^2(T^2 - T_1^2)}\right)\cos\frac{2\pi t}{T_1}\right] \quad (74)$$

The terms T, T_1, and T_2 represent natural periods of the system and are given by the following expressions:

$T = 2\pi\sqrt{\frac{W}{g(k_1 + k_2)}}$ = the natural period of the unsprung weight W, under the action of the track spring of stiffness k_1 and the car spring of stiffness k_2, g being the constant acceleration of gravity.

$T_1 = \frac{l}{v}$ = the time required to cross the spot.

$T_2 = 2\pi\sqrt{\frac{W}{g\,k_1}}$ = the natural period of the unsprung weight W, considering only the action of the track spring of stiffness k_1.

The solution given for Δ represents the added deflection of the rail due to the flat spot. Since the track is assumed to be an elastic spring the load or force on the track will be proportional to this deflection and the moment and stress at the point of application of the load will also be proportional to the deflection. The spring constant for the track is, of course, calculated on the basis of a single load on the track.

The usual flat spot or low spot is of relatively short length and the period of time required to cross it is correspondingly small. The flat spots used in the tests were about 4 in. in length and 0.11 to 0.13 in. in depth. The two flat spots were located directly opposite each other on the wheels of the third axle of the heavy car. The average wheel load was 26,500 lb. Contours of the two flat spots are plotted as full lines in Fig. 41. The ordinates are the variation of the spot from a true circular curve of the wheel diameter. The broken line curve gives for comparison a flat spot of the shape assumed in the analysis having approximately the same length and maximum depth as the actual spots. The analytical curve is seen to be similar to the actual flat spots.

The maximum speed of the test runs was limited to 30 miles per hour because the wheels had been turned down in service until the diameter was reduced from the usual 33 in. to 30½ in. and the resulting thickness of rim was considered insufficient for higher speeds. The noise of the impact was very great as the wheel ran along the track. The minimum speed was 11 miles per hour. At the time of the tests this range was

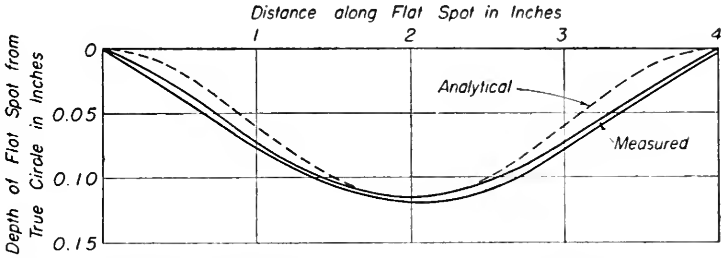

Fig. 41.—Profiles of Flat Spots on the Two Wheels of Heavy Car—Ordinates Measured from True Circle—Also Assumed Analytical Curve.

thought to include the speed for maximum analytical effect. Later calculations showed that the maximum analytical effect with such a short flat spot comes at about five miles per hour, so in this respect the data are deficient for comparison with the analysis.

Slipping the wheels on an oiled spot enable the flat spot to be brought nearly over the gage. For the various runs the longitudinal distance between the gage and the contact of the flat spot with the rail averaged three inches with a maximum distance of six inches. A still closer position would have been advantageous, for these distances are large compared with the length of the flat spot and will influence the magnitude of the records. It should be borne in mind that at only one instant is the wheel directly over the instrument and that at all other times in approaching or leaving the instrument location the values recorded were influenced by the manner in which the moment at the instrument is affected by the position of the wheel and the flat spot with respect to the instrument. In other words, only one point on the record can correspond exactly with the analytical value. At other points the values are affected also by the wheel position.

Film records are not shown for these flat spot tests. The variations take place so quickly that some of the lines of the record are very thin and would not survive the processes of reproduction, and even on the original film the records must be magnified for study. Fig. 42 illustrates approximately the form of the stress and depression records. The horizontal scale of the diagram has been made relatively larger than on the film to show more clearly the shape of the curve. As the wheel approaches the instrument, an increase in stress was recorded. On the arrival of the flat spot a sudden drop in stress is shown, followed with a very rapid increase to a peak value of as much as 25,000 lb. per sq. in. The record again drops below a normal amount (reverse peak) before assuming the usual form of variation found for the other wheels. This record has the same general form as the analytical curves.

On the film itself the stress record trace is very faint and with the film speed used (about 2.5 in. per sec. for the 30 mile per hour record) its slope cannot be measured with sufficient accuracy to state whether the rate of change of the deflection is within the capabilities of the oscillograph galvanometer. The galvanometer is oil damped and its response is stated to be almost without error up to 500 cycles per second, but the response is about 12 percent low at 700 cycles and 23 percent low at 1,000 cycles. While it is not known to just what frequency the rates of change of the galvanometer deflection in the records correspond, the changes are probably too rapid for the galvanometer to indicate the full amount of the stress under the flat spot.

This reduction in the recorded value may also be present in the depression records to some extent. The slope of the rise of the depression curve is not measurable with the

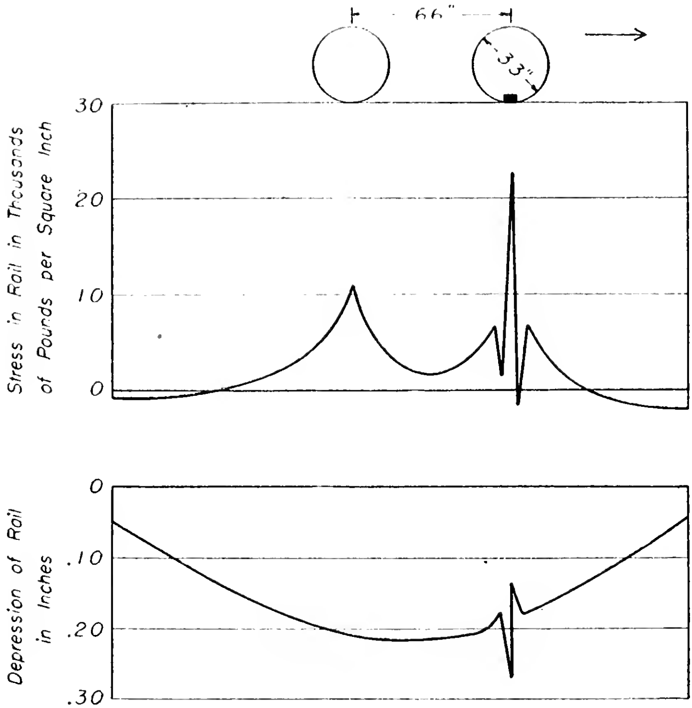

Fig. 42.—Stress in Rail and Depression of Rail as Flat Wheel and Round Wheel Pass the Instruments.

film speed used, so no definite statement can be made of the rate of change of depression other than that it appears to be an instantaneous change as in the case of the stress records. The amount of the increase in depression due to the effect of the flat spot may thus not be fully indicated on the film.

The depression record in Fig. 42 is seen to have a variation of form under the flat spot similar to the stress record, as might be expected from the assumptions of the analyses discussed. The rate of recovery of the track under sudden release of load has been a subject of some speculation. The depression records under the flat spot indicate that with the sudden release of load the track springs back upward an appreciable amount very quickly; the depression variations appear to take place simultaneously with the stress variations.

The peak values of the stresses and depressions recorded under the flat spot at gage Location 4 are plotted with respect to the speed of the car in Fig. 43. The stresses in the middle of the base of the 131-lb. RE rail shown are as high as 25,000 lb. per sq. in. They appear to have a fairly definite trend with speed and to have a maximum at about 20 to 22 miles per hour. This maximum is reached at a speed well above the speed for maximum stress indicated by the analysis, about five miles per hour. The average value of the stress in rail for the wheels in normal condition at a speed of 11 miles per hour was found to be 10,000 lb. per sq. in. The stress under the impact load is thus 2½ times that for the wheels in a normal condition. The moment developed

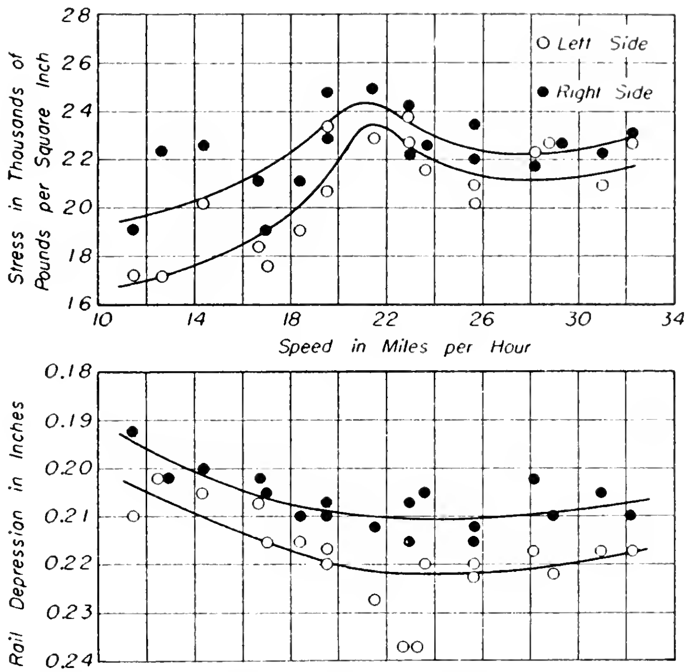

Fig. 43.—Stress in Rail and Depression of Rail under Flat Wheels of Heavy Car at Various Speeds.

with a stress of 25,000 lb. per sq. in. is 685,000 in.-lb. and for 10,000 lb. per sq. in. is 275,000 in.-lb.

The modified analysis with the assumptions used predicts a maximum increase in rail depression due to the flat spot of 1.35 times the depth of the spot. Since the depth was about 0.13 in., this factor makes the increase in depression 0.18 in., which corresponds to an increase in load of about 41,000 lb. for the test track with a modulus of 2,500 lb. per in. per in. This load is calculated on the basis of a single wheel load on the rail. The maximum increase of load would give a total maximum moment, including the static effect of the wheel load, of about 710,000 in.-lb. at the flat spot. This calculated moment is somewhat in excess of that found from the test results but the difference may be due in part to the lack of full indication of peak stresses by the galvanometers and also to the flat spot contact not coming exactly at the instrument.

The values for the rail depression in Fig. 42 show trends similar to those found with the stresses. The maximum values occur at about 22 miles per hour and are less at both higher and lower speeds. In this respect the findings for both depressions and stresses are similar to the results of the analyses. The maximum depressions are seen to be about 0.22 in. with a few values up to 0.24 in. The depressions previously recorded for this location with normal wheels were about 0.18 to 0.20 in., making an increase of considerable amount. The calculated depression for a normal wheel is about 0.15 in. not considering the effect of play.

It is clear from these data and a consideration of the conditions involved that the assumptions of the analyses are not fulfilled in several important respects. The most important defect in the assumptions probably is that the wheel fails to maintain continuous contact with the rail and that when it again contacts the rail there is considerable impact effect which makes the action much more complicated and possibly more severe than would be found with continuous contact. The likelihood of loss of contact is discussed by Thomas and Roy with the assumption of no uplift of the rail during loss of contact. The depression records of these tests show that the rail does rise toward the wheel very quickly. However, the very small amount of downward movement of the wheel possible in the time available makes it unlikely that contact will be maintained. The loud noise or slap accompanying the running of the flat wheel tends to corroborate this conclusion.

It is not known how much mass should be considered to act in the rail and track. There is a considerable mass that has movement of greater or lesser amounts and the inertia forces involved may be an important factor in the action.

It is assumed in the analyses that the shape of the depression curve and distribution of the stresses and depressions along the rail are not affected by the very rapid action in any way that changes the relation between load and stress and depression. A differing relation has been found by R. N. Arnold[13] to be a very important matter where the action is very rapid. It may cause serious error.

The presence of stresses as high as 25,000 lb. per sq. in. in a 131-lb. rail (moment of 685,000 in.-lb.) indicates the presence of very large forces, and since the rapidity of the changes in stress is probably greater than the oscillograph galvanometers will record accurately the values registered are thought to be lower than the actual values. Further experimental work along this line would be of value and could be more wisely conducted through experience gained in these exploratory tests. It would be desirable to use, if possible, instruments adapted to accurate registration of even higher frequencies of stress than the magnetic strain gage equipment of these tests.

22. **Effect of Batter in the Rail Surface.**—Batter in the rail surface is one of the principal detrimental features that develop at the rail joints in track under service. As it was not practicable to obtain joints from service with batter developed to the extent desirable for test purposes, the rail surface at a joint and at places on two rails away from a joint was ground to a shape similar to that found in service, and records were made of the stresses in the joint bars and the stresses and depressions in the full rail under these conditions of batter. This batter constitutes an irregularity in track such as was intended also to be covered by the analyses discussed in Article 21.

The surface at the rail ends at joint location 1 was first ground to a maximum depth of 0.025 in. at the rail gap, sloping back uniformly to nothing at a distance of 2 in. on the leaving rail and 4 in. on the receiving rail, making a total length of 6 in. of batter. A similar batter spot was ground in the right rail at gage Location 5. These batter spots will be termed shallow six-inch batter. After tests were made with shallow batter, the depth of batter at the rail gap and in the full rail was increased to 0.050 in., sloping to nothing in 3-in. on the leaving rail and 6-in. on the receiving rail. This batter spot will be termed deep nine-inch batter. Later the length of the batter spot at both the joint and the full rail was increased to 36 in., with the maximum depth of batter kept at 0.050 in. and symmetrically disposed with respect to the rail gap and a point in the rail; this is termed the deep 36-in. batter. Batter was also ground into the left rail at rail location 6 to conform to the expression $y = h \sin^2 \frac{\pi t}{T_1}$,

[13] "Impact Stresses in a Freely Supported Beam" by R. N. Arnold, (B.Sc., Ph.D., M.S.), A.M.I. Mech. E., Proceedings Institution of Mechanical Engineers, Vol. 137, 1937, part 3, page 217.

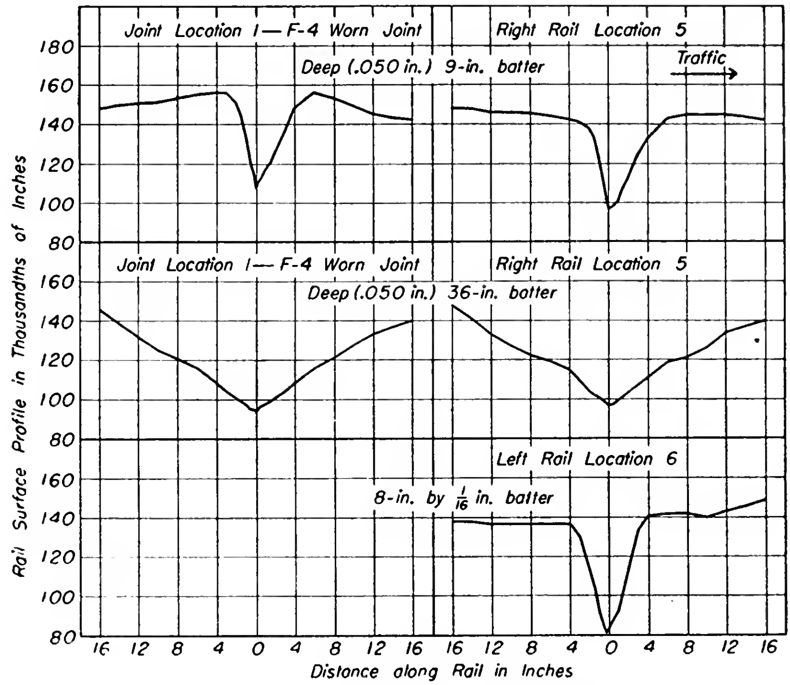

Fig. 44.—Profiles of Batter Spots Ground into Rail.

(a shape assumed in the analyses) where h is maximum depth, T_1 the period of time required to cross the batter spot, and t the time elapsed from the first contact of the wheel with the batter spot. The ratio $\frac{t}{T_1}$ corresponds to the distance the wheel has traveled along the batter at any instant expressed in terms of the full length of the batter spot. h was made 1/16 in. and the length of the batter spot was 8 in. This batter spot is termed the 8-in. by 1/16-in. batter spot.

The measured profiles of the deeper forms of batter are shown in Fig. 44. It may be noted that the nine-inch batter is not a symmetrical curve and in this respect does not conform to the curves assumed in the analyses. All the batter curves, (except the 8-in. by 1/16-in. batter) are also not continuous curves as was also assumed in the analyses. The meeting of the two sloping sides of the batter gives a point of discontinuity in the batter. These differences between the analytical and the test conditions may be expected to affect the agreement of the test results and analytical values somewhat.

The tests made with rail joints without batter showed that the gap between the rail ends affects the form of the records in many cases so that the form of the records taken with joints having batter will also be influenced by the rail gap.

It should be borne in mind that the instruments recording the stresses and depressions in the batter tests are attached to the rail or the joint bars, and thus the position of a moving wheel is varying continuously with respect to the batter spot and to the instrument position. The analysis deals with the values at the wheel position as it proceeds across the batter spot and thus the recorded values will not be identical with the analytical values under the test conditions.

Less slap or noise was produced when the wheels passed over the batter spots than was produced by the flat spot. Speeds as high as 90 miles per hour over the batter spot did not cause undue disturbance. The surface of the rail was chalked at the 8-in. by 1/16-in. batter spot. The chalk was found to be removed in a path over the full length of the batter spot even at a speed of 90 miles per hour. This is an indication of the probability of continuous contact over this batter spot by any wheel, even though all wheels passed over it. Although at the high speeds a wheel will not drop or be forced into the batter spot before it is well beyond the middle of the length, the upward recoil of the rail may be fast enough to account for nearly continuous contact.

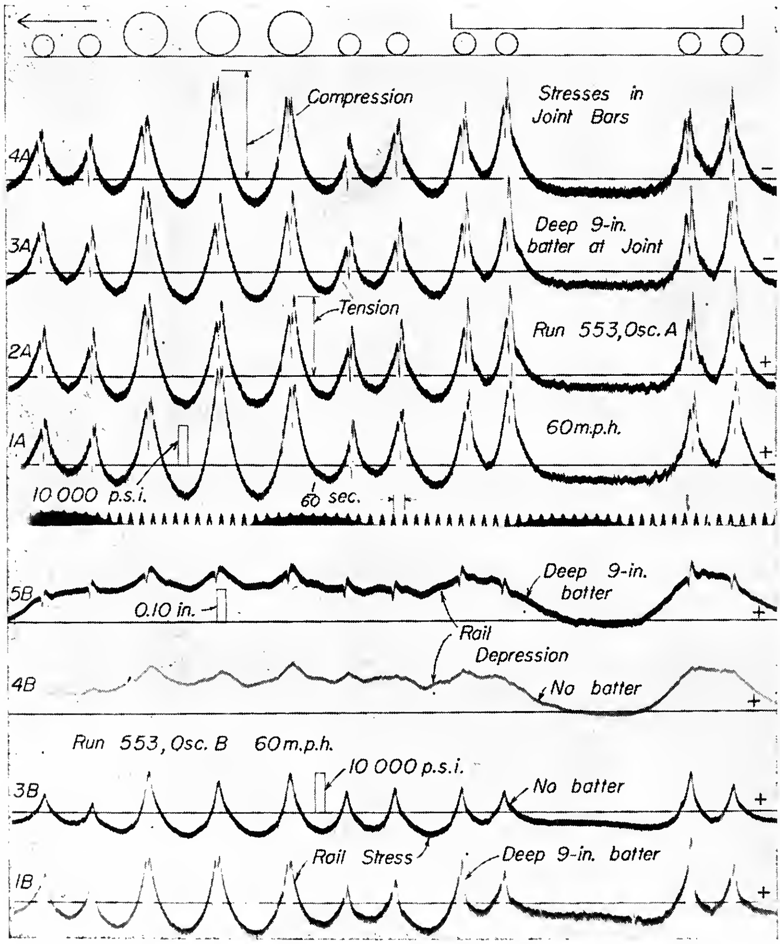

Fig. 45.—Typical Records of Stress and Depression for Deep 9-in. Batter Spot at a Rail Joint and in Full Rail at 60 Miles per Hour.

Since the records taken for the batter spots were somewhat clearer and easier to interpret than those for the flat spots some representative records are shown for comparison and study. In Fig. 45 are shown the records of stress and depression for the deep 9-in. batter for the locomotive and car at 60 miles per hour, the highest speed run with the car. The upper film is from oscillograph A and the records are numbered from 1A to 4A inclusive. All records in this film (except the 60 cycle timing wave at the extreme bottom edge) are stresses in the bars of an F–4 worn joint at Joint Location 1 and the records in order from bottom to top are gage lines C (see Fig. 25 for location of gage lines) at the bottom of the outer and inner bars respectively and gage lines B at the top of the outer and inner bars respectively. The lower film has records of the stress in the base of the right rail at gage Location 5 with deep 9-in. batter (1B)

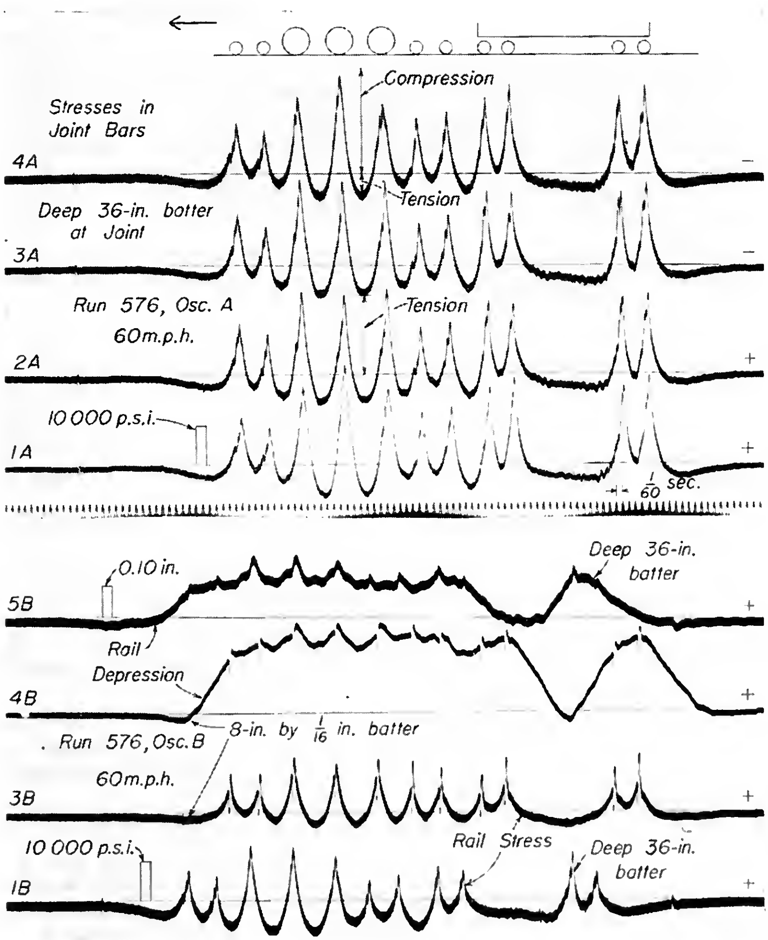

Fig. 46.—Typical Records of Stress and Depression for Deep 36-in. Batter Spot at a Rail Joint and in Full Rail—Also 8-in. by 1/16-in. Batter in Full Rail at 60 Miles per Hour.

and in the base of the left rail at gage Location 5 with no batter (3B); 4B is the depression of the left rail with no batter and 5B is the depression for the right rail with the deep 9-in. batter. In Fig. 46 is shown a set of records, also at 60 miles per hour, with the test conditions similar in all respects except that the deep 9-in. batter has been lengthened to 36 in. and records 3B and 4B are now stress and depression records for the Gage Location 6 on the left rail with the 8-in. by 1/16-in. batter of the form denoted by the expression $h \sin^2 \frac{\pi t}{T_1}$.

It will be seen that the records for the batter tests are similar in form to the sketch shown for the flat spot record (see Fig. 42). However, the original records show that the rates of change of stress and depression as the wheel crosses the batter are less than with the flat spot, though the changes in the records for the batter spot are still quite rapid due partly to the higher speeds used. The test speeds were as high as 90 miles per hour for the batter tests. The gap at the rail ends introduces an additional effect in the records for joint bars (records 1A to 4A, Fig. 45). This effect can be seen by comparing the shape of the records for the joint with those for the full rail (records 1B and 3B, Fig. 45). The records for the locomotive wheels in some instances have forms differing somewhat from those for the car wheels; the car wheel records are quite consistent in form but vary in magnitude. There is generally an initial decrease of the stress or the depression as the wheel first reaches the batter and then a very quick rise followed by a fairly rapid drop to resume the normal shape for an unbattered rail. Comparisons of form can be made by reference to record 3B in Fig. 45, which is for the full rail without batter. Some of the difference in the form of the records for the locomotive and the car may have been due to differences in the contact on the batter spot of the large locomotive wheels and the small car wheels.

The records shown in Fig. 46 for the tests with the deep 36-in. batter for the joint and the rail are chiefly of interest in that almost all of the difference of form of the stress and depression records observed for deep 9-in. batter, when compared with full rail records, has been eliminated or very greatly decreased by lengthening the batter. The magnitude of the stresses and depressions has also been decreased as will be shown later. The lengthening of the batter has decreased the impact and speed effect and has also decreased the vibrations developed.

It may be seen from the records for the batter tests that a wheel crossing the batter spot causes very rapid changes of stress and depression, as is indicated by the steepness of the slopes of the lines of the record and their relatively lesser weight. It is possible that these changes were so fast that the galvanometers did not record the full height of the peak values. However, it is judged from examination of the records that the changes were less rapid than in the tests of the flat spot and the indications for the batter tests are therefore probably more nearly correct than for the tests with the flat spot. It should be stated that since the galvanometers are critically damped, their indications will be less than the full amount when the changes become too rapid.

The bending moments in the rail joint and in the full rail at the batter spots developed by the three driving wheels of the locomotive are shown in Fig. 47. For the deep 9-in. batter at a speed of 15 miles per hour the moment in the joint is about 380,000 in.-lb. With the batter extended to 36 in. the moment developed has decreased to about 325,000 in.-lb. However, with the deep 9-in. batter the moments drop off somewhat as the speed is increased. With the deep 36-in. batter the change in moment in the joint, as the speed increases, is first one way and then another with a possible peak at 50 or 60 miles per hour. It has been found that variation in the action of the locomotive at or above 60 miles per hour causes large changes in the moment developed

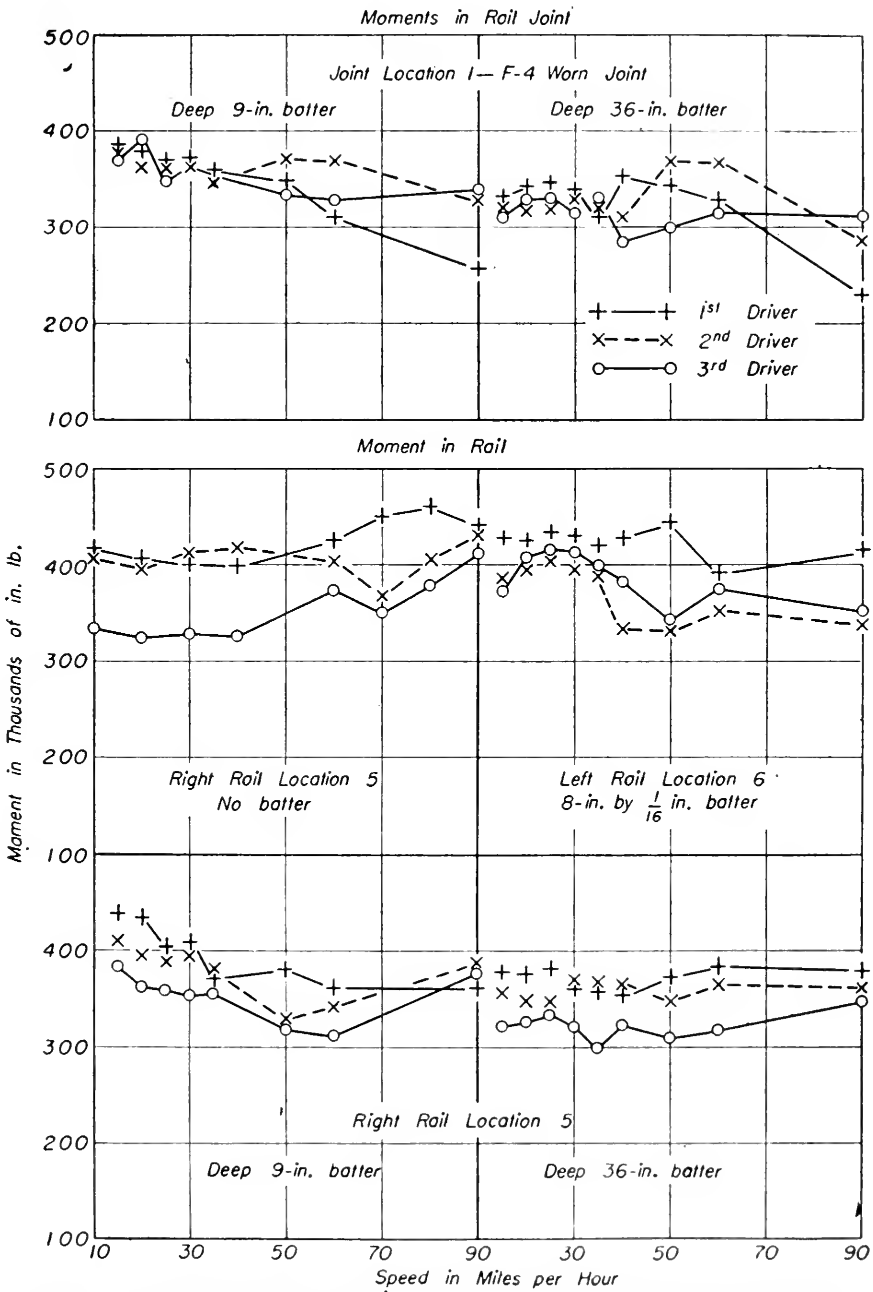

Fig. 47.—Bending Moments Developed at the Batter Spots in the Rail Joint and Full Rail by the Three Driving Wheels of Locomotive 4779.

The moments developed by the car at 60 miles per hour, shown in Fig. 48, are seen to be somewhat at variance with the trends at the lower speeds and are also erratic for some wheels both for the rail joint and the full rail. The moments at 60 miles per hour for most of the tests made at Gage Location 5 show points of similarity. It appears likely that some action of the car is a principal factor in the variability, one of the outstanding examples being the large moment developed by the third wheel at 60 miles per hour in several instances when the other wheels show a large decrease in moment.

It will be noted that in all tests the first car wheel develops markedly less moment than the others. This wheel has relatively heavy wheel loads immediately ahead and behind it and thus gets a greater negative moment (helping effect) from these adjacent wheels than do the other car wheels.

Comparison of the moment diagrams for the joint and the full rail for tests with the deep 9-in. batter and with the deep 36-in. batter shows that the two kinds of batter have a similarity in their variations in moment with speed for both joint and rail up to a speed of 50 miles per hour, above which the car itself apparently develops some action that is the governing factor in the magnitude of the moment developed at a given location.

The moments developed at the shallow six-inch batter spot are not shown; they are similar in form to those for the deep nine-inch batter but of somewhat lesser magnitude. The car was not run for the shallow nine-inch batter tests, so values are available only for the locomotive.

The form of the records of the depression of the rail for the batter tests may be seen in Figs. 45 and 46 and may be compared to a record on the same film for a rail that has no batter. It is apparent from the diagrams that the batter caused changes in the form of the depression records as compared to those for the rail with no batter. Greater depressions were also found with batter in the rail than with no batter at the identical gage location. Under the car the average depression was about 0.15 in. with no batter, 0.17 in. with deep 9-in. batter, 0.16 in. with deep 36-in. batter, and 0.26 in. with 8-in. by 1/16-in. batter. The increases of depression under the locomotive driving wheels due to batter were somewhat greater. The average depression was about 0.15 in. with no batter, 0.20 in. with deep 9-in. batter, and 0.28 in. with 8-in. by 1/16-in. batter. Despite the fact that the batter increased the depression of the rail over that found with no batter, there was little increase in the maximum depression at the higher speeds in the tests with batter, such as was observed with the flat spot. However, since the effect of the batter was considerably less than the effect of the flat spot, any changes in depression caused by speed may be expected to be less noticeable for the batter tests.

The depressions of the rail for the tests with batter are not given in detail because of the lack of appreciable change with speed. The form of the records may be observed in the films shown. The general values given in the foregoing discussion are considered sufficient for the purpose.

Comparison may be made between the test results and the values calculated by the modified analysis, discussed in Art. 21 "Effect of Flat Wheel", which consider the effect of the car spring. The calculated effect of the car spring is to decrease somewhat the magnitude of the maximum effect of the batter over that calculated without consideration of the spring. The amount of this decrease is about ten percent. The comparisons will be made with test results from the loaded car for the full rail because the results for the rail joint are affected by other factors besides the batter.

The speed calculated from the formula at which the deep 9-in. batter would have the maximum effect is about 9 miles per hour, and the depression due to the batter alone was calculated to be 1.35 times the depth of the batter. As the depth of the batter was 0.050 in. the calculated depression caused by the batter alone is 0.068 in. This depression may be expressed in terms of load. Considering the stiffness of the track, it will be equivalent approximately to a 15,000-lb. load in addition to the static wheel load. This added load was calculated on the basis of a single concentrated load on track with a modulus of 2,500 lb. per in. per in. The added load would develop a total calculated moment of about 400,000 in.-lb., considering the weight of the car and the effect of an adjacent wheel. The moments shown in Fig. 48 for the deep 9-in. batter are seen to be between 350,000 and 400,000 in.-lb., a fair agreement with the calculated value.

The test results indicate that the maximum effect of the 9-in. batter occurred at about 25 miles per hour, a speed considerably above the calculated speed. This disagreement may be the result of some loss of contact in crossing the batter despite the probability of continuous contact indicated by the track of the wheel through the chalk as discussed previously.

The analytical speed for maximum effect of batter for the deep 36-in. batter is 35 miles per hour and the test results gave maximum moments at about 35 to 50 miles per hour, which is considered a good agreement. However, the analysis gives the same increase in load as for the 9-in. batter, because the greatest depth of batter is identical, the calculated maximum being at a higher speed for the 36-in. batter than for the 9-in. batter. The calculated total moment of about 400,000 in.-lb. for a wheel is seen from the diagram to be considerably greater than the maximum moments found for the 36-in. batter, which were in general about 275,000 to 310,000 in.-lb.

From the closer agreement between some of the test and the calculated values it seems probable that the assumptions of the analysis were more nearly fulfilled in the batter spot tests than in the flat spot tests, especially in regard to the assumption of continuous contact of the wheel on the rail. The batter spots were all of greater length and lesser depth than the flat spot, both conditions being favorable to maintenance of contact. If contact is lost the force in the car spring and the track reaction are no longer in equilibrium and accelerations are imparted to the wheel and track that may be expected to increase the severity of the action when contact is again established.

The grinding of the deep 9-in. batter to a length of 36 in. to lessen the slopes of the batter spots gave a definite decrease in the stress developed by the car wheels. The lengthening of the batter also decreased the rail vibrations as shown by the smoother records obtained. The grinding out to a longer length has been tried in service by one railroad to decrease the detrimental effect of the batter at the rail joints but the results are not known. However, it should be stated that the stresses were materially increased by the presence of batter of all forms in both the full rail and the rail joint.

The rail depressions with batter in the rail were also found to be greater than without the batter. The 8-in. by 1/16-in. batter caused the largest increase in depression and the deep 36-in. batter the smallest, with the deep 9-in. batter intermediate between the two. The higher speeds caused little or no addition to the depression, as compared with the lower speeds, even though the stresses observed at the same locations showed material changes. The reason for this lack of speed effect upon the depression is not known, though it is possible that the changes were small relative to the total amount of the depression and thus are not readily recorded.

Tests were also made with two wheels mounted eccentrically on an axle of the heavy car. The eccentricity, which was 1/16 in. or less, was apparently too small to show an appreciable effect on the stresses and depressions of the rail, and the results will not be given. Out-of-round wheels have been found to cause track damage. Tests on the effect of this not unusual condition may well be included in a future program.

As previously stated, the tests with flat spots and batter were undertaken in a preliminary way largely to learn whether the testing equipment available would be satisfactory for determining the effect of such conditions on the stresses and depressions developed in the rail. The apparatus was found to give rather definite and consistent information. Besides, despite the short time taken in making the tests, it is believed that the data obtained have given significant indications of the magnitudes and trends of the stresses produced by the flat spot and the batter spots.

23. **Rail Stresses and Depressions With Steam Locomotive.**—Tests were made with steam locomotive No. 6718, a fast freight locomotive of the M1a class, (4–8–2), to study effects of counterbalance, as it existed in a steam locomotive, on the stresses developed in the base of the rail and the corresponding depressions of rail. The spacing of the wheels, the normal wheel loads and other data of the locomotive are given in Fig. 3. Other information is likewise given in Article 6 "Locomotives and Cars".

In these tests the magnetic strain gages were mounted on the center line of the base of the two rails at gage locations 4, 5 and 6, spaced at 10-ft. intervals, the gages on one rail being directly opposite corresponding ones on the other rail. Six solenoid depression gages to record depression of the rail with reference to a support fixed in the roadbed were also mounted on the two rails at the three gage locations. Thus the strain gage and the depression gage of each gage location recorded stress and depression measurements simultaneously.

For the one day of testing with this locomotive 23 runs were made, 3 runs at 5 miles per hour and 20 runs at 75 miles per hour. The stresses in the base of rail developed under speeds of five miles per hour are considered to be due only to static loads, this low speed producing negligible dynamic effects. All three of the runs at five miles per hour were made prior to any run at the higher speed.

In all runs steam was shut off as the locomotive approached the test section of track, and the locomotive drifted past the gages. The speeds were read from the speedometer in the cab of the locomotive and checked against the speeds given by the timing wave on the oscillograph records.

The position of the counterweight as the locomotive passed over a gage location was recorded photographically. It was found unnecessary to control the position of the counterweight on different runs as the starting and stopping of the locomotive and the running over curves within the length of runs gave considerable distribution of position of counterweight with respect to any one instrument.

In Table 11 are given the weights of the reciprocating and rotating parts of the Class M1 Locomotive with counterbalance weight and weight placed in each wheel for reciprocating parts as reported by the Mechanical department of the Pennsylvania Railroad.

For the possible benefit of some readers, the methods of calculation and the comparison of measured data will be treated at somewhat greater length than would be desired by other readers. In order to fully interpret the stress measurements, it was necessary to make a comparison between calculated stresses due to counterweight influences and the measured stresses. Such a comparison involves an analysis of the effects of the unbalanced weight in or upon each driving wheel. For this analysis it was necessary to consider the weight of the main rod, side rods, eccentric crank, and counterweight and also the distance between their respective planes of rotation. For this par-

Table 11

Weights of Rotating and Reciprocating Parts in Pounds — Class M1 Locomotive of Pennsylvania Railroad

All weights given for the rotating parts are at crank pin radius or the equivalent weights at crank pin radius.

Reciprocating Parts

Total weight of reciprocating parts (one side)	1807 lb.
47% of reciprocating parts	850 lb.

Rotating Parts

Driver number	4	3	Main	1
47% of reciprocating parts	212½	212½	212½	212½
Main rod, weight on crank pin			606	
Side rod, weight on crank pin	146	464	625	146
Total	358½	676½	1443½	358½
Total counterbalance weight (weighed or checked with crank pins, collars and eccentric in place)	358½	676½	1443½	358½

ticular comparison, it was thought desirable to make certain refinements in the determination of the effective revolving weight of the main rod and the eccentric crank, and also to include the vertical component of the force exerted by the main rod on the crank pin in accelerating and decelerating the reciprocating weights.

The motion of the main rod, relative to the locomotive, is of course rotational at one end and reciprocating at the other. The equivalent revolving weight of the crank pin end may be determined by the equations for plane motion of a rigid body. Investigations of a number of main rods by locomotive builders and by mechanical engineers has shown that the equivalent revolving weight may be closely approximated as seven-eighths of the scale weight of the crank pin end, and this value was accordingly used in this analysis.

The weight of the eccentric crank was computed to be 130 lb. and to have its center of gravity 10.5 in. from the center of rotation of the main driver. Converted to crank pin radius the weight of the eccentric crank becomes 91 lb. A radial line through the center of gravity of the eccentric crank makes an angle of approximately 10 deg. with a radial line through the crank pin and lags the pin in position in both main drivers when the motion of the locomotive is forward. For purposes of analysis it was convenient to divide the eccentric crank weight into two components, one component being parallel to a radial line through the crank pin and the other at an angle of 90 deg. thereto. For this locomotive these two components are 88 lb. and 24 lb. respectively. The equivalent revolving weight of the back end of the eccentric rod, assumed to be 12.5 lb. at crank pin radius, was added to this latter component giving a total weight of 36.5 lb. for the 90-deg. component. To the component parallel to a radial line through the crank pin was added the weight of the included part of the main pin (25 lb.) giving a total component of 113 lb.

In Table 12 are given the horizontal center-to-center distances between side rods, main rods, eccentric cranks and counterweights. Also given are the values of the total weight of the rotating parts. These values of total weights include the weights given in Table 11 to which have been added the calculated weights of included parts of crank pins. The weight of the included part of the crank pin added to a side rod or main rod has also been added to the corresponding counterweight values given in Table 11 to give the total value of counterbalance weight acting at crank pin radius. For convenience in rotational calculations, all these weights have been given as at crank pin

Table 12

Total Weights of Rotating Parts and Center to Center Distances — Class M1 Locomotive of Pennsylvania Railroad

Weights are in pounds and distances in inches. All weights given are at crank pin radius or the equivalent weights at crank pin radius.

Center to Center Distances	
Side rod, main pin	76 3/8
Main rod, main pin	91 1/2
Eccentric crank, main pin	103
Counterweight, main driver	63 1/4
Counterweight, drivers 1 and 4	60 7/8
Counterweight, intermediate driver	61

Weights of Rotating Parts	
Side rod and included pin, drivers 1 and 4 (146 + 36)	182
Side rod and included pin, intermediate driver (464 + 36)	500
Main rod and included pin, main driver (7/8 x 606 + 109)	639
Side rod and included pin, main driver (625 + 108)	733
Eccentric crank and included pin (88 + 25)	113*
Counterweight, drivers 1 and 4 (358½ + 36)	394½
Counterweight, intermediate driver (676½ + 36)	712½
Counterweight, main driver (1443½ + 242+ 88)	1773½

* Component of eccentric crank weight acting in direction opposite counterweight plus included part of eccentric crank pin. Component at 90 degrees is 36.5 lb. which leads counterweight position in both right and left main drivers.

radius. No consideration was given to the weight of the hub of the main pin as it is practically in the same plane as the counterweight and would have negligible out-of-plane effect.

The weights referred to above may be considered to be proportional to the rotational or centrifugal forces which act radially, for any given speed of the locomotive, and for convenience they may be used as forces with horizontal and vertical components. Using the values of these forces given in Table 12, with the counterweight on the right side in a down position, moments of first the vertical forces and second the horizontal forces acting on a pair of driving wheels are taken about a vertical plane through the center of the counterweight of the left wheel of the pair. Corresponding moments are then taken about the vertical plane through the center of the counterweight of the right driver. From these moments the resultant unbalance (horizontal and vertical components and their resultant) in the plane of the counterweight is determined. The resultant unbalance in each driver with its components, as calculated in this manner, is shown in Fig. 49 together with positions with respect to the counterweight.

It will be observed in Fig. 49 that the calculated resultant unbalance in the right main driver is 305 lb. and that it leads the counterweight position by approximately 82 deg. whereas the resultant unbalance in the left main driver is only 207 lb. and lags the counterweight position by approximately 84 deg. The resultant unbalance in both the first and fourth drivers is 191 lb. It leads the counterweight position by 7 deg. in the right drivers and lags by 7 deg. in the left drivers. For the third drivers the resultant unbalance is found to be 161 lb. per driver and it leads the counterweight position by approximately 22 deg. in the right driver and lags by the same amount in the left driver.

It should be understood that these calculated values of resultant unbalance do not in any way show lack of proper attention to the counterbalancing of the locomotive. It is common practice to place more counterweight in the driving wheel of a locomotive than is required to balance the rotating parts in order that the inertia effects of

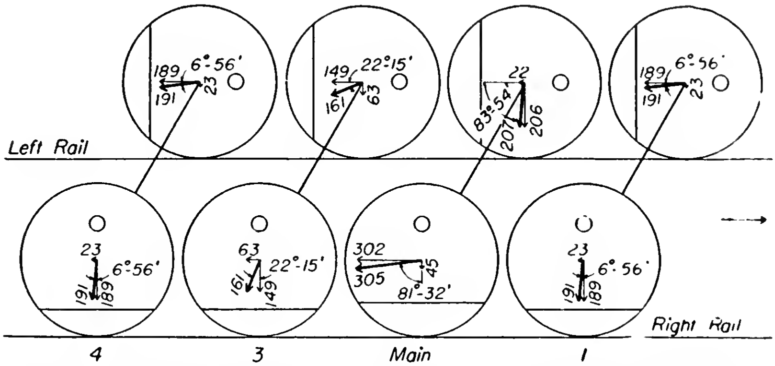

Fig. 49.—Calculated Components and Resultant Unbalance in Pounds at Crank Pin Radius in Locomotive Driving Wheels—Class M1 Locomotive of the Pennsylvania Railroad.

the reciprocating parts may be reduced with resulting reduction in the shaking forces on the locomotive frame and in the reduction of the nosing tendency of the locomotive. It is necessary, however, to know the amount and position of the resultant unbalance in each driving wheel brought about by this practice in order that proper interpretation may be placed on the measured values of stress and bending moment developed in the rail by the locomotive.

The general formula for calculating the dynamic augment produced by the unbalanced rotating parts is the formula for centrifugal force,

$$C = \frac{W}{g} \frac{v^2}{r} \quad \text{(12)}^{14}$$

in which

W = the weight of the rotating part for which the dynamic augment is desired, or the unbalanced part of the rotating parts in case the rotational effect is wanted.
g = the acceleration of gravity.
v = the rotational velocity or speed of the part.
r = the radius of the circle described by the center of gravity of the rotating part.

The equation implies consistent units, and the values may be taken in pounds, feet, and seconds, with g as 32.2 ft. per sec. per sec.

The above formula is converted to the following form for convenience in use:

$$\text{Dynamic Augment } C = \frac{3.21 W S^2 R}{D^2} \quad (75)$$

in which

W = the weight of the unbalance at crank pin radius in pounds.
S = locomotive speed in miles per hour.
R = crank pin radius in inches.
D = diameter of drivers in inches.

For the speed of the tests (75 miles per hour) the calculated dynamic augment for each individual driver resulting from substituting in the above equation the values of resultant unbalance given in Fig. 49 becomes for the right side, from front to rear, 10,000, 15,900, 8,400, and 10,000 lb., respectively, and for the left side 10,000, 10,800, 8,400, and 10,000 lb., respectively. The vertical component of the dynamic augment for any position of a wheel then is a force applied to the rail in addition to the

[14] AREA Proceedings, Vol. 21, 1920, page 653.

static wheel load. Calculations for bending stress in rail may then be made for such loads by the methods used for calculating stresses in rail developed by a combination of static wheel loads.[15] The stresses thus determined may be added algebraically to the stresses developed under the combination of static wheel loads.

For a modulus u of 2,500 lb. per in. per in., the measured modulus for this track, the stresses in the base of the rail produced by the combined effect of the individual dynamic augments were calculated to be + 3,700, + 6,000, + 1,900, + 3,400 lb. per sq. in. under the first, second, third and fourth drivers on the right side, respectively, and on the left side + 3,900, + 3,900, + 2,100 and + 3,500 lb. per sq. in. respectively. It should be noted that these values of stress in base of rail, under the individual drivers, are calculated for the instant that the resultant unbalance for the driver under consideration is in a down position (see Fig. 49) and do not in all cases represent the maximum stress developed under that driver due to the simultaneous combined effects of the dynamic augments of the other drivers on the same rail. The maximum effect of the different drivers on the rail do not occur simultaneously with each other. Nevertheless, the values of stress given are usually fairly close to the maximum calculated values.

Other variable vertical forces applied to the track include the vertical component of the force transmitted to the main driver crank pin by the main rod. As the locomotive was allowed to drift over the gage locations and as information is not available on the pressures applied to the piston when steam is shut off no attempt will be made to take into account forces of this kind. The inertia effects of the reciprocating parts, however, have a magnitude that requires consideration.

It is not known whether the vertical component of these inertia forces of the reciprocating parts applied to the main pin by the main rod may in any part be transmitted to wheels other than the main driver. In the calculations this vertical force has been considered to be applied wholly to the main driver.

The vertical variable force on the main pin produced by the inertia effects of the reciprocating parts and transmitted to the main pin through the main rod may be closely calculated by the formula,

$$V = \frac{W}{g} r\omega^2 \left[\frac{r}{l} (\cos \Theta + \frac{r}{l} \cos\ 2\,\Theta) \frac{\sin \Theta}{\cos \phi} \right] \quad (76)^{16}$$

in which

V = the vertical component of the force on the main pin transmitted to the pin through the main rod and produced by the inertia effects of the reciprocating parts.
W = total weight of reciprocating parts on one side of the locomotive.
g = acceleration of gravity.
ω = angular velocity of main driver.
r = crank arm radius.
l = length of connecting rod (115 in.).
Θ = angle which the crank arm makes with the horizontal.
ϕ = angle which the connecting rod makes with the horizontal.

[15] Reference to the principles given in the analysis of track action in the Sixth Progress Report (pages 278–291) will show that the moment and, therefore, the stress produced by a combination of wheel loads may be found by calculating the load for a single wheel which is equivalent to the combined effect of the several wheels in moment producing effect, and using the resulting load (which is termed the equivalent single wheel load) in the formula for bending moment in rail. The formula for bending moment in rail is $M_0 = 0.318\ Px_1$ (Equation (8) page 279 of the Sixth Progress Report) where P is the equivalent single wheel load and x_1 is the distance from the wheel load to a point of zero bending moment in the rail for a single wheel load on the track in question.

[16] This equation was derived by using the equation for acceleration of the crosshead of a steam engine as given in Seely and Ensign's "Analytical Mechanics for Engineers" (second edition) p. 164.

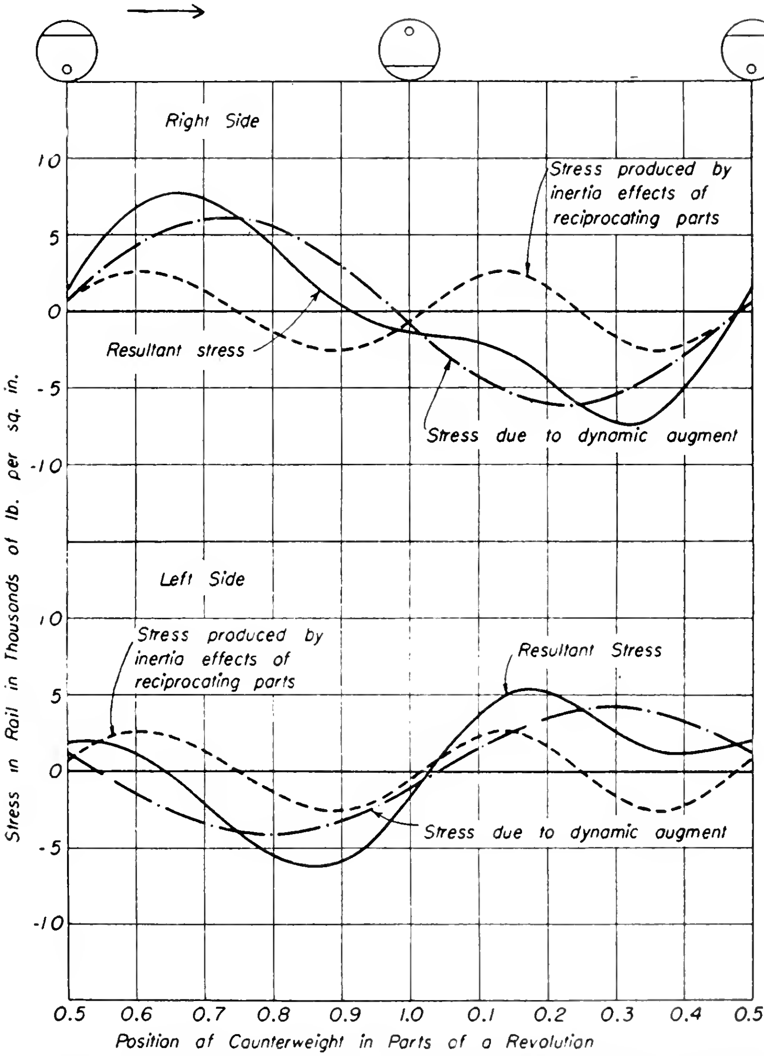

Fig. 50.—Calculated Stresses in Base of Rail under Main Driver Due to Dynamic Augment and Inertia Effects of Reciprocating Parts for Speed of 75 Miles per Hour—Class M1 Locomotive—131-lb. RE Rail.

It should be noted that θ should be taken as zero degrees for the position of the stroke in which the piston is farthest from the driver. The equation implies consistent units, and the values may be taken in pounds, feet and seconds.

This resulting vertical variable force on the main pin at any point in the revolution may be treated as an additional vertical force applied to the rail by the main driver. The additional stress produced by this force may be added algebraically to the stress due to static load and dynamic augment.

In Fig. 50 are given, through a complete revolution of the main driver, curves for the stresses in the base of the rail calculated by the methods described above and produced by the unbalanced rotating parts and the inertia effects of the reciprocating parts. The ordinates of the diagram represent stresses in the base of the rail in pounds per square inch, calculated for a speed of 75 miles per hour and a modulus *u* of 2,500 lb. per in. per in. The abscissas represent the position of the counterweight with respect to its down position, the scale being in fractions of a complete revolution of the driver. The curve shown as a dot-dash line and varying nearly as a sine wave, with the same frequency as the rotational frequency of the driver, represents the stress produced by the combined effects upon the rail of the dynamic augments for the several drivers. The curve shown as a dashed line and varying nearly as a sine wave but

Table 13

Measured Stresses and Calculated Stresses in Base of Rail — M1a Locomotive 6718 of the Pennsylvania Railroad at Elkton, Maryland

Stresses are given in thousands of pounds per square inch. Measured values are for 5 miles per hour.

	Location	Trailer	Driver Number				Truck Wheel	
			4	3	Main	1	2	1
				Left Rail				
Measured stress - Average of 3 runs at 5 m.p.h.	4	13.4	9.7	7.3	9.8	11.2	3.5	4.9
	5	11.9	11.6	10.0	8.8	7.9	0.9	4.6
	6	12.3	10.1	7.1	11.4	10.1	3.8	4.9
	Av.	12.5	10.5	8.1	10.0	9.7	2.7	4.8
Calculated from scale weights		13.4	11.0	6.8	8.2	9.1	1.4	4.4
Calculated from nominal weights		11.6	9.8	7.7	8.2	9.3	1.7	4.8
				Right Rail				
Measured stress - Average of 3 runs at 5 m.p.h.	4	8.3	9.8	7.9	9.8	10.4	3.8	5.6
	5	7.7	12.1	12.8	12.7	12.6	1.0	4.9
	6	7.9	8.9	7.5	12.7	9.9	2.6	4.4
	Av.	8.0	10.3	9.4	11.7	11.0	2.5	5.0
Calculated from scale weights		9.9	10.4	8.2	7.8	8.3	1.9	4.9
Calculated from nominal weights		11.6	9.8	7.7	8.2	9.3	1.7	4.8

having a frequency twice that of the rotational frequency of the driver represents the stress produced by the vertical component of the force on the main pin due to the inertia effects of the reciprocating parts, no account having been taken of the out-of-plane effect of the force. These two curves have been added algebraically to give the resultant varying stress in the base of the rail due to dynamic augment and inertia effects of reciprocating parts. The resultant stress is shown by the heavy full line. In calculating the vertical component of the force on the main pin produced by the inertia effects of the reciprocating parts, the total weight of the reciprocating parts on one side (1,807 lb.) was used.

In Table 13 are given the measured stresses in the base of each rail at each gage location for each wheel of the locomotive at a speed of five miles per hour. The given values are the average of three runs. The average of the values at the three gage locations for each rail and individual wheel are also given. Computed stresses in the base of rail based on the reported scale weights and on the nominal wheel loads are included in Table 13 to afford a comparison between the measured and calculated stresses under static loading conditions.

It will be observed that the measured values of stress in the left rail for a given wheel differ at the three gage locations and that no one of the three locations gives values consistently high or low for all wheels of the locomotive. The stresses under the first and the main driver at Location 5 are 1,000 to 3,000 lb. per sq. in. lower than those at locations 4 and 6, but under the third and fourth drivers the stresses are 1,500 to 3,000 lb. per sq. in. higher than at locations 4 and 6. The stresses under the first truck wheel and the trailer are substantially the same for all three locations. The differences noted are not great and may be due in part to irregularities in track support and transfer of load between adjacent wheels through equalizer action. However, the variations in stress at the three locations for a given wheel may in general be considered not unexpectedly great and the average of the values given at the three locations for each wheel may be considered representative of the track and locomotive conditions.

The measured values of stress given for the right rail show about the same range of differences in values at the three locations for each wheel as was found for the left rail. It will be observed, however, that for all four drivers the stresses at Location 5 are from 2,000 to 5,000 lb. per sq. in. higher than at locations 4 and 6. The measured play between rail and tie and tie support at Location 5 was somewhat less than at locations 4 and 6, which would normally result in lower stresses at Location 5. The fact that the measured stresses at Location 5 were higher than at the other two locations would further seem to indicate transfer of load from the adjacent drivers to the driver passing location 5.

In Figs. 51 and 52 are plotted for all eight driving wheels of the locomotive, through a complete revolution of the drivers, the measured stresses in the base of the rail at the three gage locations on each rail, for all runs at 75 miles per hour. The curves given for the individual driving wheels are analytical curves. They represent the stresses in the base of the rail computed, as outlined previously, on the basis of a modulus u of 2,500 lb. per in. per in. and a speed of 75 miles per hour. The curve for each driving wheel other than the main driver is the algebraic sum of the calculated stress in the base of the rail produced by the nominal static wheel loads (values given in Table 13 and represented in the figures by the horizontal dashed lines) and the calculated stress produced by the combined effects of the dynamic augments of the drivers. For the main drivers the analytical curve includes also the stress produced by the vertical component of the force on the main pin due to the inertia effects of reciprocating parts. The heavy horizontal lines represent the average of the measured stresses for a given wheel at five miles per hour.

The number of observed points for each driver is not sufficient to establish definitely a curve for probable average stress throughout a revolution of the driver, though in general the points are fairly uniform in their distribution horizontally. In particular, for the first and fourth drivers and the left main driver the agreement between the trend of an averaging curve and the analytical curve is quite good. The results for the right main driver are obviously discordant. They do not follow the pattern of the calculated curve nor is the maximum measured stress for the right driver in excess of that for the left, as would be expected from the values of calculated resultant unbalance in these two drivers. No definite effect of unbalance in this driver is shown in the plotted points throughout a revolution. The range of stress each side of the average measured stress is not large. It would be interesting to know what principal contributing sources influence this departure from a definite counterbalance trend.

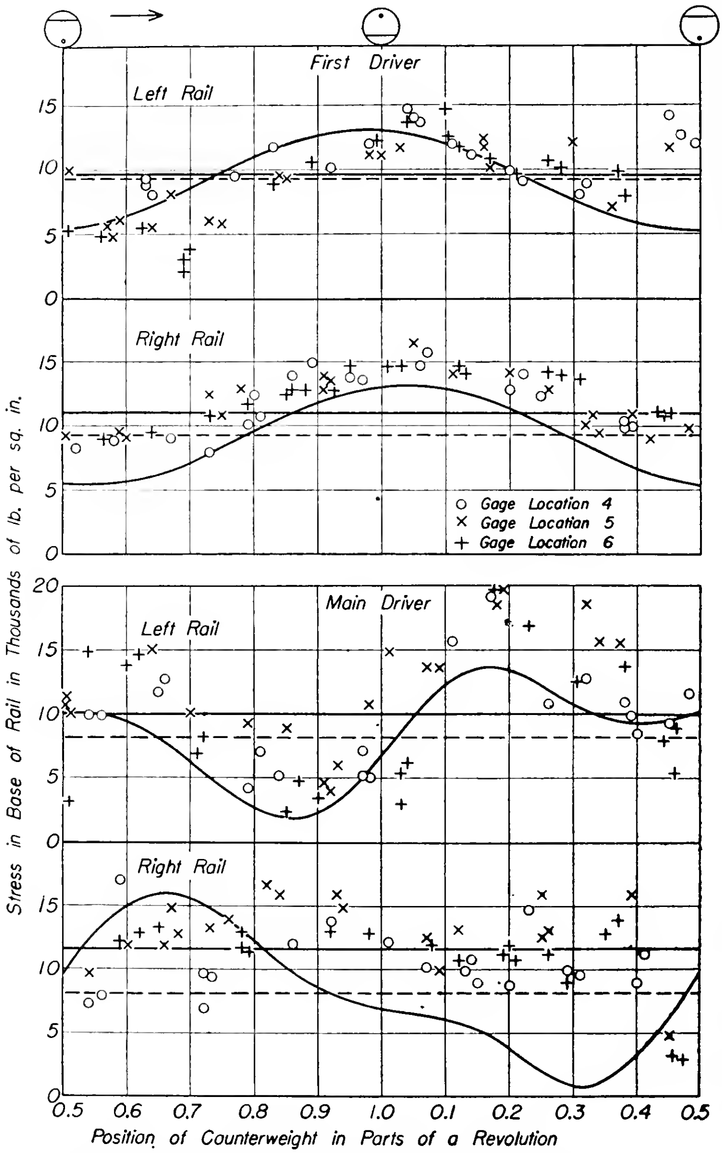

Fig. 51.—Observed Stresses in Rail with M1a Locomotive 6718 of the Pennsylvania Railroad at 75 Miles per Hour—131-lb. RE Rail.

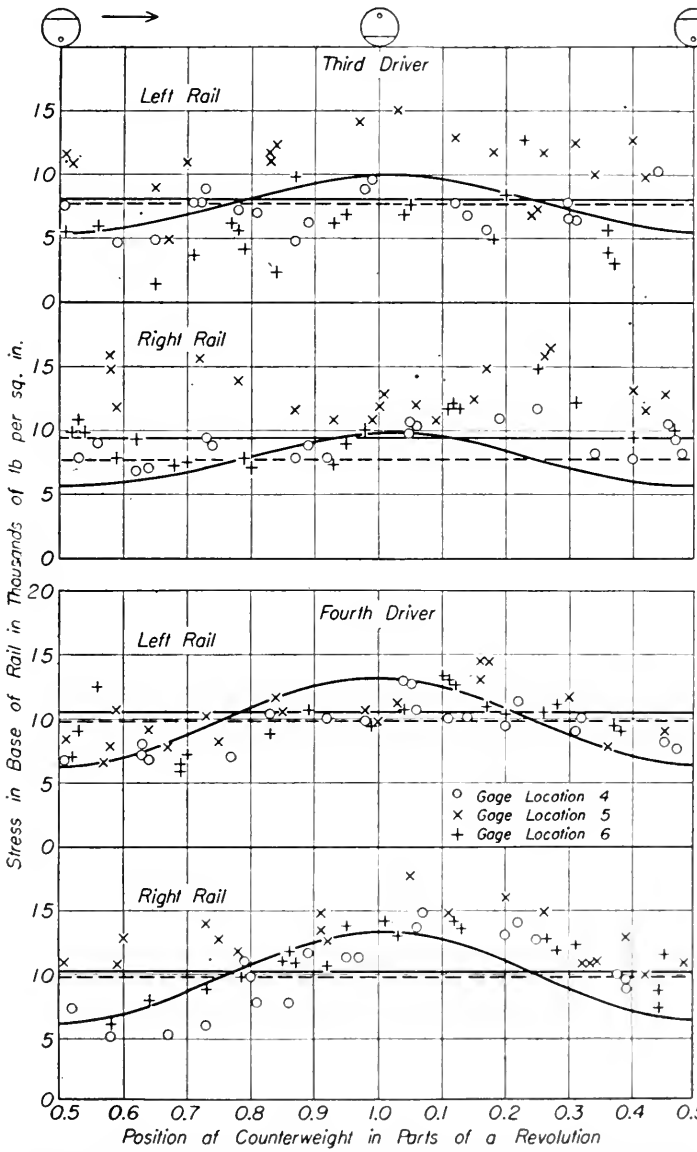

Fig. 52.—Observed Stresses in Rail with M1a Locomotive 6718 of the Pennsylvania Railroad at 75 Miles per Hour—131-lb. RE Rail.

It will be noted that for several of the drivers the agreement between the trend of the observed points and the vertical position of the analytical curve would be improved by moving the analytical curve upward by the amount of the difference between the average measured stress at five miles per hour and the calculated static stress based on the nominal wheel weights. For instance, for the right first driver the average measured stress in the base of the rail is about 1,700 lb. per sq. in. greater than the calculated static stress. Moving the analytical curve for this driver vertically upward by this difference would result in better agreement between the resulting curve and the average of the measured values.

It should be understood that the analytical curves given for the individual drivers do not take into consideration possible effects of the forces due to locomotive oscillation, vibration, etc., and do not take into account additional forces that may be pro-

Table 14

Measured and Calculated Depressions of Rail — Class M1a Locomotive 6718 of Pennsylvania Railroad at Elkton, Maryland

Depressions are given in inches. Measured values are for 5 miles per hour.

	Location	Trailer	Driver Number				Truck Wheel	
			4	3	Main	1	2	1
Left Rail								
Measured gross depression - Average of 3 runs at 5 m.p.h.	4	.206	.209	.215	.218	.206	.143	.107
	5	.147	.164	.168	.158	.138	.088	.067
	6	.243	.259	.265	.278	.257	.194	.145
	Av.	.199	.211	.216	.218	.200	.142	.106
Calculated from scale weights		.144	.168	.187	.196	.180	.097	.059
Calculated from nominal weights		.124	.159	.192	.199	.181	.102	.065
Right Rail								
Measured gross depression - Average of 3 runs at 5 m.p.h.	4	.162	.210	.218	.226	.200	.142	.102
	5	.135	.196	.208	.212	.185	.104	.083
	6	.187	.234	.243	.258	.226	.154	.112
	Av.	.161	.213	.223	.232	.204	.133	.099
Calculated from scale weights		.107	.165	.198	.192	.169	.098	.066
Calculated from nominal weights		.124	.159	.192	.199	.181	.102	.065

duced by the variations in the track support, the changing distribution of the individual driver and wheel loads, the inertia effect of unsprung weight, and the effect of speed. Any one or a combination of these factors may influence the measured stresses in the base of the rail to a considerable degree.

A fact of significance to be observed from these measured stress values is the comparatively low maximum stresses recorded in the base of the 131-lb. rail at 75 miles per hour. The highest individual stress value was about 20,000 lb. per sq. in. corresponding to a bending moment in the rail of 548,000 in.-lb. It is apparent that the counterbalancing conditions of the locomotive do not give unduly high stresses in the rail for this speed of operation.

As the plotted positions of counterweight are distributed fairly evenly throughout the revolution of the driver, the average of the plotted points will not differ far from the average stress throughout a revolution. The difference between this average stress

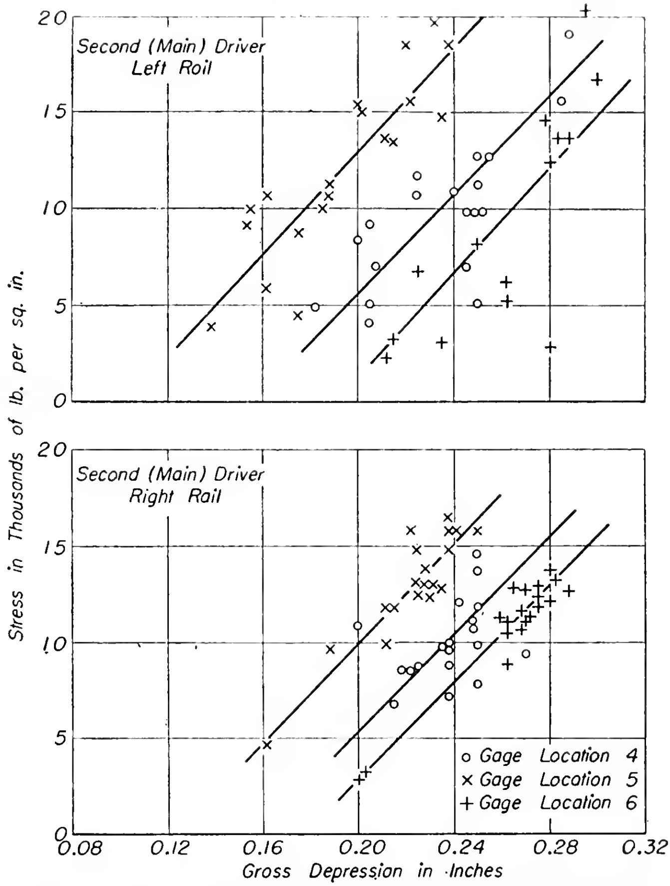

Fig. 53.—Observed Stresses in Rail and Observed Rail Depressions for Main Drivers for Steam Locomotive 6718 at 75 Miles per Hour.

and the average of the measured stresses at five miles per hour may be thought of as representing the effect of speed independent of counterbalance and inertia effects. On this basis the effect of speed at each driver of this locomotive was slight, very much less than found in a variety of steam locomotives tested in earlier years.

At the six locations where magnetic strain gages measured rail stresses, solenoid depression gages were mounted to indicate the depression of the rail with reference to a support fixed in the roadbed. In Table 14 are given the measured gross depressions at each test location for each wheel of the locomotive. The values given are the average of three runs at 5 miles per hour. The averages for the three locations on each rail are also given. Depressions of the rail calculated on the basis of the reported scale weights of the wheels of the locomotive and on the basis of the nominal wheel loads are also given in Table 14. In comparing the values of measured depression with the values of calculated depression it should be remembered that the measured values are gross values which include the play between rail and tie and tie support.

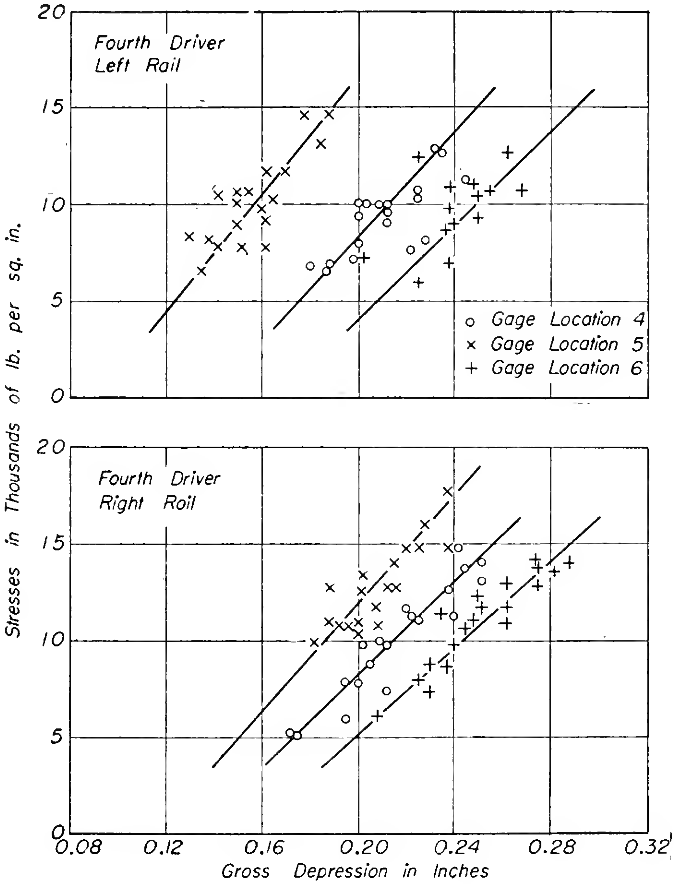

Fig. 54.—Observed Stresses in Rail and Observed Rail Depressions for Fourth Drivers for Steam Locomotive 6718 at 75 Miles per Hour.

In Figs. 53 and 54 the measured stresses in the base of the rail at the three gage locations for the main and the fourth drivers have been plotted against the corresponding measured gross depressions of the rail for all runs at 75 miles per hour. It will be seen that the trend of the plotted points for each location is well represented by a straight line. Plots similar to those shown in Fig. 53 were made for each of the drivers and locations and in all cases a straight line of the proper slope expressed the relationship between the measured values of stress and depression.

In Fig. 55 the data given for the right fourth driver in Fig. 54 are plotted in a different manner to further demonstrate the linear relationship between measured values of stress and depression. The ordinates on the left of the figure represent the stress in the base of the rail and those on the right represent the gross depression of the rail. The scales of the stress and depression values, plotted as ordinates, are related

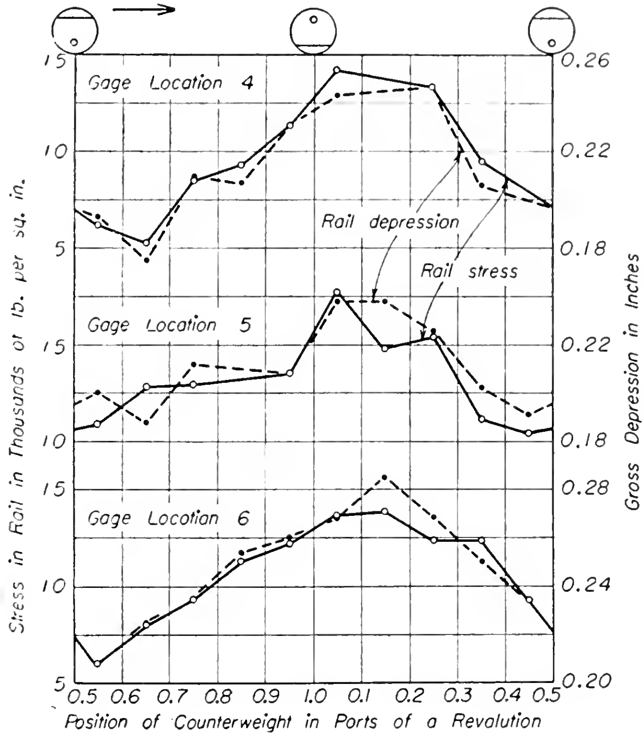

Fig. 55.—Measured Stress in Rail and Depression of Rail under Right Fourth Driver for Speed of 75 Miles per Hour—Class M1a Locomotive 6718—131-lb. RE Rail.

according to the average slope (0.008 in. depression per 1,000 lb. per sq. in. stress) obtained from the lines given in Fig. 54. The plotted points in the figure are the averages of the measured values of stress and depression taken in groups for each one-tenth of a revolution of the driver. It may be seen from Fig. 55 that for each gage location the same curve would represent the position and trend of either the average values of stress or the average values of the depression equally well. The same statement, of course, would be true for the curve representing the position and trend of the average of the values of all three locations.

It is thought not necessary to give diagrams of measured rail depressions plotted with respect to the position of counterweight. As would be expected from the concordance between stresses and depressions given in Figs. 53 and 54 and 55, the diagrams of rail depression throughout the revolution of a driver correspond closely with the diagrams for stresses. In general the trends of averages of points followed the form of the analytical curves in a way similar to the plotted stresses and corroborated the stress relations in a surprisingly close manner. The one exception was the right main driver, where the distribution of points gave no indication of counterbalance effect. Even the extreme points of the measured depressions substantiated the corresponding stress values. In fact, as a whole, the depressions and stresses were mutually confirmatory.

VI. Other Activities

24. **Other Activities.**—Other activities of the staff of the committee during the past few years have been quite varied and extensive. The progress of several of the analytical and experimental investigations has been reported from time to time in the annual discussions by the chairman published in the Proceedings of the American Railway Engineering Association. A few of the activities of the staff may be mentioned.

The observations on stretches of continuously welded rail have now covered a period of four years on the Delaware & Hudson Railroad and three years on the Bessemer & Lake Erie Railroad. Observations on the service tests of various types of joint bars, made in cooperation with the Committee on Rail, have now extended over a period of three years. These observational tests of rail joints have been continued on 12 half-mile stretches of track on the Pennsylvania Railroad and 9 one-mile stretches on the Atchison, Topeka & Santa Fe Railway.

Tests with the rail joint rolling load machine have continued over a period of 1½ years. These laboratory tests of long-time repetitive loading of rail joints have been made to study some of the many problems of rail joints. They include forms of joint bars, manner of failure, wear of bar and fishing surface, and sources of failure. The life of joint bars under repetitive loading given by very heavy wheel loads and moderately heavy wheel loads and lighter loads and the possible relations between cycles of loading and the fatigue strength of joint bars of different form and different material have been taken up. The effect of abnormal stresses and bearing pressures between bar and rail and magnitude of bolt tension have been considered.

In the summer of 1939 the committee again cooperated with the Pennsylvania Railroad in making field tests at Dover, Del. The purpose of these tests was to obtain quantitative information on the action of types of locomotives with the driving wheels slipping and spinning and also to learn the action of the locomotive and track when a mechanical oscillator is attached to a main driving wheel. The results of these tests will be reported at some later time.

The staff has continued the study of electrical strain measuring and recording instruments and when funds were available purchases have been made of items that seemed most immediately useful and most adaptable to probable future needs. A considerable amount of development work has been done in connection with the use of the resistance strip gage. Experimental units constructed showed considerable promise for improving the usefulness and reliability of the strip gage and giving advantages in calibration, frequency response, and elimination of certain troubles experienced previously. As a result of the satisfactory operation of the experimental models, six complete units have been built and used in recent tests on the Denver & Rio Grand Western Railroad at Green River, Utah. These tests were somewhat of an exploratory nature to determine if possible by means of measurements of vertical web stresses in the rail, developed under the passage of locomotive and cars, the possible cause of longitudinal web cracks in the 112-lb. rail that has been in service only a comparatively short time. It is believed that the new equipment represents an important advance in stress measuring apparatus for track and equipment, both in simplicity and in applicability in making tests.

Many problems of importance bearing on the behavior of railroad track under moving loads of locomotives and cars still call for information and explanation. The committee is considering plans for further work.

THE SPECIAL COMMITTEE ON STRESSES IN RAILROAD TRACK

A. N. TALBOT, *Chairman.*

MEMOIRS

MEMOIR

George Stokes Fanning

Died January 2, 1941

George Stokes Fanning was born in Detroit, Mich., on April 25, 1885, the son of Charles A. and Carrie (Stokes) Fanning. He attended the University of Michigan at Ann Arbor and was graduated with the degree of B.S. in C.E. in 1906. He married Nola M. Bell of Saegertown, Pa., on June 18, 1914. They had one daughter, Janet A., who, with Mrs. Fanning, survives him.

George Stokes Fanning

Mr. Fanning entered railroad service in 1906 as a rodman for the Michigan Central Railroad. From 1907 to 1910 he was instrumentman and assistant engineer of the Detroit River Tunnel Company. From 1910 to 1913 he was resident engineer on the Algoma Central & Hudson Bay Railway. In 1913 Mr. Fanning entered the employ of the Erie Railroad and served in 1913–14 as resident engineer; 1914–16 as estimating engineer; 1916–18 as chief draftsman; 1918–20 as assistant to chief engineer; 1920–25 as office engineer; 1925–27 as principal assistant engineer; 1927–29 as assistant chief engineer; and from 1929 until his death as chief engineer. His office as chief engineer of the Erie was at Cleveland, Ohio.

He became a member of the American Railway Engineering Association in 1918, and gave a great deal of time and interest to committee work. He was chairman of Committee 1—Roadway, from 1933 to 1938. He was a director of the Association from 1933 to 1936; vice president from 1938 to 1940; and president from March 1940 until the time of his death. He was also a member of the American Society of Civil Engineers, having just been elected to membership in that society in December 1940.

His work with the American Railway Engineering Association was outstanding. He was a familiar figure at the annual conventions of the Association and actively entered into the discussion of committee reports, contributing largely through his constructive thinking and the clear expression of his views. Mr. Fanning had an unusual ability to express himself forcibly and clearly in discussing committee reports from the floor of the convention, and his work with the committees played an important part in the presentation of informative reports.

He was energetic in presenting new ideas, and strove constantly to improve the work of the committees, with the object of strengthening the position of the Association and giving greater force and weight to its conclusions.

Mr. Fanning had a thorough grasp of engineering problems which he always presented in a very forceful manner; his disarming frankness and pleasing personality were of great help to him in all of his contacts with his superiors, associates, public officials and others. He possessed to a marked degree the faculty of inspiring confidence and invariably insisted on obtaining definite results. He had a fine ability to grasp a situation quickly and make a prompt decision. He devoted his time to the main essentials of matters before him and was willing to leave the details to his subordinates.

During the portion of the year in which Mr. Fanning was president of the American Railway Engineering Association he was most active and interested in the work of the committees. To present his ideas effectively, he attended at least one meeting of 14 of the committees and wrote letters to the chairmen of 8 others setting forth what he would have said if he had been present at their meetings.

During his terms as vice-president and president of the Association he was very active and helpful in the work of the General Committee of the Engineering Division of the Association of American Railroads and also as a member of the Research Committee of the General Committee. His ideas and suggestions concerning the work of the General Committee and of the Research Committee contributed largely to the building up of the organizations of these committees as they now exist.

Mr. Fanning was a well balanced engineer; he combined practical knowledge with technical training and these, together with his pleasing personality, placed him at the top of his profession where he commanded the respect of all of his colleagues.

He was a member of the University of Michigan Club, a member of the Cleveland Chamber of Commerce, and a member of the "Cleveland Roamers", a golf organization in Cleveland and vicinity from which he derived a great deal of pleasure. He belonged at one time to the Canterbury Country Club in Cleveland, resigning about 1939 when the acquisition of a farm in Western Pennsylvania gave him a new interest. From that time on much of his spare time was occupied in the keenest of enjoyment of leisure hours on this farm and in plans to make this country place in Pennsylvania his home after his retirement from active professional life.

He was a man of broad interests, and read extensively on topics of a general nature in addition to engineering literature. Although it was not generally known to many associates, he possessed a natural talent for art and music, and the sketches which he made of scenes and objects that interested him were of considerable merit. As a young man he played the piano very well and he was not too busy to continue this through his later years.

Mr. Fanning was deeply interested in young men, particularly in those who entered the engineering profession, and he was influential in putting forward the recent amendment to the constitution of the AREA establishing the grade of Junior Member. Through his sympathetic interest he made a lasting impression on a number of young men who came to him for assistance and who gained much from his wise counsel.

While he was known throughout the AREA and admired greatly for his professional attainments, and his opinions and judgment were greatly respected by the membership, those who knew Mr. Fanning best admired him most for those fine qualities of character, moral integrity, high and noble purposes and for his love of home and family. He was the type of engineer and gentleman who attains the summit of his profession and whom the profession delights to honor. In the untimely death of Mr. Fanning the Association, the engineering profession and the railroad industry have sustained great loss.

E. M. Hastings, *Chairman*
C. J. Geyer
H. F. King
F. R. Layng
F. E. Morrow
W. H. Penfield
Committee on Memoir.

Memoir

John V. Neubert

Died June 4, 1940

The American Railway Engineering Association records with deep regret the death, at New York, on June 4, 1940, of Past-President John V. Neubert.

John V. Neubert was born at Kittanning, Pa., on July 18, 1876. Upon graduation from Pennsylvania State College in 1899 with the degree of Bachelor of Science in Civil Engineering, he entered the service of the New York Central & Hudson River Railroad, now a part of the New York Central System, with which system he spent his entire professional life.

Following his employment as a clerk on July 3, 1899, his personality and outstanding abilities were recognized by successive promotions. In August, 1899, he was transferred to the engineering department where he served as chairman, rodman and inspector prior

John V. Neubert

to being appointed assistant supervisor of track in September, 1900. In May, 1902, he became supervisor of track, and in July, 1903, assistant engineer in the office of the division engineer at Albany, N. Y. In 1907, he was promoted to division engineer at Albany, and in April, 1909, to engineer of track, Lines East of Buffalo, exterior zone. He became engineer maintenance of way of the same territory in July, 1920, with headquarters at New York. In October, 1927, he was appointed chief engineer maintenance of way of the New York Central Lines East and West of Buffalo, including the Ohio Central Lines, with headquarters as before at New York. In September, 1931, his jurisdiction was extended over the Cleveland, Cincinnati, Chicago & St. Louis and the Michigan Central railroads, thus becoming chief engineer maintenance of way of the New York Central System, which position he held at the time of his death.

Mr. Neubert became a member of the American Railway Engineering Association in 1911. He served as a member of Committee 2—Ballast, as a member of Committee 3—Ties, as a member and for four years as chairman of Committee 4—Rail, as a member and for six years as chairman of Committee 5—Track, as a member of Committee 26—Standardization, as a member of the Special Committee on Stresses in Railroad Track, as a member of the Special Committee on Clearances, and as a member and for two years as chairman of the Special Committee on Complete Roadway and Track Structure. He became a director of the American Railway Engineering Association in 1927, second vice-president in 1930, first vice-president in 1931 and president in 1932.

Mr. Neubert displayed intense interest in the affairs of the American Railway Engineering Association, and gave unselfishly and unstintingly of his time and experience in the furtherance of its activities. He was widely known, highly respected, and held in deep affection throughout the railway world. His ability as a railway engineer was only enhanced by his many endearing human qualities. In addition to those qualities so essential to effective leadership, he was endowed with and had fully developed a high order of mental alertness which enabled him to grasp quickly the essential elements of any problem with which he was confronted. The capacity and accuracy of his memory was amazing.

All who knew Mr. Neubert will miss him keenly. By his death the American Railway Engineering Association has lost a valued member.

John E. Armstrong, *Chairman*
C. B. Bronson
E. M. Hastings
F. E. Morrow
A. R. Wilson
W. P. Wiltsee
Committee on Memoir.

Memoir

Robert Faries

Died September 8, 1940

The American Railway Engineering Association records with deep regret the death at Philadelphia on September 8, 1940, of Robert Faries, a director of the Association.

Robert Faries was born at Bellwood, Pa. November 30, 1881. Upon graduation from high school at Altoona, Pa., in May, 1899, he entered the service of the Pennsylvania Railroad as a laborer in the maintenance of way department, and his entire professional career was spent in the service of that property.

His outstanding ability and leadership were recognized by successive promotions to the position of rodman, transitman, assistant supervisor, supervisor, division engineer and superintendent, and on February 15, 1928 he was appointed assistant chief engineer-maintenance, which position he held at the time of his death and in which he exercised general supervision over maintenance of way on the Pennsylvania system.

As assistant chief engineer-maintenance, he was largely responsible for marked improvements in track conditions and reduced maintenance expenditures brought about by the stablization of roadbed that resulted from the comprehensive system of drainage

Robert Faries

which he initiated. He also believed firmly in the mechanization of maintenance of way forces in all departments, and because of his leadership in this field the Pennsylvania became one of the outstanding railroads in the use of work equipment. He had an active and personal interest in the development and advancement of younger men serving under him, and he gave freely of both time and thought to the building of a strong personnel.

Mr. Faries became a member of the American Railway Engineering Association in 1929. He served as a member of Committee 27—Maintenance of Way Work Equipment; the Special Committee on Stresses in Railroad Track; Committee 4—Rail, of which committee he was vice-chairman at the time of his death; and served as chairman of the Committee on the Relation of Track and Equipment of the Association of American Railroads from the time of its formation until his death. He was elected a director of the American Railway Engineering Association in 1939. During all the years of his membership he was keenly interested in the affairs of the Association and gave fully and unselfishly of his time and ability to the advancement of its interests.

Mr. Faries was widely known, and his ability as a railroad maintenance officer was recognized. His long experience in and practical knowledge of railroad maintenance of way problems and practices qualified him to serve on and direct fact finding committees representing the railroads in a number of hearings before committees of the United States Senate and other governmental bodies. In this capacity he performed a very valuable service for the railroads. His now well known testimony in the minimum wage hearings under the provisions of the Fair Labor Standards Act of 1938 is outstanding and has been frequently used.

All who knew Mr. Faries miss him keenly. His unassuming leadership won for him an enviable position in his chosen work and endeared him to all his associates. By his death, the American Railway Engineering Association has lost a valued member, and the railroad industry a man who cannot well be spared.

Memoir

Lawrence Aloysius Downs

Died August 10, 1940

Lawrence Aloysius Downs was born at Greencastle, Ind., on May 9, 1872. His parents were James and Mary (McCarthy) Downs. He was the youngest of a family of eight—six sons and two daughters.

His earliest impressions of business or a chosen occupation were associated with railroad operation through his father's employment as a section foreman on the Vandalia Railroad, now a part of the Pennsylvania System.

The maintenance of a family group of ten in the late eighties necessitated the sustained observance of diligence, thrift and resourcefulness. The father, a strict disciplinarian, by the example he set, instilled in his children these qualities as well as

Lawrence Aloysius Downs.

mutual helpfulness and tolerance. The salary of the section foreman was supplemented by the products raised through work of the children on the small farm where the family lived. Each son and daughter was allotted tasks about the house and farm. It is well known that these assignments when well done received the approbation of the superior officer. If improperly executed, the worker was given another chance. During the summer vacations the boys, when old enough, were given jobs on the section gang with their father.

It was during this early period that Lawrence Downs acquired the fundamental qualities which were so manifest in his life's work. He entered heartily into all these boyhood jobs with the definite assurance that he would succeed, and at the same time was engaged in making a study of some other position he confidently hoped to occupy. This principle controlled his varied activities during his many years of railroad service. He accepted a promotion to an office he knew he was qualified to fill and then began an intimate study of the duties and responsibilities of the next higher office to which he might be appointed.

Lawrence Downs obtained his preliminary educational training in the public schools, St. Paul's Academy and DePauw University at Greencastle, Ind. He entered Purdue University at Lafayette, Ind., in 1890 and graduated in 1894 with the degree of B.C.E. He completed the curriculum for a degree in engineering with distinction and acquired an enviable reputation in athletics and other student activities. He was a tackle on the undefeated Purdue football team in 1892, was a member of the glee club and engaged in debates. He was elected a member of the Sigma Chi Fraternity in his sophomore year. In his senior year he was elected president of the University Athletic Association, the highest honor which could be conferred on a student by the student body. Purdue University conferred the degree of Doctor of Engineering on Lawrence Downs in 1929, and Centenary College (Shreveport, La.) the degree of L.L.D. in 1931.

Immediately after his graduation from Purdue University he took his initial step in railway service by accepting the position of rodman in an engineering party of the Vandalia Railroad, at a salary of $40 per month. In March 1896 he entered the engineering department service of the Illinois Central System as a rodman at $60 per month, the beginning of a railroad service of more than forty-four years, ending with his death August 10, 1940, as chairman of the board. His first promotion came six months after he entered the service when he was advanced to the rank of instrumentman. A year later he was promoted to assistant engineer and about another year later was appointed roadmaster. During the period 1898–1907 he served in this capacity on four of the operating divisions of the railroad. Each change as roadmaster brought him into fields of more complex road department problems and greater responsibility.

His success in handling division maintenance of way work led to his promotion to assistant chief engineer maintenance of way, Illinois Central System, with supervision over roadway and maintenance work for the entire system. Here was offered the wider field of studying the needs for organization, use of materials and standards for a north and south trunk line system. It was while occupying this responsible position that Lawrence Downs made a decision which changed the character of his railroad service and eventually carried him to the post of greatest responsibility in the Illinois Central organization. His fourteen years' service in the engineering department brought him in intimate touch with the work of the operating officers, and he observed the rapid promotions made in that department. He knew too the position immediately ahead of him was filled by a capable young man who without doubt would be chief engineer for many years. Accordingly, at his own request, Mr. Downs was transferred in 1910, at the age of 38, to the operating department on a division on the western extremity of the system. After mastering the details of his new position and studying the needs of divisional operation he devised ways and means for presenting essential operating data. His engineering training and experience impressed him with the value of analytical charts and diagrams, and he adapted such implements for his use. With data compiled in this manner the whole operation would indicate at a glance where the weak spots were and what remedial measures should be applied. Under his forceful direction, in two years the Iowa division was deemed the model of divisional operation on the system. From 1910 to 1915 he accepted two transfers as superintendent, each being in recognition of work well done and each successive assignment of greater responsibility.

The success of Lawrence Downs as a superintendent and his ability as an operating officer was rewarded in 1915 by his promotion to the office of general superintendent on the Illinois Central System lines south of the Ohio river. Then followed his transfer to a similar position of greater responsibility on the system lines north of the Ohio river in 1916, and in 1919 his responsibilities were again increased by his promotion to the position of system assistant general manager.

In 1920 he was elected vice-president and general manager of the Central of Georgia Railway, a subsidiary of the Illinois Central, operating 1,800 miles of railroad in Alabama, Georgia and Tennessee. Four years later he was advanced to the presidency of the Central of Georgia as well as its subsidiary, the Ocean Steamship Company of Savannah, a coastwise steamship line serving the ports of Savannah, New York and Boston. During his term as president directing the policy and operation of these properties they were substantially improved and their earnings were increased beyond those of any like previous period.

The conspicuous success of Lawrence Downs as an engineer, minor operating officer and chief executive railway officer won his election as president of the Illinois Central System to succeed the late Charles H. Markham, who retired from the presidency of the company in September 1926. Under Lawrence Downs' direction the Illinois Central System pursued a progressive and long distance policy; the roadbed and the motive power and equipment were improved to meet the wishes of the public for faster and better passenger service and a speedier delivery of freight; stress was placed on the development of industry and agriculture on the Illinois Central System territory; a higher value on the development of foreign commerce through the gulf ports; and the use of analytical charts disclosing new records of operating efficiency.

Lawrence Downs was "Larry" to his associates who grew up with him in the service of the Illinois Central System. They had learned to appreciate "Larry's" sincerity, judgment, fairness and integrity. They were delighted to witness his rapid advancement in responsibility in the company's service. They worked as willingly and diligently to advance the company's interests as "Larry" was earnestly striving to protect theirs. The relationship was not that usually existing between the employer and the employee. It was that growing out of the application of the principles of the golden rule.

On the eve of the present century, when the railroads of the United States were emerging from the depression of 1893, there was urgent need for an engineering organization whose medium would permit of the exchange of views on railway engineering standards and practices. The forward looking railroad companies had adequate engineering staffs that had developed good practices and economical designs of track, bridges and other structures. Some of them might have been reluctant to permit the less fortunate lines to benefit from their work. The benefits of such an organization so far outweighed the loss to an individual company that in 1898 the leaders in railway construction and maintenance formed an organization which would admit to its membership railway officers engaged in the construction and maintenance of railways in the United States, Canada and Mexico. This organization came into being as the American Railway Engineering and Maintenance of Way Association (now the AREA). Lawrence Downs was admitted to membership in 1898 as Charter Member No. 80.

Mr. Downs visualized the benefits accruing to such a membership. He not only anticipated the value to him in his advancement in the railway engineering profession, but also the benefits accruing to the company that employed him. He found out in what respect his fellow engineers' designs and practices were better than his, and it gave him an opportunity of contributing his full share to the success of railway engineering.

MEMOIR

William Benson Storey

Died October 24, 1940

William Benson Storey was born in San Francisco on November 17, 1857, and spent much of his boyhood in Colfax, Placer County, Calif. Following attendance at high school in Oakland, he worked for a year in a railroad engineering party before entering the newly established University of California at Berkeley, where he took the mechanical engineering course and from which he graduated in 1881, receiving the degree of Bachelor of Philosophy. He married Laura B. Roe (nee Rice) of San Francisco on May 21, 1913, who died September 3, 1940. Mr. Storey is survived by a sister, Mrs. J. F. Nash of Alameda, Calif., and a brother, Alfred J. Storey of Humboldt County, Calif.

His career following graduation from the university was spent almost entirely in railroad work—in location and construction parties, much of it in the mountainous wilderness that was the West; on lines that are now parts of the Santa Fe, the Southern

Pacific and the Union Pacific systems; and in reconstruction, improvement and administrative work. In 1894 and 1895 he was assistant engineer for the California Debris Commission, in the regulation of hydraulic mining debris discharged into streams.

In 1900 Mr. Storey was appointed chief engineer of that portion of the Atchison, Topeka & Santa Fe System east of Albuquerque, N. M., and north of Purcell, Okla., with headquarters at Topeka, Kans., and in 1906 was promoted to chief engineer of the system, with headquarters at Chicago. He was then, successively, vice-president of the Santa Fe from 1909 to 1917, federal manager from 1918 to 1919, and president from 1920 to 1933, when he resigned as president but remained as a member of the board of directors and of the executive committee.

Mr. Storey was a charter member and a past-president of the American Railway Engineering Association; he served as director in 1911–1912, second vice-president in

1912–1913, first vice-president in 1913–1914, and president in 1914–1915, and was made an honorary member in 1938. He also served on the committees on Water Service in 1900–1901, Ballasting in 1902–1903 (chairman in 1903), Economics of Railway Location in 1905–1909 (chairman in 1908–1909), and Cooperative Relations with Universities in 1924–1925.

He was a life member of the American Society of Civil Engineers, a life member of the Western Society of Engineers, and a life member of the American Society for Testing Materials. He was given the honorary degree of LL.D. by the University of California in 1924, and was a member of Phi Beta Kappa, Sigma Xi, and Zeta Psi. He held memberships in the Pacific Union Club and the Bohemian Club of San Francisco; the Chicago Club and the University Club of Chicago; and the Midday Club of New York.

Among his interests outside the fields of railroading and engineering, Mr. Storey was a director of the Continental Illinois National Bank & Trust Company and of the Personal Loan & Savings Bank, both of Chicago, and a trustee of the Carnegie Institution of Washington. Beginning in 1934 he was a member of a board of review appointed by the Secretary of the Interior which passed on plans for the construction and improvement of the sewage purification works of the Chicago Sanitary District. He was also, from 1933, a member of the board of directors of the Chicago Crime Commission.

Mr. Storey's unostentatious interest in philanthropic, cultural and educational work is revealed by his bequests of $8,000 each to the Community Trust, the Art Institute and the Field Museum, of Chicago, and a gift of $25,000 to the University of California, divided equally between the university endowment fund and a fund for the aid of needy engineering students.

A highly interesting autobiography was prepared by Mr. Storey in 1939. Born in San Francisco when the epic days of California were opening into full flower, Mr. Storey proved himself a capable and worthy heir to the many and great opportunities for service and accomplishment which that era provided. The first four decades of his life were filled with the work and hardship associated with pioneer life and railroad reconnaissance, construction and operation in newly developed territory, and were only the opening chapter of an exceptionally able and distinguished career. Quiet and reserved by nature, but with a balanced personality, his sterling qualities won the highest regard and devotion of his associates and a host of his friends. Possessed of the concentration and energy of a splendidly trained and disciplined mind, and an impersonal, unbiased and decisive judgment, he was elevated to a position of great responsibility by his high and ready abilities vitalized and supported by integrity, strength and decision of character, and by courage and promptness in accepting responsibility, seizing initiative and giving leadership. His life and achievements constitute a tribute and monument to the engineering profession, and his death is a great loss to his friends, to the American Railway Engineering Association, and to his country. Such great and honorable success, such happy exemplification of opportunity and reward profusely written upon the pages of the American Way of Life, are inspiration and hope through all the years to every generation of American youth.

Edwin F. Wendt, *Chairman*
J. L. Campbell
L. C. Fritch
G. W. Harris
G. W. Kittredge
C. A. Morse
Committee on Memoir.

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(An autobiography, reprinted with permission from the Journal of the Western Society of Engineers for February 1940)

Born in San Francisco, Calif., on November 17, 1857, I remember very little of my early years except that we lived in various places. Finally, in 1866, we located in Colfax, a small town in the foothills of the Sierra Nevada mountains, in Placer county, Calif. This was then the terminus of the Central Pacific Railroad which was building from Sacramento eastward over the mountains toward a connection with the Union Pacific to form the first transcontinental road and, late in 1865, the line had been completed to Colfax, a distance of 54 miles.

My father was express, stage and news agent and early put me to work, first in delivering the daily newspapers about the town and later in assisting him in the express business, the principal work of which was to transfer express matter from stage to train and from train to stage. The express office was located at the railroad station and, early in life, I became familiar with the details of railroad practices. As the trains and stages arrived in the mornings and evenings, I was able to do the work required without interference with school hours. I attended the village school until 1874, when I was sent to Oakland, where I entered the high school and where I remained for three years until I was graduated.

During these three years I lived in private families where, for work out of school hours, I was given room and board. In the summer vacation of 1876 I began my first work in an engineering party. The State University had just been established at Berkeley, north of Oakland, and a railroad was being constructed to serve the new community. I was given a position as stake driver and at the end of the vacation found I had earned twenty dollars. The last two years of my stay in Oakland I lived in the family of the chief engineer of the Central Pacific Railroad and my experience there, together with the fact that I found geometry and trigonometry very easy, probably first turned my mind toward the engineering profession.

I recognized, however, that an engineer requires an education, and that at first seemed beyond my reach, since my father was not able to send me to college. I finally decided to go to work for a year and then by using the money thus earned and with what I had succeeded in saving while a boy in Colfax, I could manage to get in two years at the University. I passed the entrance examination at the university and then went to work with an engineering party, on construction, where I worked for about fourteen months until the opening of the next college year. I entered the university in 1878 and devoted myself largely to studies that would be useful to me as an engineer. At the end of the two years' course I found I could be graduated with one year more of work. Upon consultation with my father, he offered to loan me enough to carry me through, and so I remained the additional year and was graduated, not as a civil engineer, but with degree of Bachelor of Philosophy in the class of 1881. While at college, with my year's experience on railroad construction before me, I had reached the conclusion that my decision to follow civil engineering as a profession was a mistake, since the openings were few, the returns small and the future very uncertain. It should be explained that at that period there were only two important organizations in California that had need for engineers—the Central Pacific Railroad and the Spring Valley Water Company, that supplied water to San Francisco—and these companies employed only a limited number. Because of these facts I did not take the civil engineering course, but instead, the mechanical engineering. As I had had in my year's work on railroad construction more practice in the use of instruments and in surveying than was given in the university course, I felt it would be a waste of time to go over this work in the civil engineering course and that I could gain more theoretical knowledge in the mechanical course. Fate, however, overruled me and I became a civil engineer in spite of myself.

After graduation it was very necessary that I find some kind of work, as I had no money and I owed my father about five hundred dollars. I learned that a surveying party was about to be sent into Idaho by the Central Pacific, and since there was no other work in sight, I applied for and obtained a position as rodman. As it was leaving several days before commencement, I was forced to miss that great day in a young man's life. Since I had passed all final examinations, this did not affect my graduation.

We were sent to a point on the railroad in Utah north of Great Salt Lake and made a reconnaissance survey north into Idaho looking for a possible route into Oregon. We went north to a pass in the mountains separating the Great Salt lake and Snake River drainages, down Raft river to the Snake, across the Snake river desert to Wood river, up that valley to its source, over a divide into the Salmon River country along the easterly base of the Sawtooth range, and finally reached a point beyond which it was evidently impracticable to build a railroad. We had a wagon and a mule team, but as the wagon road ended at Ketchum, a town at the head of Wood river, we then had to convert our team and riding animals, seven in all, into a pack train and I was detailed as swamper to our teamster, who was head packer. We went with the pack train 125 miles beyond Ketchum and through what is known as Sun Valley—a skiing resort now being exploited by the Union Pacific. We retraced our route to the railroad and there found further instructions awaiting us. We were to go to South pass in the Rocky mountains.

We shipped our outfit to Ogden, Utah, and then added another wagon and mules; purchased supplies, made certain changes in personnel and went to South pass via the Union Pacific to Green River and from there overland. Our instructions were to make a reconnaissance survey from the summit at South pass toward Yankton, Dakota. We found out later that our survey was only a demonstration and that it was part of a game being played by the heads of the Central Pacific and Union Pacific railroads. The Union Pacific was back of a plan to build another road over the Sierras from Salt Lake into California and had seven parties in the field surveying for such a line. When this became known the Central Pacific people sent out three parties, one from a point on its line to survey to South Pass, ours from South Pass eastward, and one from Yankton to work west to a connection with us. Much publicity was given in the newspapers about our survey and the excellent route we were finding, although as a matter of fact we had sent in no report. This publicity was evidently to impress the head of the Union Pacific and in the end led to an agreement between the two roads. Each dropped its plans for building into the territory served by the other and they united in buying a controlling interest in the St. Louis & San Francisco, which, jointly with the Atchison, Topeka & Santa Fe, was building the Atlantic & Pacific west from Albuquerque, N. M., toward California. As co-owner of the Atlantic & Pacific, the two northern roads then forced the latter to stop at the Colorado river, while the Southern Pacific, which was owned by the Central Pacific people, built from its line at Mojave to connect with the Atlantic & Pacific at Needles. The Southern Pacific had shortly before connected its line with lines in Texas and this connection at the California–Arizona boundary made the third overland route, but with the Central–Southern Pacific having control of all rail entrance to California.

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However, after a few weeks in San Francisco, when offered further work on a survey to investigate the approach to Yosemite valley, I accepted and spent several months still working as a rodman. When the survey was done I assisted in mapping the country we had covered.

In the spring of 1882 I was given a position as levelman on surveys for the road toward Oregon. We worked all summer near Mt. Shasta, running lines from the Shasta summit north to the Klamath valley and south well down into the canyon of the Sacramento. At the end of the season we were called in, and while I do not recall how I was employed that winter, it was probably in working up estimates on our summer's work.

The following spring construction was begun on the extension of the Central Pacific, toward Oregon, from Redding at the upper end of the Sacramento valley through the Sacramento canyon. This work was heavy, the line was very crooked, the cuts were of rock, with many tunnels and crossings of the river. Each engineer had charge of about six miles and I was given charge of the third section, which included two tunnels. When this was finished I was moved farther up the river and on a section that had one tunnel. This construction work was carried on for a year and then, for financial reasons, was stopped and all engineering parties called in.

In the winter of 1883–84, excessive rains and floods caused much damage to the Southern Pacific in southern California when miles of track were washed out in Soledad canyon, north of Los Angeles. In Arizona the Gila river destroyed many miles of track east of Yuma and in Texas the Rio Grande caused damage for 50 miles east of El Paso. The line through Soledad canyon was relocated and I was employed for some weeks in making plans for new masonry piers and abutments. I was then sent to the line east of El Paso to give center and grade stakes for rebuilding the fills that had been washed away.

I was also sent to Yuma to retrace the original located line along the Gila and to cross-section this line for graders. At the time the line was originally built it was located above high water, but this entailed much heavier work than a line in the bottom land. Due to difference in cost, it was decided to build the cheaper line and take the chance of being flooded in the near future. However, the flood had come and taken out about twenty miles of track. While this had been replaced temporarily it was the intention to build permanently on the old and safe location. But after I retraced this line and prepared plans for construction the authorities decided not to build at that time, as floods were assumed to come long distances apart and, money being scarce, the new work could be deferred until times were more propitious, while in the meantime the old line would serve.

I was next instructed to investigate the grade on Tehachapi mountain. This line had been located on a 2.2 percent grade basis with compensation of 0.02 per degree. The line had many miles of development and was nearly all curves—a majority being ten degrees. The original location of the Central Pacific over the Sierra Nevadas was made on the same grade basis as a maximum but without any compensation. The operating department reported that identical locomotives could haul more tonnage over the Central Pacific than up the Tehachapi. I therefore undertook to find out why this should be. First I reestablished the original 50-ft. stations, and then took levels on top of each rail at each station and platted these, thus getting the mean grade line. I found the grade in many places, on the ten-degree curves, as high as 2.5 percent or higher and in such places the grades on succeeding tangents were less than 2 percent. Most of such excessive gradients were on high fills. The high fills had settled during the first years after construction and in filling up this settlement, without stakes to guide them, the trackmen had overfilled, since the curves prevented sighting with the eye, which is the usual method of the trackman. As the grades on the fills were too steep there naturally had to be compensation on the tangents.

Following these pieces of work a reorganization of the engineering department took place. The entire staff was dispensed with, excepting only men on work not yet finished. The chief engineer was left in charge of the engineering office and records, the balance of the men found themselves without work. With another engineer, I then opened an office in San Francisco under the name of Palmer and Storey. During the time this firm was in existence we built two short lines of railroad, one in Colusa county and one in Monterey county. Mr. Palmer was in charge in the field and I was in the office, but the returns were small and prospects of future work were poor. Therefore, when the Southern Pacific offered me work in charge of location and construction of a short line of road in the San Joaquin valley, I accepted and the partnership was dissolved. After this construction was finished I was offered the position of locating engineer on a line that started on the main line of the Southern Pacific at a station called Saugus, north of Los Angeles, ran down the Santa Clara valley to the coast at Ventura, up the coast to Santa Barbara and then on to San Luis Obispo and over the mountain to a connection with the Southern Pacific line already built south to a station called Templeton. I accepted this position and was engaged on this work for about a year during 1886–1887. This line from Ventura north is now part of the through Coast Line of the Southern Pacific from Los Angeles to San Francisco.

In 1888 I was sent to Washington, which was then a territory, to build a short line up the canyon of the Carbonado river connecting the Northern Pacific with the coal mine owned by the Southern Pacific. This was only about six miles long, but the work was heavy and it took me until early in 1889 to complete it. It was then turned over to the Northern Pacific under an agreement by which that road was to pay for it out of the freight earnings.

Between 1889 and 1893 I had charge of building two branch lines, one extending from Knights Landing on the Sacramento river in California, across what is known as Sutter basin, to the Feather river and connecting with a line which had been built south from the City of Marysville; the other between Merced, on the main line of the Southern Pacific in the San Joaquin valley to Oakdale in Stanislaus county, where it connected with a line from Stockton, thus forming a loop line from Stockton to Merced which opened up some fine agricultural land. I also built two stretches of the Southern Pacific in Arizona, one extending east from Yuma for 35 miles, where excessive floods on the Gila river had again taken out the original track for that distance, and the other east of Tucson to Dragoon summit, where the original line was built on a 1.5 percent basis, and it was decided to put in one on a 1 percent basis in order to make it conform with the grade system on the rest of the division.

In between these pieces of work I made examination of and reported on sections of the country not then served by the railroad. One of these was the canyons of the two forks of Feather river which afforded a railroad route to the Beckwith pass in the Sierra Nevada mountains, which pass is about 1,800 ft. lower than the pass used by the Central, now known as the Southern Pacific. This route has since been occupied by the Western Pacific, using the north fork of the Feather river. The trip through this canyon was a particularly hard one. I had to make it on foot and it took me six days from Oroville at the mouth of the canyon to Quincy in Plumas county, the first town after emerging from the canyon. There were no trails in the canyon and I carried my supplies on my back and slept on the banks of the river, without blankets. The trip down the middle fork was equally hard.

In the summer of 1893 I was sent to run a survey through the desert from San Gorgonio pass on the Southern Pacific to a connection with the Santa Fe at or near the station of Cadiz. I made a preliminary exploration to locate water holes and then organized a party and began the survey. I had asked for a sixty-day leave, beginning in time to enable me to attend the convention of the American Society of Civil Engineers in Chicago. This was granted and, therefore, before this survey was finished I went to Chicago, attended the convention and visited the World's Fair of that year. I then visited Boston, New York and Washington, and came back to San Francisco to find that there was no further work for me. In my absence the panic of 1893 had struck the country and, as a consequence, all construction work, not only on railroads but in every other line, had stopped. I could find no work of any kind for several months.

In the spring of 1894 I obtained a position as assistant engineer on the California Debris Commission. This commission had recently been formed to regulate hydraulic mining and prevent debris from being discharged into the navigable rivers of the state. It was made up of army engineers, with headquarters in San Francisco. My duties were to inspect the impounding works authorized by the commission and to see that the mining companies did not evade the law. I was engaged on this work and required to live in the mountains for about a year.

Early in 1895 a railroad company was organized to build a railroad from San Francisco down the San Joaquin valley and I applied for and obtained the position of chief engineer. The task presented was to find a way over the Coast Range into the San Joaquin valley and through this valley to its southern end, a total distance of over three hundred miles, to tap only the most important towns in the valley and to otherwise place the line a sufficient distance from the existing lines of the Southern Pacific (the only other railroad) to enable new business to be opened up, also to provide terminals on San Francisco bay. This was accomplished with a grade maximum of 1 percent for a distance of about twenty-seven miles from San Francisco bay and a maximum of 0.3 percent for the balance of the distance. Two difficult engineering problems presented themselves on this work, one the swelling ground in the 1¼ mile summit tunnel and the other, building over swamp and overflow land at the mouth of the San Joaquin for a distance of about sixteen miles.

The swelling ground was caused by the rock absorbing moisture from the air and acting similar to slaking lime. We first tried to hold this by additional timber lining, but the timbers broke like matches. We then adopted the plan of timbering lightly and, when the squeeze came, removing the lagging and excavating back of the timbers. This prevented crushing for a time, but finally the pressure above and below would get too great and the main timbers would break. We then would remove the entire set of timbers, excavate back of them and put in a new set. The time between each squeeze became longer until after we had renewed the sets in the center of the tunnel five times the squeeze ceased entirely. As we approached the ends of the tunnel the renewals grew less and less. The theory on which we worked was that the influence of the air on the rock could only extend from the walls of the tunnel a certain distance into the mountain and the affected material would form a layer beyond which there would be no swelling action.

The swamp land was composed largely of vegetable or peaty matter mixed with water, with depths to hard material of clay or sand of as much as twenty feet. Some of the country had been leveed, but the engineers said we could not maintain a railroad bank through the particular section we had selected. We succeeded, however, in spite of these predictions. Our method was to use long-arm clamshell dredges and, starting with a base one hundred feet wide, place a layer of the peaty material and allow this to dry for a number of weeks. On this we placed a layer of sand or clay from the hard bottom of our borrow pits and allowed this to dry, next was placed a layer of peat and then hard material and so on until we reached the proper height. The last layer was hard material and when this was dry we shaped it with scrapers and horses. We did have some bad slips back into the borrow pits, and slips of this sort were what made the levee engineers doubtful of our success. We, however, drove temporary trestles in these places and later, when the track was laid, hauled in and filled with sand, of which there was plenty about fifteen miles away.

About three years after we began this work the Santa Fe bought the stock of the company and made arrangements to use the Southern Pacific from the south end of our line at Bakersfield to Mojave, thus giving the Santa Fe an outlet to San Francisco and furnish a new overland route from that point. We were instructed to complete the road according to our plans, which we did, building floats to transfer cars from the east side of the bay at Point Richmond to San Francisco, tugs to handle the floats, ferry boats to transfer passengers, wharves and slips to enable transfers to be made. In July, 1900, the road was turned over to the operating department of the Santa Fe.

My experience on the construction of the Valley Road, as it was called, was of great value to me as it brought me into contact with all elements of railroad work—the construction, the accounting and the operation. We had a secretary who kept all the books, while I passed on all vouchers, supervised the preparation of all plans, both for bridges and buildings, and let all contracts. In a large corporation all these are handled by separate departments and one department knows little about the work of any other, while with our small road all departments were united in the secretary and myself.

Upon turning the road over to the operating department of the Santa Fe I was offered the position of chief engineer of its Eastern Lines, with headquarters in Topeka. The Eastern Lines at that time included all territory east of the Rio Grande, or what is now included in the Eastern and Western lines. It did not include the Gulf, Colorado & Santa Fe, as this is a Texas corporation and handled separately. I remained in this position for six years or until the middle of 1906, except that I was given leave of absence of one year—1903–1904—to make investigation relative to possible railroad routes in California between San Francisco bay and Eureka in Humboldt county.

The Santa Fe and the Southern Pacific had clashed in trying to get into this redwood country, the former having acquired an existing road from Eureka south for about fifty miles and the latter another existing road, from the bay north and access to the Eal river, down which it began surveys and announced the intention of building. I made various surveys and estimates and finally reported that in my judgment two separate railroads through the country could not be supported, and suggested that the companies form a joint company, build one road to connect the two existing roads and operate the whole for the joint benefit. This plan was followed and the Northwestern Pacific was formed; it took over the two existing roads and finally, when the new construction was completed, operated the entire property.

I then came back to the Eastern Lines and resumed work there. During my term as chief engineer we put in many permanent masonry structures in the shape of piers and abutments for bridges on the Chicago–Kansas City line, cut down the grades on the line as far west as La Junta to a 0.4 percent basis, built a number of branch lines, double tracked and reduced grades on the cut-off between Holliday and Emporia, enlarged the Argentine and Emporia yards and erected the Argentine and Chicago elevators.

During this period we had a very severe flood at Kansas City and a flood on the western territory between Byron, Colorado and El Paso, Texas, which took out the bridges over nearly all main streams and necessitated building new bridges and making certain changes of line. It was altogether a very busy period in the task of improving and modernizing the road.

In July, 1906, I was made chief engineer of the Santa Fe System, with headquarters in Chicago, having charge of all new construction and acting in a consulting capacity on all maintenance work, which was in direct charge of the chief engineers of the several parts of the System.

When I assumed this office the so-called Belen cut-off from the New Mexico–Texas line to the Rio Grande river at Belen and to a junction with the main line at Rio Puerco had been located and about half completed. I completed this and took up the work of reducing the grades on the line from Mulvane in Kansas to and through the panhandle of Texas to a connection with the Belen cut-off to a 0.6 percent basis, the cut-off having been built on the same limiting grades. This line had originally been built as a cattle line and on a 1 percent basis with 5 deg. maximum curves. We reduced the curvature to 3 deg. Later, when the second track was built from the junction of the cut-off with the main line over the transcontinental divide in New Mexico, we put this on a 0.6 percent basis, leaving the old line on a 1 percent basis as the downhill grade. We thus established a ruling 0.6 percent grade from the Missouri river to the station at Winslow, Ariz., except for two or three short stretches of pusher grade. We then constructed a connecting line between this new overland route and our Gulf lines, and succeeded in getting a 0.6 percent line all the way from the junction point at Texico to the junction with the Gulf lines at Coleman, and part of this, that from Texico to Slaton, a distance of 105 miles, on a 0.4 percent basis. In doing this we had to miss Abilene, one of the most important centers in that section, but the 0.6 percent line for through traffic was deemed of greater importance.

In addition we built many branches in the panhandle of Texas, thus opening up that country for agriculture. When we first began operations there it was entirely a grazing country and today it is covered with farms. When we opened the first line across this territory not a single car of wheat was shipped. Since then, in a good year, as much as 60 million bushels has been sent out. In addition they raise large amounts of row crops and cotton. There have been also extensive oil fields developed, and while the crude oil goes out by pipe line there is a large tonnage of lampblack which moves by rail.

I was made vice-president in charge of construction in 1909 and in 1910 I was assigned the operating department in addition to the construction. Then followed two very busy years, since it was necessary to read each file from bottom to top whenever a new subject came before me.

I served as vice-president until the end of 1917 when, our country then having become involved in the World War, the government took over the railroads and I was made federal manager of the Santa Fe.

The roads, due to the sudden increase in freight to be transferred, became badly congested and in an attempt to operate them as a unified whole a small committee was formed to which all roads became subordinate. The attorney general of the United States issued notice that if this committee acted it would be in violation of the anti-trust laws and that he would have to prosecute them. To meet this difficulty Congress could have, as a war measure, suspended the act so far as it applied to railroads for the duration of the war, but the President solved it by taking over the railroads and placing their operation in the hands of one man. He selected for this assignment Mr. W. G. McAdoo, the secretary of the treasury. Although the Armistice, which really ended the war, came in November, 1918, the government retained possession until March 1, 1920, which date was fixed by Congress. During the period of government control the properties were entirely separated from the corporations that owned them, but on the passage of the Act fixing the date for return of the roads the corporations began to prepare to receive them by arranging the personnel to handle them. The president of the Santa Fe decided to retire, and I was elected to succeed him and took office on January 1, 1920—resigning as federal manager on that date.

Under federal control the morale of the organization had suffered greatly and the roads became badly disorganized. The Santa Fe forces had been completely unionized, whereas we had contracts only with the train and enginemen brotherhoods at the time the roads were taken over. In 1922 a nationwide strike of the shop crafts occurred that seriously affected all the roads, but the Santa Fe overcame this by hiring new men, placing them under instructors, and in a few weeks were able to operate satisfactorily. Many other roads that did not pursue this method had much more trouble and finally made new contracts with the unions. After things were again running smoothly with us I asked the men to organize a Santa Fe union, feeling that if they had grievances they should have some way to deal with the authorities over them. This plan worked well during my entire encumbency. From 1920 to 1929 the business of the road increased and the net earnings went up from 52 to nearly 74 millions, the dividends on the common stock were increased from 6 percent, which had been paid for many years, to 10 percent, and the surplus increased from 87 millions in 1920 to 314 millions in 1929. We had increased the mileage by over a thousand miles by the purchase of the Kansas City, Mexico & Orient, and by building new branches and extensions. The entire business of the country was booming, production was heavy, building was active. In 1929, however, earnings began to decline and in 1932 amounted to only 20 millions, dividends had to be cut and in the following year omitted entirely on the common stock. Inasmuch as I had reached the age of seventy-five and no immediate recovery was in sight, I signified to the board of directors that I thought it wise for me to retire. The board therefore elected my successor at the reorganization meeting in May, 1933. I remained, however, as a member of the board and of the executive committee.

In the following year (1934) I was asked by the Secretary of the Interior to be a member of a board of review to pass on the plans of the Chicago Sanitary District for purification of sewage. A grant of money and a purchase of bonds had been arranged with the government, subject to its approval of the plans. This board spent several months in reviewing these plans, and on completion of this assignment we were asked to continue as a board to pass on any changes that might become necessary as the construction progressed. We hold meetings three or four times a year for this purpose but the work is expected to be completed this year.

In 1889 I was made a member of the American Society of Civil Engineers, in 1906 was elected a director, and in 1924 became a life member. I became a charter member of the American Railway Engineering Association, was elected a director in 1911, second vice-president in 1912, first vice-president in 1913 and president in 1914. I was made an honorary member in 1938. I was elected a member of the Western Society of Engineers in 1907 and became a life member in 1937. I am also a life member of the American Society for Testing Materials. In 1910 I was elected to the honor societies of Phi Beta Kappa and Sigma Xi of the University of California and in 1924 was given the honorary degree of LL.D. by my Alma Mater. In 1924 I was elected a trustee of the Carnegie Institution of Washington.

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