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BULLETIN
OF THE
NATIONAL RESEARCH
COUNCIL

PROCEEDINGS

OF THE

THIRD ANNUAL MEETING

OF THE

ADVISORY BOARD ON HIGHWAY RESEARCH, DIVISION
OF ENGINEERING, NATIONAL RESEARCH COUNCIL

Held at Washington, D. C.

November 8-9, 1923

EDITED BY

WILLIAM KENDRICK HATT, *Director, Advisory Board*

AND

E. R. OLBRICH, *Assistant to the Director*

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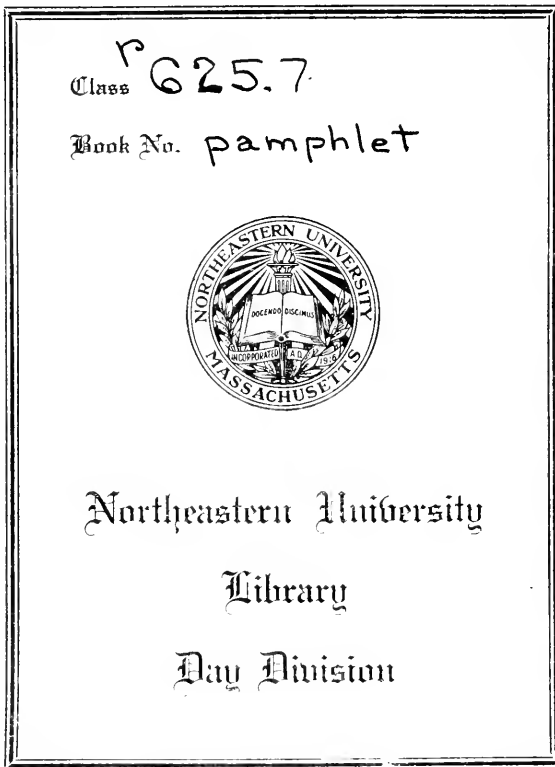
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THE ADVISORY BOARD ON HIGHWAY RESEARCH,
DIVISION OF ENGINEERING, NATIONAL
RESEARCH COUNCIL

Edited by WILLIAM KENDRICK HATT, *Director, Advisory Board*
and
E. R. OLBRICH, *Assistant to the Director*

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PART I

SUMMARY OF DEVELOPMENT OF ADVISORY BOARD

CHRONOLOGICAL STATEMENT

The National Research Council was established in the spring of 1916, when President Wilson requested the National Academy of Sciences to organize the scientific and engineering forces of the United States for the purpose of defense. The Engineering Committee of the National Research Council did effective work during the war.

On May 18, 1918, by executive order, President Wilson perpetuated the National Research Council and attached it to the National Academy of Sciences, which had been incorporated by congressional charter, approved by President Lincoln, March 3, 1863.

The Division of Engineering of the National Research Council occupies offices in the Engineering Societies Building, New York. The Engineering Foundation, which is closely affiliated with the Engineering Division, provides an office for the Division adjoining its own, and contributes a portion of the funds needed for the administrative expenses of the Division.

Advisory Board on Highway Research:

On October 26, 1920, the Chairman of the Engineering Division addressed a communication to the governing boards of certain national organizations, Federal and State departments, and educational institutions, stating the need for highway research, outlining projected committee organization, and inviting representatives to a conference for the purpose of completing the organization.

At that meeting, held November 11, 1920, an Advisory Board on Highway Research was organized and by-laws adopted.

BY-LAWS OF ADVISORY BOARD

*As Adopted November 11, 1920, and Amended January 16, 1922;
August 4, and March 23, 1923*

- (1) *Name:* Advisory Board on Highway Research of National Research Council.
- (2) *Purposes:*
 - (a) To assist in outlining a comprehensive national program of highway research and coordinating activities thereunder.

- (b) To organize committees for specific problems.
 - (c) To deal with ways and means.
 - (d) To act in a general advisory capacity.
- (3) *Membership:* Those organizations of national importance interested in design, construction, economics, maintenance and financing of highways, in materials and equipment therefor, and in vehicles used on highways; governmental departments and bureaus of similar interests, and the higher educational institutions, each acting through one duly appointed representative, with authority to name an alternate, serving until appointment of his successor. New organization members shall be elected by letter ballot of the Board upon recommendation by Executive Committee. Qualification shall be completed within three months by appointment of a representative.
- (4) *Officers:* Chairman, Vice-Chairman and Director, who shall perform the usual functions. Chairman and Vice-Chairman elected annually by the Board in meeting or by letter ballot; to serve one year from January 1 following election, or until successors qualify. In case of letter ballot, nominations shall be made by Executive Committee or by Division of Engineering.
- (5) *Director:* Shall be engaged by Executive Committee and serve at the will of that committee; shall be paid a salary fixed by that committee; shall be the executive officer of the Board; shall be a professional engineer; shall devote his whole time to the duties of his office; shall account to the Executive Committee for all moneys received and disbursed.
- (6) *Administrative Committees:*
 - (a) *Executive:* Consisting of the Chairman, the Vice-Chairman and five additional members chosen by the Board, at least two of whom shall also be members of the Division of Engineering. Should a vacancy exist in the Executive Committee, it shall be filled by a vote of the remaining members.
 - (b) *Ways and Means:* Three members appointed by the Chairman.
Duties: Those indicated by the titles and such others as may be assigned by the Board. Executive Committee shall also aid Chairman and Director in carrying out instructions of the Board and in formulating projects to be

presented to the Board; shall act for the Board in routine matters, and shall control publicity.

- (7) *Research Committees*: Shall be created by the Board, as deemed necessary, with the approval of the Division of Engineering. Members shall be appointed by the Chairman of the Board with approval of the Executive Committee, and need not be limited to members of the Board. The term of services of members of Research Committees shall be limited to one year, but they are eligible to re-appointment. The following are established upon adoption of these By-Laws:

(a) Bibliography.¹

1. Economic Theory of Highway Improvement.
2. Structural Design of Roads.
3. Character and Use of Road Materials.
4. Highway Traffic Analysis.
5. Highway Bridges.¹
6. Highway Finance.
7. Maintenance of Highways.

- (8) *Meetings*: Annual meeting, second Thursday of November, at a place to be designated by the Chairman. Other meetings at call of Executive Committee, on twenty days' notice.
- (9) *Amendments*: May be made by a majority of the Board, on thirty days' notice, by letter ballot.

The purposes of the Board are, briefly: To prepare a comprehensive national program for highway research; to assist existing organizations in coordinating their activities and to collect and distribute information of completed and current research.

On July 11, 1921, the Executive Committee met and engaged a Director and authorized the Chairman and Vice-Chairman to prepare cooperative agreements with the Bureau of Public Roads, the State Highway Departments, and other organizations adapted to instituting and coordinating a national program for highway research. It was voted that the National Research Council be requested to act as financial agent for the Advisory Board, and that the Vice-Chairman of the Board be authorized to approve bills and sign requisitions for payment of expenses.

The following resolutions on committees were adopted:

Noted,—that no person be appointed to a research committee under the auspices of the Advisory Board on Highway Research who

¹ Committee not organized.

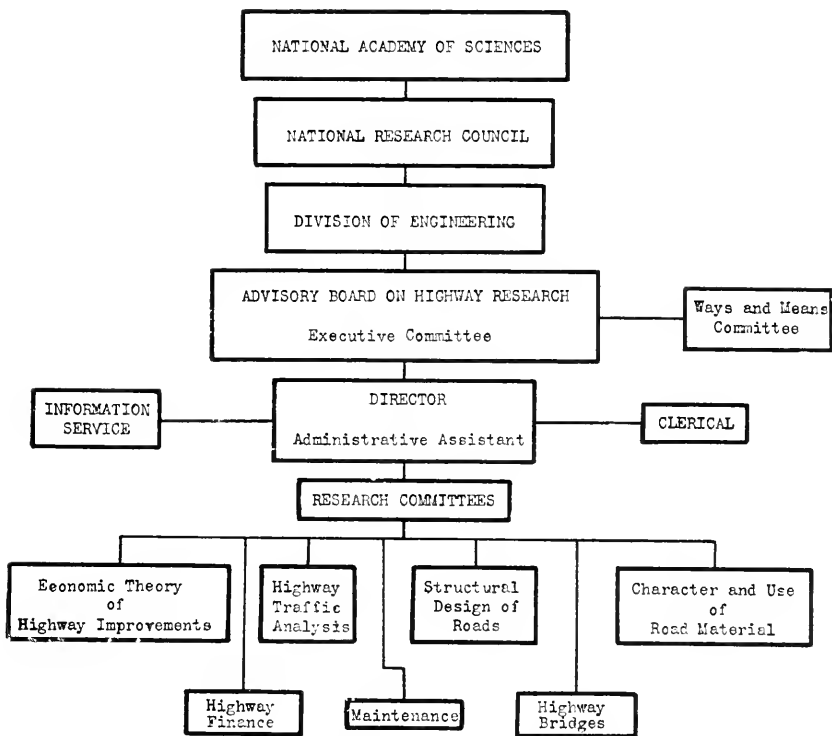
cannot devote sufficient time to the committee's work and that the personnel of each committee be subject to approval by the Executive Committee.

It is the consensus of opinion that, whenever desirable, the personnel of a committee shall include suitable representatives of interested industries.

On December 2, 1921, a report of this conference was sent to all participating individuals and organizations.

Later activities of the Advisory Board on Highway Research are summarized in the published proceedings of the annual meetings.

ADVISORY BOARD ON HIGHWAY RESEARCH: CONSTITU- ENT MEMBERS AND REPRESENTATIVES



OFFICERS AND MEMBERS OF EXECUTIVE COMMITTEE FOR 1924

Chairman: A. N. Johnson, Dean, College of Engineering, University of Maryland.

Vice-Chairman: Alfred D. Flinn, Member, American Society of Civil Engineers; Director, Engineering Foundation; formerly Deputy Chief Engineer, Catskill Water Supply for New York City.

Other Members of Executive Committee:

Thomas H. MacDonald, Chief of Bureau of Public Roads, U. S. Department of Agriculture.

T. R. Agg, Division of Engineering, N. R. C., Iowa State College.

H. C. Dickinson, U. S. Bureau of Standards.

A. J. Brosseau, President, Mack Trucks, Inc.

C. M. Upham, State Highway Engineer, North Carolina.

MEMBER ORGANIZATIONS AND THEIR REPRESENTATIVES

- American Association of State Highway Officials:
Representative, Clifford Older
- American Concrete Institute:
Representative, C. R. Ege
Alternate, E. J. Moore
- American Institute of Consulting Engineers:
Representative, Philip W. Henry
Alternate, F. A. Molitor
- American Society of Civil Engineers:
Representative, Robert A. Cummings
Alternate, J. S. Langthorn
- American Society of Mechanical Engineers:
Representative, H. de B. Parsons
Alternate, Daniel E. Moran
- American Society for Municipal Improvements:
Representative, Nelson P. Lewis
Alternate, Manley Osgood
- American Society for Testing Materials:
Representative, Prevost Hubbard
Alternate, A. N. Johnson
- Associated General Contractors of America:
Representative, H. H. Wilson
Alternate, George M. Eady
- Association of American State Geologists:
Representative, H. A. Buchler
Alternate, E. B. Mathews
- Bureau of Public Roads, U. S. Department of Agriculture:
Representative, Thos. H. MacDonald
Alternate, A. T. Goldbeck
- Bureau of Standards, U. S. Department of Commerce:
Representative, W. A. Slater
Alternate, H. L. Whittemore
- Corps of Engineers, U. S. Army:
Representative, Col. John C. Oakes
- Eno Foundation for Highway Traffic Regulation:
Representative, William P. Eno
- Engineering Foundation:
Representative, Alfred D. Flinn
- National Automobile Chamber of Commerce:
Representative, A. J. Brosseau

- National Highway Traffic Association:
 Representative, Arthur H. Blanchard
 Alternate, George H. Pride
- Rubber Association of America:
 Representative, H. S. Firestone
 Alternate, A. L. Viles
- Society of Automotive Engineers:
 Representative, David Beecroft
 Second Representative, H. W. Alden
 Alternate, Henry M. Crane
- Western Society of Engineers:
 Representative, A. N. Talbot
 Alternate, Linn White
- American Road Builders Association:
 Representative, H. E. Breed
 Alternate, H. G. Shirley
- National Safety Council:
 Representative, R. I. Kelker, Jr.
 Alternate, Fred M. Rosseland
- Association of Land Grant Colleges:
 Representative, Anson Marston

RESEARCH COMMITTEES

(1) COMMITTEE ON ECONOMIC THEORY OF HIGHWAY IMPROVEMENT

Problem: To determine all of the elements of cost of highway improvement.

The following will suggest the type of research involved:

- A. Effect of grades, alignment, rise and fall, weather and speed and methods of operation on cost of transport.
- B. Determination of all of the elements entering into the resistance to translation of vehicles (tractive resistance) and magnitude of each element.
- C. Determination of the elements of cost of vehicle transportation classed as capital costs, and operating costs exclusive of those included in A and B.
- D. To determine the relation between traffic and capital and maintenance costs of roads.

Membership:

- Chairman, T. R. Agg, Iowa State College
 L. E. Conrad, Kansas State Agricultural College

H. C. Dickinson, Society of Automotive Engineers
 H. S. Fairbank, U. S. Bureau of Public Roads
 A. B. Fletcher, Boston, Mass.
 H. J. Hughes, Harvard University
 Mark L. Ireland, Quartermaster Corps, U. S. Army
 E. W. James, U. S. Bureau of Public Roads
 H. J. Kuelling, Wisconsin State Highway Commission
 E. H. Lockwood, Yale University
 Charles M. Manly, New York City
 Tom Snyder, Indianapolis, Ind.

(2) COMMITTEE ON STRUCTURAL DESIGN OF ROADS

Problem: To establish all of the data required for the rational design of a road surface.

The following will suggest the type of research involved:

- A. To determine all facts relative to the behavior of the soil upon which roads are constructed, when under load from the road structure.
- B. To determine the relation between traffic loads and stress in road surfaces, and to establish the laws that control.
- C. To determine the effects of the elements on road structures.
- D. To determine the structural strength of all types of road surfaces.
- E. Relation of the vehicle to the road.

Membership:

Chairman, A. T. Goldbeck, U. S. Bureau of Public Roads
 C. A. Hogentogler, U. S. Bureau of Public Roads,
 Secretary
 Lloyd Aldrich, San Francisco, California
 H. C. Berry, University of Pennsylvania
 H. E. Breed, New York University
 F. H. Eno, Ohio State University
 E. W. James, U. S. Bureau of Public Roads
 Clifford Older, Division of Highways, State of Illinois
 H. G. Shirley, Virginia State Highway Commission
 E. B. Smith, U. S. Bureau of Public Roads
 C. M. Strahan, University of Georgia

E. W. Templin, Akron, Ohio
C. M. Upham, North Carolina State Highway Commission
H. M. Westergaard, University of Illinois

(3) COMMITTEE ON CHARACTER AND USE OF ROAD MATERIALS

Problem: To determine the most effective combinations of materials to give desired strength, and to investigate possible new combinations of materials.

The following will suggest the type of research involved:

- A. To establish the most effective combinations of materials now in use, with particular reference to the exigencies of the field control.
- B. To promote research looking to the establishment of new combinations of materials, or of the new materials suitable for road surfacing.

Membership:

Chairman, H. S. Mattimore, Pennsylvania State Highway Department
B. A. Anderton, U. S. Bureau of Public Roads
E. W. Crum, Iowa State Highway Commission
F. C. Lang, University of Minnesota
C. S. Reeve, New York City
H. H. Seofield, Cornell University
M. O. Withey, University of Wisconsin

(4) COMMITTEE ON HIGHWAY TRAFFIC ANALYSIS

Problem: To establish an adequate method of studying highway traffic and to show how traffic records should be interpreted.

The following will suggest the type of research involved:

- A. To study relation of community development of the origin and destination of traffic, and to devise means for estimating potential traffic.
- B. Proper method for studying and recording volume of traffic and for interpreting traffic records.
- C. To devise units of measure to apply to traffic and to define those units.
- D. To study the relation of highway betterment to traffic increases.

Membership:

- Chairman, Geo. E. Hamlin, Connecticut State Highway Commission
 T. R. Agg, Iowa State College
 A. H. Blanchard, University of Michigan
 N. W. Dougherty, University of Tennessee
 A. N. Johnson, University of Maryland
 Nelson P. Lewis, New York City
 J. H. Mullen, Minnesota State Highway Department

(5) COMMITTEE ON HIGHWAY BRIDGES

Problem: To establish all of the data required for the design of highway bridges.

The following will indicate the type of research required:

- A. Determination of loads for which bridges should be designed.
 - B. Study of impact on highway bridges.
 - C. Determination of the proper requirements for standards of design as regards allowable stresses, width and requirements of foundations.
- (Committee not yet organized.)

(6) COMMITTEE ON HIGHWAY FINANCE

Problem: To determine the equitable basis for financing highway improvements.

The following will indicate the type of research involved:

- A. Definition of an equitable basis for highway financing.
- B. Study of possible methods of financing improvements in the various political units.
- C. Administrative methods required to insure equitable financing.

Membership:

- Chairman, J. G. McKay, U. S. Bureau of Public Roads
 (Committee not yet organized.)

(7) COMMITTEE ON MAINTENANCE

Problem: To determine the relation between traffic and maintenance costs of roads, to investigate methods of maintenance and organization of maintenance forces.

The following will suggest the type of research involved:

- A. Establishment of accounting methods that will give accurate data on cost of maintenance.
- B. Methods of correlating maintenance costs and volume of traffic.
- C. Relation of maintenance costs to methods of maintenance.

Membership:

- Chairman, W. H. Root, Iowa State Highway Department
- H. K. Bishop, U. S. Bureau of Public Roads
- G. C. Dillman, Michigan State Highway Department
- J. T. Donaghey, Wisconsin State Highway Commission
- A. H. Hinkle, Indiana State Highway Commission
- H. G. Hotchkiss, Jr., New York State Highway Commission
- Wm. Arthur McLean, Department of Public Highways, Ontario, Canada
- T. E. Stanton, California State Highway Commission, Sacramento, California
- W. A. Van Duzer, Pennsylvania State Highway Department

REGISTRATION OF ATTENDANCE AT MEETING OF
NOVEMBER 8 AND 9, 1923

- Agg. T. R..... Iowa State College
- Alden, H. W..... Society of Automotive Engineers
- Almquist, E. G..... U. S. Bureau of Public Roads
- Anderton, B. A..... U. S. Bureau of Public Roads
- Anmun, von S..... U. S. Bureau of Standards
- Bachman, B. B..... Autocar Company, Ardmore, Pa.
- Berry, H. C..... University of Pennsylvania
- Bibbins, J. R..... Consulting Engineer, Washington, D. C.
- Bishop, H. E..... U. S. Bureau of Public Roads
- Blair, Will B..... National Paving Brick Manufacturers Association
- Boyd, J. R..... U. S. Bureau of Public Roads
- Braume, G. N..... University of North Carolina
- Breed, H. E..... New York University

Casman, M. L.....	Motor Transport Engineer, Pennsylvania Department of Highways
Christie, Ward P.....	Research Manager, Association General Contractors
Crandell, John S.....	The Barrett Company
Crane, Henry M.....	Society of Automotive Engineers
Curtiss, C. D.....	U. S. Bureau of Public Roads
Dalton, James.....	Editor, Automotive Industries
Dickinson, H. C.....	U. S. Bureau of Standards
Duchastel, J. A.....	Canadian Good Roads Association
Duff, Edward E., Jr.....	National Paving Brick Manufacturers Association
Ege, C. R.....	American Concrete Institute
Eldridge, M. O.....	American Automobile Association
Elveljen, O. M.....	U. S. Bureau of Public Roads
Eno, F. H.....	Ohio State University
Fairbank, H. S.....	U. S. Bureau of Public Roads
Fenner, D. C.....	Motor Vehicle Corporation Commission
Fletcher, A. B.....	U. S. Bureau of Public Roads
Flinn, Alfred D.....	Engineering Foundation, New York
Forrest, C. H.....	The Barber Asphalt Company
French, Owen B.....	George Washington University
Goldbeck, A. T.....	U. S. Bureau of Public Roads
Greer, W. C.....	Goodrich Rubber Company, Akron, Ohio
Hamlin, George E.....	Connecticut State Highway Department
Hatt, W. K.....	Director, Advisory Board on Highway Research, National Research Council
Hill, Charles S.....	Engineering News-Record
Hoag, G. S.....	Field Secretary, Lincoln Highway Association
Hogentogler, C. A.....	U. S. Bureau of Public Roads
Holt, W. L.....	U. S. Bureau of Standards
Hubbard, Prévost.....	American Society for Testing Materials
Hughes, H. J.....	Dean, Harvard Engineering School
Jackson, F. H.....	U. S. Bureau of Public Roads
James, E. W.....	U. S. Bureau of Public Roads
James, W. S.....	U. S. Bureau of Standards
John, W. C.....	Secretary, Highway Education Board
Johnson, A. N.....	University of Maryland
Johnson, Pyke.....	National Automobile Chamber of Commerce

Kearney, W. G.....	Goodrich Rubber Company, Cleveland, Ohio
Ketchum, M. S.....	University of Illinois
Lapman, J. R.....	George Washington University
Lay, W. E.....	University of Michigan
Lemon, B. J.....	U. S. Tire Company, New York
Litchfield, P. W.....	Goodyear Rubber Company, Akron, Ohio
Lord, W. E.....	U. S. Bureau of Public Roads
Love, H. J.....	National Slag Association
McComas, W. E., Jr.....	Portland Cement Association, Baltimore, Md.
McDaniel, A. B.....	General Staff, War Department
MacDonald, T. H.....	U. S. Bureau of Public Roads
McKay, J. G.....	U. S. Bureau of Public Roads
McNown, W. C.....	University of Kansas, Lawrence, Kans.
Manly, Chas. M.....	Society of Automotive Engineers
Markham, W. C.....	Secretary, American State Highway Officials
Mitinger, H. C.....	Gettysburg, Pennsylvania
Mullis, Ira B.....	U. S. Bureau of Public Roads
Olbrich, E. R.....	Assistant Director, Advisory Board on Highway Research
Older, Clifford.....	Division of Highways, State of Illinois
Page, Frank.....	North Carolina State Highway Commission
Reed, Edward E.....	Assistant State Highway Engineer, Trenton, N. J.
Reeve, C. S.....	The Barrett Company, New York
Reid, J. W.....	U. S. Bureau of Public Roads
Rieker, George A.....	Portland Cement Association, D. C.
Robinson, V. D. L.....	American Motorist
Root, W. H.....	Iowa State Highway Department
Selden, H. W.....	Society of Automotive Engineers
Shirley, H. G.....	Virginia State Highway Commission
Smith, E. B.....	U. S. Bureau of Public Roads
Sparrow, Stanwood W....	U. S. Bureau of Standards
Spraragen, W.....	Engineering Division, National Research Council
Sprawls, G. M.....	Goodyear Rubber Company, Akron, Ohio

- Sprull, J. C. Goodrich Rubber Company, Akron,
Ohio
- Strahan, C. M. Athens, Georgia
- Teller, L. W. U. S. Bureau of Public Roads
- Tilden, C. J. Yale University and Eno Foundation
- Tobin, J. J. Granite Paving Block Manufacturing
Association, Boston, Mass.
- Upham, C. M. North Carolina State Highway Com-
mission
- Warner, J. A. C. Society of Automotive Engineers
- Westergaard, H. M. University of Illinois
- Woods, S. H. Mack Trucks, Inc.

PART II

PROGRAM OF THIRD ANNUAL MEETING

First Session, Thursday, November 8, 10 a. m.

- (1) Approval or correction of minutes of November 23, 1922
Announcement of vote on changes in By-Laws
- (2) Approval of interim actions of the Executive Committee
- (3) Appointment of Committee on Nomination of Officers
- (4) Report of Director
- (5) Report of Committee No. 1, Economic Theory of Highway Improvement—Chairman, T. R. Agg
“Research on Rubber Tires,” W. L. Holt, U. S. Bureau of Standards
- (6) Report of Committee No. 2, Structural Design of Roads—Chairman, A. T. Goldbeck
- (7) Report of Committee No. 3, Character and Use of Road Materials—Chairman, H. S. Mattimore

Afternoon, 2:30 p. m.

A visit of inspection was made to the new building of the National Research Council, located near the Lincoln Memorial, and to the highway research projects of the Bureau of Public Roads at Arlington, Va.

Second Session 7:30 p. m.

- (8) Address: “Objectives in Highway Research”—Thomas H. MacDonald, Chief, U. S. Bureau of Public Roads
- (9) “Highway Research Work of American Association of Land Grant Colleges”—Dean Anson Marston, Iowa State College
- (10) Report of Committee No. 6, Highway Finance—Chairman, J. G. McKay
- (11) “Research Program of North Carolina State Highway Commission”—Charles M. Upham, State Highway Engineer of North Carolina

Third Session, Friday, November 9, 9:30 a. m.

- (12) Report of Committee No. 4, Highway Traffic Analysis—Chairman, Geo. E. Hamlin
“Analysis of Motor Transport in New England,” Dr. J. G. McKay

- (13) Report of Committee No. 7, Maintenance—Chairman, W. H. Root
- (14) Statements of representatives of constituent organizations
- (15) Report of Committee on Ways and Means
- (16) Election of officers

The presiding officer, Dean A. N. Johnson, of Maryland University, Chairman of the Advisory Board, called the meeting to order at 10 a. m.

The minutes of the second annual meeting, November 23, 1922, were approved.

An announcement was made of the amendments to the By-Laws, as stated in Section 5 of the Director's report.

INTERIM ACTIONS OF THE EXECUTIVE COMMITTEE

Chairman Johnson: There are some interim actions of the Executive Committee which the Director will report.

The Director: The actions that should be reported are:

(1) The resignation of Director Hatt was accepted, to take effect on the date mutually agreed upon by the Director and the Chairman of the Executive Committee.

(2) Amendments to Sections 6a and 7 of the By-Laws, as stated in Section 5 of the Director's report, were authorized for submission to letter ballot.

(3) Provision was made for the employment of a full-time technical assistant. Upon the authorization of the Executive Committee, Chairman Johnson and Director Hatt recommended to the Executive Committee Mr. E. R. Olbrich, Construction Engineer, North Carolina Highway Commission, to be appointed as Technical Assistant to the Director. The appointment was made by the Executive Committee.

(4) The Executive Committee on March 10, 1923, adopted the following resolution:

"It is the sense of the Executive Committee of the Advisory Board that interest in the work of the Board would be more widely spread if the terms of service of the official representatives of constituent organizations of the Board were limited to three years."

Dr. Hatt read a letter from Morris L. Cooke, Director of the Giant Power Survey of the Commonwealth of Pennsylvania, requesting that the Board undertake an inquiry as to possible cooperation between the state highway commissions and the power companies for mutual benefit in erecting transmission lines, on a joint right of way.

to carry electric current to rural communities. Mr. Cooke's letter was referred to the Executive Committee for such action as they should deem advisable.

NOMINATION OF OFFICERS

The chairman appointed the following Committee on Nomination, consisting of Professor Tilden, Mr. Goldbeck and Mr. Root.

REPORT OF THE DIRECTOR, ADVISORY BOARD ON HIGHWAY RESEARCH

I. PROGRESS SINCE NOVEMBER, 1920

The third annual meeting of the Advisory Board on Highway Research offers occasion for a retrospect of the progress of the Advisory Board since the inaugural meeting in New York, November 11, 1920. At that time Dean Anson Marston, of Iowa State College, then Chairman of the Advisory Board, spoke in part as follows:

“. . . It (highway research) must be of a highly scientific character and devoted very largely to consideration of fundamental engineering science because the fundamental theory of highway engineering has not been developed.”

“. . . We have run ahead of our theory. There is no engineer at the present time who can build either a concrete, bituminous or brick road with absolute certainty that it will carry the traffic of motor trucks weighing a given number of tons, traveling at specified speed, with certainty that it will not be broken by traffic instead of gradually worn out. There is no way to tell stresses in various parts of a structure which we are to build.”

“This general principle applies not only to experimental work, but to economic research. Who has adequate data for determining how the roads of a state should be classified into primary, secondary and third-class roads, or who can tell us the proper relation of transportation over country highways to railway and waterway transportation, considered from the standpoint of the interests of the entire country? The best administration of this great program requires research.”

“. . . We have to think of road surfaces which vary from mud of some localities, dry sands of the desert, to solid rock of the mountain regions; climates which vary from tropical to roads above the snow-line in the mountains. Adequate highway research will require an accumulation of an immense mass of data to solve the problem adequately. . . . Chairmen of research committees should be in every instance scientific research men actively engaged in re-

search personally. I don't think we can carry this on with men who will only conduct the administrative operations. They should be men of the highest scientific attainments and able to analyze results from a theoretical point of view as well as to conduct the tests. They should devote at least a greater part of their time to the work. It is not a case where two or three can be called together once or twice a year and do nothing in the meantime. The greatest obstacle we have had is the fact that the chairmen in each case have been men whose regular duties require the greater part of their time. The ideal plan would be to have each man employed on a salary, who would devote full time to the work of the committees. Those should also be men with some administrative ability, men of judgment and so on."

" . . . Each committee should have a salaried chairman. If we can't get that, we should get the right to use as much of his time as practicable. We should have sufficient money to pay mileage and similar expenses of members of the committees."

During the three years that have elapsed since Dean Marston's address, much progress has been made in quickening the will to research, in mobilizing the energies of research agencies and in assembling the data necessary for judgment upon questions of highway planning, construction and operation.

It may be said with a large degree of confidence that at present a well-trained and experienced highway engineer, in possession of available data, can select a type of highway suitable to the conditions of climate and traffic of a given situation, can select the materials and design the section with a reasonable certainty that it will withstand the specified conditions of service.

It is true that the communication of these data to engineers in general has not kept pace with the accumulation of the data, nor has a working organization for the process of analyzing the data and translating the discovered principles for the use of engineers been adequately provided. The Advisory Board has published bulletins of information on existing research projects, on apparatus for research, and the Director has written many occasional papers. Its research committees have summarized progress. Much remains to be done, however, in unlocking the stored-up data, especially those in the files of the state highway commissions, which are now such active agencies in highway research.

It is still true that the conditions of future service of our highways can not be closely specified. In the majority of cases the classification of highways is based on general impressions. However, such traffic surveys as those under way in New England, Pennsylvania, Iowa, California, Tennessee, etc., permit a classification based on

actual measurements and an intelligent allocation of construction and maintenance funds. Furthermore, commodity movements, such as determined in the Connecticut Survey, go a long way in fixing the boundaries of the field of economic highway transport.

While much remains to be done in coordinating the activities of the various research agencies, a human problem in many cases, the highway engineer and the automotive engineer have come to a better understanding of their mutual relations in the field of research and to a combined effort to determine the mechanical relations of the road and vehicle.

Questions of finances and taxation have been actively debated during the past year. Gradually an understanding of the elements of the subject and of their application to specific situations is reaching the mind of the public.

The paper entitled "The Human Factor in Highway Regulation and Safety," by Dr. Raymond Dodge, presented to the second annual meeting of the Advisory Board, called attention to the mental problems in traffic control, including tests for driving ability. The alarming number of fatalities attending highway traffic indicate a need for research, not only in respect to the field dealt with by Dr. Dodge, but in respect to vehicle design, road location, and signals. Matters of this kind tend to become legislated and standardized prematurely without a scientific basis of research.

II. RESEARCH COMMITTEES OF THE ADVISORY BOARD

Dean Marston's reasonable specifications for the chairmen of research committees remain unfulfilled in one respect. The present chairmen of our research committees are distinguished leaders in their respective fields and actively interested in research. The Advisory Board is very grateful for the amount of energy and excellent service that our chairmen have given to the committee work on the Advisory Board. But each is a busy man, with heavy responsibilities to discharge and duties to perform in the organization to which he owes his first allegiance. Some way should be found to free their energies to a greater extent for the work of the Board.

III. RESEARCH INFORMATION SERVICE

An important service, one which the Advisory Board might well accomplish on the basis of its present position and through the contacts already made, has not been rendered, namely, the preparation of research information in form for busy executives and engineers. Such a service would require a small staff of specialists who would garner up the crops of research data in the several fields and prepare

them for use. The channel of publication might be a monthly magazine or a more frequent leaflet service. The complete publication of ambitious research projects is now well provided for in the magazine of the Bureau of Public Roads, entitled "Public Roads," and the transactions of various national societies.

A research information service supplied by the Advisory Board on Highway Research would require financial support beyond the present budget of the Advisory Board. Whether the service would be self-supporting by subscriptions from the state highway commissions and other organizations is a matter for examination. The Director again suggests this project for careful consideration. Such a service should not be limited to materials of construction or to the design and construction of the road bed, but should embrace the mutual relations of road and vehicle, the economics of highway location, the operation of loads and all elements of highway transport.

IV. MEETINGS OF THE EXECUTIVE COMMITTEE

A meeting of the Executive Committee was held on Thursday, November 23, 1922.

Present: Chairman, Dean Anson Marston; Messrs. Crane, Spraragen (representing Mr. Flinn), Director Hatt.

Various routine matters were discussed. A budget of \$36,000 was approved for the year January 1, 1923, to December 31, 1923. Of this amount \$20,000 was not in sight. A project for the appropriation of \$500 for establishing a Findex file of highway research workers in the office of the National Research Council was discussed without recommendation.

A report of the Committee on Nominations for the Executive Committee of the Board was received and ordered placed before the meeting of the Advisory Board.

A meeting of the Executive Committee was held in Washington, D. C., on July 30, 1923.

Those present were Chairman A. N. Johnson; Messrs. Crane, Flinn, MacDonald and Director Hatt.

The resignation of Director Hatt was accepted, to take effect on the date mutually agreed upon by the Director and the Chairman of the Executive Committee.

Provision was made for the employment of a full-time technical assistant.

A resolution was passed by the Executive Committee expressing the appreciation of the Advisory Board to the officers of Purdue University for their cooperation with the work of the Advisory Board by granting Director Hatt a leave of absence for the past two years, and

expressing to Director Hatt a sense of deep regret that he was unable longer to continue as active head of the work of the Advisory Board.

Amendments to Sections 6a and 7 of the By-Laws were authorized for submission to letter ballot.

Upon the authorization of the Executive Committee, Chairman Johnson and Director Hatt recommended to the Executive Committee that Mr. E. R. Olbrich, construction engineer, North Carolina Highway Commission, be appointed as Technical Assistant to the Director. The appointment was made by the Executive Committee.

V. AMENDMENTS TO BY-LAWS

INCREASE IN EXECUTIVE COMMITTEE

On August 4, 1923, the Executive Committee submitted the following amendment to the By-Laws: Section 6a, change the word "three" to "five." The amended section will then read:

Section 6a. "*Executive*: Consisting of the chairman, the vice-chairman, and five additional members chosen by the Board, at least two of whom shall also be members of the Division of Engineering."

Add the following: "Should a vacancy exist in the Executive Committee it shall be filled by a vote of the remaining members."

The amendment was adopted by the following vote: Yes, 24; no, 0.

TERM OF SERVICE OF MEMBERS OF RESEARCH COMMITTEES

On the authority of the Executive Committee, the following amendment to the By-Laws was submitted to a vote of the Advisory Board, March 10, 1923:

"Members of the Research Committees of the Advisory Board are appointed for a term of three years; at the expiration of the term of office they are eligible for reappointment."

This amendment was adopted by the following vote: Yes, 20; no, 1.

On August 4, 1923, the following amendment was submitted by the Executive Committee to a vote of the Advisory Board. Add to Section 7 the following: "The term of services of members of Research Committees shall be limited to one year, but they are eligible to reappointment."

Vote—Yes, 24; no, 0.

The complete section as amended will, therefore, read as follows:

Section 7. "*Research Committees*: Shall be created by the Board, as deemed necessary, with the approval of the Division of Engineer-

ing. Members shall be appointed by the Chairman with approval of the Executive Committee, and need not be limited to members of the Board. The term of services of members of research committees shall be limited to one year, but they are eligible to reappointment."

VI. RELATIONS WITH OTHER ORGANIZATIONS

ENO FOUNDATION

A resolution was passed by the Executive Committee December 2, 1922, by letter ballot:

"The Executive Committee of the Advisory Board on Highway Research recommends that the Eno Foundation take up the study of the leading principles of traffic handling and traffic regulations and offers the services of the Advisory Board in a liaison of this work with the constituent organizations, and the publications of the Advisory Board as a channel of communication for the reports of this study."

HIGHWAY EDUCATION BOARD

The following subjects for research were submitted to the Advisory Board by the Highway Education Board:

- a.* In highway economics and highway sociology, in metropolitan and urban highway and highway transport problems.
- b.* In highway traffic in connection with the Eno Foundation and other organizations.
- c.* Cooperative studies between representatives of motor trucks and the railroads.
- d.* In highway finance.
- e.* In highway legislation with special reference to uniformity of codes and the avoidance of conflict of laws.

AMERICAN SOCIETY OF CIVIL ENGINEERS

The American Society of Civil Engineers has appointed an Advisory Committee on Civil Engineering Research to cooperate with the Engineering Division of the National Research Council. It is understood that this committee of the American Society of Civil Engineers, acting in this capacity, is a sponsor of research in the civil engineering field.

The American Society of Civil Engineers has also a Committee on Research and special committees on Highway Engineering and on Impact and Highway Bridges. This latter committee has presented a progress report, published in the March, 1923, Proceedings.

At the first meeting of the Advisory Board on Highway Research, on October 8, 1919, a recommendation was made for the appoint-

ment of a committee on Highway Bridges and Culverts, and the By-Laws adopted November 11, 1920, specify a research committee of the Advisory Board on Highway Bridges. During the past year considerable discussion has taken place between the Advisory Board and the Committee on Impact and Highway Bridges of the American Society of Civil Engineers concerning mutual support in this field of research. The Advisory Board should not organize its Committee on Highway Bridges until the possibility of useless duplication of work is eliminated.

THE SOCIETY OF AUTOMOTIVE ENGINEERS

After mature discussion of a combined attack upon relations of road and vehicle, a research project has been adopted on the part of representatives of the Automotive Engineers, the Rubber Association and the U. S. Bureau of Public Roads. This project is now under operation at Arlington, Va., and will be discussed in the report of Committee No. 2 on Structural Design of Roads.

THE COMMITTEE ON SUBGRADE OF THE FORMER FEDERAL HIGHWAY COUNCIL

Letters have been exchanged between the Director of the Advisory Board and those interested in the work of the Committee on Subgrade of the Federal Highway Council looking to a mobilization of the activities of these two organizations. No definite result has as yet been attained.

NATIONAL TRANSPORTATION INSTITUTE

The National Transportation Institute is devoted to the work of assembling information on problems of national transportation and distributing this information to the public. The Research Council of the National Transportation Institute is located in Washington and has functions described by its title. The Department of Public Relations of the National Transportation Institute will communicate to the public, through the various channels of broadcasting, newspapers and magazines, only such information as is endorsed by the Research Council of the National Transportation Institute. The Director of the Advisory Board has called the attention of the National Transportation Institute to the work of the Advisory Board on Highway Research in the field of highway transportation. If the Advisory Board on Highway Research occupies its special field with energy, it would seem that the Research Council of the National Transportation Institute might accept the output of the Advisory Board.

AMERICAN ROAD BUILDERS ASSOCIATION

This friendly organization has appropriated a sum of one thousand dollars for the support of the Advisory Board on Highway Research, for which the Board is grateful.

ENGINEERING FOUNDATION

The Director of the Engineering Foundation, Mr. Alfred D. Flinn, is vice-chairman of the Executive Committee of the Advisory Board. His long-continued interest in the work of the Advisory Board has brought about helpful relations between these two organizations. The Engineering Foundation has also appropriated a thousand dollars for the support of the Advisory Board.

U. S. BUREAU OF PUBLIC ROADS, DEPARTMENT OF AGRICULTURE

The main support for the operations of the Advisory Board is from the U. S. Bureau of Public Roads. Without the sympathetic and active support of the Bureau of Public Roads, through Mr. Thomas H. MacDonald, Chief, the Advisory Board could not have functioned.

REPRESENTATIVES OF CONSTITUENT ORGANIZATIONS

The Executive Committee, on March 10, 1923, adopted the following resolution:

"It is the sense of the Executive Committee of the Advisory Board that interest in the work of the Board would be more widely spread if the terms of service of the official representatives of constituent organizations of the Board were limited to three years."

VII. MEETING OF THE COMMITTEE CHAIRMEN

A meeting was held at Atlantic City, June 30, 1923. Present: Messrs. Agg, Goldbeck, Mattimore, Root, Chairman Johnson and Director Hatt.

A meeting was held at Richmond, Va., on October 17, 1923. Present: Messrs. Goldbeck, Hamlin, McKay, Mattimore, Chairman Johnson, Director Hatt and Mr. Olbrich.

VIII. FUNCTION OF RESEARCH COMMITTEES

The following definition of the function and field of activity of Research Committees of the Advisory Board was formulated and approved by the Executive Committee in March, 1923.

1. The entire purpose of the Advisory Board on Highway Research is to render service to investigators, and to accelerate progress in the attack upon important problems of highway transportation.

The Board avoids any attitude of proprietorship in the researches which form the subject-matter of the deliberations of its committees, or of any control or direction of the individual research worker, whose initiative and freedom are necessary conditions of his work. Coordination of research is attempted, inspiration given to those who are at work and the broad interests of research advanced by reasonable publicity concerning activities. Information of work under way is spread abroad, so that seekers after knowledge may know where to find it: communication is established between fields of research, as for instance, the vehicle and the road.

2. Research committees do not formulate standards of methods of test or approved practices in construction.

3. Reports of these research committees are not channels for publication of investigations, although a summary of established conclusions from published investigations should appear in the reports to show the status of research.

4. The unique work of the research committees of the Advisory Board is:

- a.* To bring together research men working in the same field in order to reach a definition of objectives and to bring to each a knowledge of the technique and progress of his fellow-workers.
- b.* To assemble and review the published data of investigations, or the data placed at the disposal of the committees, for the purpose of judging the extent and stability of the research basis for standards, or for the principles and laws underlying the field of the work of these committees.
- c.* To study needed and profitable research activities.
- d.* To stimulate competent agencies to perform research in such fields.
- e.* To prepare working plans for specific researches in cooperation with investigators or for submission to research agencies.
- f.* To call the attention of the Executive Committee to researches which need financial support and to recommend a means for securing such support.
- g.* To publish information of researches under way, and of the tools of research, as instanced in Bulletin No. 21, entitled "A Census of Highway Research Projects in the United States," published by the National Research Council.

IX. PUBLICATIONS

Since the second annual meeting of the Advisory Board the following publications have been issued:

1. National Research Council Bulletin No. 21, "Highway Research Projects in the United States," containing a description of 479 highway research projects classified by a decimal system.

2. National Research Council Bulletin No. 32, "Proceedings of the Second Annual meeting of the Advisory Board on Highway Research," containing an account of the development of the Advisory Board, its officers and its constituent organizations, and giving reports of research committees.

3. National Research Council Bulletin No. 35, "Apparatus Used in Highway Research Projects," containing descriptions and drawings of apparatus that have been successfully used in the prosecution of highway research.

For convenience of reference, a list of 15 articles and 26 addresses by the Director since August, 1921, is appended.

X. WAYS AND MEANS

The By-Laws of the Advisory Board provide for a Committee on Ways and Means, which has been appointed but has been inactive.

Shortly after the formation of the Advisory Board, Vice-Chairman Flinn planned to circularize a number of prospective contributors to the financial budget of the Advisory Board, but the policy of the Board in respect to this matter was not settled. It appeared wise afterwards to look to official sources, such as State Highway Commissions and Federal organizations, for the main support. While the Connecticut Highway Commission aided the Board with an appropriation for a period of two years, the desire of other commissions to take similar action was checked by legal barriers. These state highway commissions have heartily cooperated in the research program of the Advisory Board and members of their technical staffs have given good service on our research committees.

At the suggestion of the Director, contributions of money and equipment have been made by industries to research projects that were languishing and to which the Advisory Board was asked to give assistance. In such cases the funds are not handled by the Advisory Board. The only responsibility the Director takes is in a matter of judgment as to the probable successful management of the research. In this way the Board, without funds of its own, can assist in supporting research.

A field of work demanding direct expenditure of the funds of the

Board is in holding conferences of research workers for the purpose of agreement on objectives of research and upon boundaries of fields of action. This fruitful service, together with the expenses attending meetings of the research committees, could be extended if funds were available.

The preparation of Major Ireland's thesis on results of Quarter-master Tractive Resistance Investigation referred to by Professor Agg in Report of Committee No. 1, has involved an expense out of all proportion to that normally expected to be borne by a candidate for a degree. The Director of the Advisory Board recommends that funds be raised in the amount of \$5,000 for the duplication of the thesis and the reimbursement of the accumulated deficit of this research.

LIST OF PAPERS AND ADDRESSES, JULY, 1921—NOVEMBER 9, 1923
BY W. K. HATT, DIRECTOR

(*) denotes published article.

No.	Date	Title	Where Published or Delivered
1921			
* 1	July 27	Program of Highway Research.	Conference on Highway Economics. University of Maryland.
* 2	Sept. 1	The need for Highway Research.	Public Roads.
* 3	Sept. 12	Discussion of Highway Research.	Western Society of Engineers. Chicago.
4	Oct. 21	Highway Research.....	Engineers Club of Philadelphia, City Paving Conference.
* 5	Dec. 8	Coordination of Highway Research.	American Association of State Highway Officials, Omaha.
* 6	Dec. 11	Research in Highway Transport.	Oakland, Calif., Tribune.
1922			
* 7	Jan. 16	Highway Research.....	American Road Builders Association.
8	Jan. 18	Report of Director, Advisory Board on Highway Research.	Annual Meeting of Advisory Board.
* 9	Jan. 20	Discussion on Research in Highway Transport.	American Society of Civil Engineers.
10	Jan. 24	Discussion on Research in Highway Transport.	Highway Education Conference, Lexington, Ky.
11	Jan. 25	Highway Research Projects	Illinois Society of Engineers and Surveyors, Decatur, Ill.
12	Jan. 27	Highway Problems.....	Purdue University Road School, La Fayette, Ind.
*13	Feb. 14	Report of Committee on Research, Report on Ball Test for Concrete and on Fatigue.	American Concrete Institute, Cleveland, Ohio.

No.	Date	Title	Where Published or Delivered
	1922		
14	Feb. 15	Highway Research.....	Boston Society of Engineers.
*15	April 1	Organizing Common Sense.	The Constructor.
16	April 17	Recent Development in Work of Advisory Board.	Report of Division of Engineering, N. R. C.
*17	May —	A Survey of the Field of Highway Research.	Highways Green Book, 1922.
*18	June 8	Review of Highway Re- search.	Automotive Industries.
*19	June 21	Progress in Highway Re- search.	A. S. C. E. Portsmouth, N. H.
20	June 23	Progress in Highway Re- search.	Society of Automotive Engi- neers. White Sulphur Springs.
21	Oct. 18	Address	Student Chapter, A. S. C. E. Massachusetts Institute of Technology.
22	Oct. 19	Address	Yale University.
*23	Oct. 26	Research in Highway Edu- tion.	Second Annual Conference of Highway Educational Board. Washington, D. C.
24	Nov. 10	Address	Student Society. University of Pennsylvania, Philadelphia.
25	Nov. 15	Address	Student Society, La Fayette College, Easton, Pa.
26	Nov. 16	Address	Student Society, Lehigh Uni- versity, South Bethlehem, Pa.
*27	Nov. —	Census of Highway Re- search Projects in U. S.	Bulletin No. 21, National Re- search Council.
*28	Nov. 21	Report of Director, Ad- visory Board on Highway Research.	Second Annual Conference of the Advisory Board.
*29	Nov. 21	Aspects of Research.....	Association of Land Grant Col- leges. Washington, D. C.
*30	Dec. 1	Moot Questions in Highway Research.	Princeton University. Reprinted in "Rock Products," March 10, 1923.
	1923		
*31	Jan. 16	How Individual Organiza- tions Can Fit Their Work into a Broad Highway Research Program.	American Road Builders Asso- ciation. Chicago, Ill.
32	Jan. 16	Address on Highway Re- search.	Crushed Stone Association. Chi- cago, Ill.
*33	March —	Research Foundation for the Economic Theory of Highway Improvement.	Journal of S. A. E., March, 1923.
*34	March —	Highway Research.....	Cornell Civil Engineer.
*35	May 8	Report on Highway Re- search Projects in U. S.	International Road Congress.

<i>No.</i>	<i>Date</i>	<i>Title</i>	<i>Where Published or Delivered</i>
	1923		
*36	June —	Proceedings of the Second Annual Meeting of the Advisory Board on Highway Research.	Bulletin No. 32, N. R. C.
*37	June —	Research Committees.....	A. S. T. M., Atlantic City. Reprinted, "Science," September 19, 1923.
*38	June 28	International Road Congress, Seville.	Engineering News-Record.
39	July 11	Opening Statement, Division of Highway Engineering, A. S. C. E.	Convention of A. S. C. E. Chicago.
40	Nov. 5	Scientific Research in the Highway Field.	Purdue Branch of Sigma Xi.
41	Nov. —	Coordinated Transportation	Purdue University Engineering Review.
42	Nov. 8	Report of Director to the Third Annual Meeting of the Advisory Board on Highway Research.	Washington, D. C.

The report of the Director was accepted.

REPORT OF COMMITTEE NUMBER 1, ON ECONOMIC THEORY OF HIGHWAY IMPROVEMENT

In its present form the committee is made up of men actually engaged in research activities and of engineers who are able to assist in the organization of research or in the evaluation of data obtained in the progress of the various activities of the committee.

There has never been a meeting of the full committee, but various members of the committee have met occasionally in connection with some scientific or technical convention.

The committee is really an informal association of men engaged in a certain line of research, and no attempt to supervise the work of the individual members is made by the chairman of the committee, but he does attempt to aid investigators who find their work handicapped in some way. Generally, financial assistance is needed, but it has not always been available. An attempt is made to interest new personnel from time to time and to expand the research work in the field of highway economics. Duplication of effort is eliminated by the publicity given the projects that are inaugurated from time to time.

There is presented herewith a chart which shows the field the committee seeks to cover and the progress that has been made up to the present time.

PROJECTS COMPLETED

The following projects in the field of Highway Economics have been completed and the results have been published or are in progress of publication at the present time:

No. 1. TRUCK PERFORMANCE ON GRADES

This research was organized under the direction of Frank F. Rogers, Commissioner of Highways of Michigan, who assigned Victor R. Burton, in his organization, to the project. The work was carried out with the cooperation of the University of Michigan, which was represented by Walter E. Lay, Assistant Professor of Mechanical Engineering.¹

No. 2. ROLLING RESISTANCE AND RELATED CHARACTERISTICS OF ROADWAY SURFACES

The research was conducted as a cooperative project, in which the U. S. Bureau of Public Roads, the Iowa Highway Commission and the Iowa Engineering Experiment Station participated.²

No. 3. ECONOMICS OF HIGHWAY GRADES

This investigation was conducted by the Iowa Engineering Experiment Station, with some cooperation from the Iowa Highway Commission.³

No. 4. SUB-COMMITTEE ON TRACTIVE RESISTANCE

The events leading up to the formation of this sub-committee of Committee No. 1 are as follows:

In February, 1920, Major Mark L. Ireland, Q. M. C., was appointed a member of Committee No. 1. Shortly after entering Massachusetts Institute of Technology in September, 1920, as a graduate student, he recommended to the Quartermaster General a research project on tractive resistance. In May, 1921, he began the preparation of a bibliography on tractive resistance. In August overtures were made to the Mason Laboratory of Yale University for laboratory tests on vehicles. In September, Prof. Adams, then Chairman of the Division of Engineering, and Mr. A. D. Flinn,

¹The results of the investigation were published in "The Proceedings of the Eighth Annual Conference of Highway Engineering," held at the University of Michigan. Requests for copies may be addressed to Commissioner Rogers or to Professor Lay.

²Bulletins 64 and 67 of the Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa.

³Bulletin 65 of the Iowa Engineering Experiment Station, Iowa State College, Ames, Iowa.

prepared a circular letter asking support for Major Ireland's researches then under way. On September 23, 1921, the correspondence and administration concerning this research, to which the Division of Engineering was rendering assistance, was assigned to Director Hatt, who organized a sub-committee of Committee No. 1 under chairmanship of Prof. Adams, consisting of the following persons directly interested in the research: Prof. C. A. Adams, Harvard University; Prof. T. R. Agg, Iowa State College; Commissioner Chas. J. Bennett, State of Connecticut; Commissioner John N. Cole, State of Massachusetts; Dr. H. O. Dickinson, Society of Automotive Engineers; Mr. A. T. Goldbeck, U. S. Bureau of Public Roads; Major Mark L. Ireland, Q. M. C., U. S. Army; Prof. D. C. Jackson, Massachusetts Institute of Technology; Prof. E. N. Lockwood, Yale University. Contribution of funds, instruments and equipment were supplied by the following parties:

Quartermaster Corps and Air Service, U. S. Army.	United States Rubber Company.
Bureau of Public Roads, U. S. Dept. of Agriculture.	Portland Cement Association.
Massachusetts Institute of Technology.	Barber Asphalt Company.
Yale University.	Locomobile Company of America.
Connecticut Highway Commission.	Goodyear Tire & Rubber Company.
Massachusetts Department of Public Works.	Firestone Tire & Rubber Company.
International Motor Company (Mack Trucks, Inc.)	Kelley-Springfield Tire Co.
	Blanchard Instrument Company.
	Schwarz Wheel Company.
	Iowa State College.

Much valuable assistance in a consultative capacity was rendered by many other interests quite too numerous to mention, with full assurance of making the acknowledgment list complete.

The corps of research workers, in addition to Major Ireland, Director of the Quartermaster Tractive Resistance, included Capt. F. I. Maslin, Q. M. C., First Lieut. Herbert C. Mitchell, Q. M. C., Mr. Wm. O. Tait, Special Asst. (Automotive Engineers), U. S. Bureau of Public Roads, Mr. Ralph M. Trimble, and Mr. A. Fleischer, who resigned and was later replaced by Mr. H. F. Gleason, Junior Civil Engineers, U. S. Bureau of Public Roads, and two Q. M. C. experimental truck drivers. The two driver positions were filled by consecutive appointment of Massachusetts Institute of Technology graduates and ex-students from available candidates. A number of part-time students were also employed from research funds. Later, Chairman Adams resigned and Prof. C. J. Tilden, Yale University, was elected chairman, Prof. Adams continuing as a member of the sub-committee. The investigation represents an expenditure for salaries, services and other tangible items, of considerably more than

\$40,000. Suitability of instruments and technique of tractive resistance have been carefully studied. A large volume of valuable data has been accumulated, covering both rolling and sliding friction results on some 10 varieties of road surface of varying age and state of maintenance, employing six types of heavy motor vehicles at speeds as high as 44 miles per hour with cargo loads from 0% to 150% of the rated capacity at all seasons of the year and under practically all weather conditions, and utilizing various types and varieties of steel, solid rubber and pneumatic tires, new and worn. Some of these data have appeared in the preliminary reports of the three officers of the Quartermaster Corps.

Considerable difficulty has been experienced in adjusting the length of the time, program of tests to available funds and the divergent needs of the many co-operative interests. The usual vicissitudes of research work, all of which make for delay, have been encountered, such as insufficient funds, administrative detail requiring time and patience to adapt to the situation of a temporary co-operative organization on a new and somewhat unusual mission which required development of instruments and methods. The progress and the results achieved, however, have been commensurate with the time, energy and funds expended and the thoroughness which should be observed in so expensive an undertaking.

On November 27, 1922, Major Ireland and Captain Maslin were transferred to the University of Michigan. In June, 1923, Major Ireland received from that institution the degree of Doctor of Philosophy, on the basis of study and a thesis embodying about one-half of the data accumulated by him while at the Massachusetts Institute of Technology. His two-volume Preliminary Report and also a short one by Lieutenant Mitchell are before you now. The records have been transferred to Professor Agg, Chairman, Committee No. 1, for completion and final report in co-operation with Major Ireland and Captain Maslin. Major Ireland is complying with an Act of Congress which requires a year of service with troops at stated intervals.

No. 5. COST OF MOTOR VEHICLE OPERATION

A preliminary study of the cost of vehicle operation was undertaken by the Civil Engineering Department, Iowa State College, under the direction of H. S. Carter, who was at that time a graduate student in highway engineering. His work was of most value in indicating some of the difficulties involved in such a study and in pointing out the direction in which the work could best proceed. He did, however, secure considerable valuable data, and it is expected that this material will be published before the end of the year, al-

though I cannot at this time announce who will sponsor the publication.

PROJECTS IN PROGRESS

The following projects have been in progress for longer or shorter periods of time. Progress reports are submitted for several of these projects.

NO. 1. WIND RESISTANCE ON MOTOR VEHICLES

Report by Prof. L. E. Conrad, of the Engineering Experiment Station, Kansas State Agricultural College

Professor Conrad was unable to be present to report in person. The report is as follows:

The investigation of wind resistance of automobiles was undertaken some two years ago by the Engineering Experiment Station of the Kansas State Agricultural College. The problem was undertaken at the instigation of the National Research Council, but from a financial standpoint the only cooperating agency has been the U. S. Bureau of Public Roads.

The original apparatus, in addition to a number of small instruments, included two circular tanks of heavy galvanized iron. The larger of these tanks, 17 feet in diameter and $3\frac{1}{2}$ feet deep, is placed in the ground at such a depth that the top edge is level with the ground surface. This tank is partially filled with water, in which the smaller tank floats. The smaller tank, which is 16 feet in diameter and 2 feet deep, has a wooden deck, on the top of which the automobile is placed. The water level is adjusted so that the top of this deck is level with the ground surface.

The additional instruments referred to are an anemometer, a stopwatch, a thermometer, a barometer, four weather vanes, and the recording mechanism. The recording mechanism is merely a device for recording on a chart the pull which the wind exerts on the automobile, as measured by the tendency of the float to move away from its initial position.

The test is made as follows:

(1) The automobile is run on to the float deck and blocked in the proper position.

(2) After a careful study of the weather vanes the float is turned until the car heads directly into the wind.

(3) The recording mechanism is located on the float directly in front of the automobile. A wire which leads from the recording mechanism is anchored to a short pipe set in concrete near the edge of the large tank.

(4) Four stay-ropes are connected to the float at right angles to the

direction of the wind. These ropes prevent side sway of the float, but can exert no force in the direction of the wind.

(5) At a given signal, one observer starts the anemometer and the other observer starts the motor which moves the chart. The observer at the anemometer records the number of feet of air passing through the anemometer each 30 seconds. At the end of the test, which runs for six minutes, both instruments are shut off and readings are taken of the anemometer, barometer and thermometer. If the wind direction shifted materially during any portion of the test, a note is made of the time, and later that portion of the test is discarded.

Because of the variable intensity of natural winds, it is necessary to average the results of the records over a certain time interval. The determination of this time interval constitutes in itself a research problem. The shorter the interval, the greater will be the accuracy; but physical limitations in instrument reading, recording, etc., make any interval less than thirty seconds impracticable. The thirty second interval was therefore adopted.

The records are worked up as follows:

The charts are divided into twelve sections, each representing thirty seconds of time. These areas are then traced with a planimeter and the average ordinate is determined by dividing the area by the length of its base line. This ordinate to scale represents the average pull over the thirty second interval. This pull after the temperature and pressure corrections have been applied, together with the corrected wind velocity, locates a single point on the velocity-resistance curve. Due to the gusty character of winds, these points are somewhat scattered, and it was found necessary to determine, by the method of averages, the equation of the theoretical curve most nearly fitting the points.

By applying this method to over 400 points the equation $F = 0.0012 A \cdot V^{2.383}$ was obtained. ($F =$ pull in pounds; $A =$ projected area in square feet; $V =$ wind velocity in miles per hour.) The results of aeronautical investigations indicate that the value of the exponent should be two. The results of Riedler on the "Scientific Determination of the Merits of Automobiles" indicate for the coefficient a value of about 0.003.

At this stage of the investigation it became evident that a greater refinement would be necessary. For a number of reasons, it was evident that this refinement would be expensive if natural winds were used, and therefore our attention was directed toward some means of producing an artificial wind.

After considerable study and investigation, it was decided to

build a wind-tunnel of sufficient size to test full-sized automobiles. This wind-tunnel, which is now nearing completion, differs from the usual type of wind-tunnel in two respects: First, the cross-section is rectangular instead of circular; second, the testing portion, where the car is placed, is enlarged in order that the air speed in this section will not be increased by the presence of the car. The cross-section of the tunnel ahead of the enlarged portion is approximately 12 feet wide by 10 feet high, while the entire length is about 40 feet. The enlargement, which is made on the two sides and top, is approximately 9 inches, making the test portion of the tunnel approximately 10 feet 9 inches high and 13 feet 6 inches wide. The amount of enlargement was calculated from the average of the projected areas of a large number of different kinds of automobiles. This area was traced with a planimeter from a plot of the car made with a *camera lucida*. The entrance of the tunnel is flared to admit the air freely, the size of the opening being $12\frac{1}{2}$ feet high by 17 feet wide. The exit end tapers down to a circular section 10 feet in diameter. An ordinary airplane propeller is used for a fan.

The platform on which the car is tested rests on long beams supported by chains from an outside framework. The zero position of the platform is determined before the fan is started. The fan is then started and, as the wind velocity is increased, the pull required to return the platform to its zero position is determined for each increment of velocity.

Although, up to the present time, no complete tests have been made, enough data have been taken to indicate that the tunnel may be expected to give satisfactory results. A wind velocity of sixteen miles per hour has been obtained, and a study of streamers placed at various points in the tunnel indicates that the air currents are sufficiently uniform for our purpose. The chief difficulty at the present time is the lack of a fan of the proper design. We have at present a combined motor and propeller efficiency of less than 20 per cent. A propeller of considerably less pitch than those used for flying is required, but such propellers, apparently, are not made except as special orders at prohibitive prices.

At the present time the roof of the tunnel is being strengthened, so that the cars may be suspended from the roof immediately above the platform to determine the resistance of the platform itself.

The problems for the immediate future are:

1. To design and build an adjustable pitch propeller having eight blades.
2. To determine the correction necessary to compensate for the effect of the wind on the platform.

3. To design and build an exit cone or draft tube for increasing tunnel efficiency.

No. 2. TRUCK PERFORMANCE ON GRADES

Report by Professor W. E. Lay

Since this is a report of progress, and as such seems rather inadequate, it appears advisable to sketch in briefly the history of research work on car and truck performance at the University of Michigan.

This work was begun in 1915, in a series of tests whose object was "To determine the H. P. which must be delivered to the road by the rear wheels of a motor car in order to drive it at given speeds." The problem was attacked by the coasting method. The car was driven up to top speed and allowed to coast over the course, on which were located at given intervals trips and electric contacts which operated pens on a somewhat crude chronograph. The magnitude of the forces resisting the motion of the car were to be computed from the rate of deceleration determined by twice differentiating the time space data given on the chronograph chart. Even at this time it was understood that allowance must be made for the deceleration of the rotating parts as well as for the linear deceleration of the whole mass of the vehicle. Unexpected difficulties met in the attempt to determine the moment of inertia of rotating parts of the vehicle put an end to the work for the time.

The following year an improved chronograph was tried out, together with another from Worcester Polytechnic, at Sheephead Bay Speedway, under the auspices of the Research Division of the Standards Committee of the S. A. E. The Worcester chronograph was carried in the car and gave a record of time, and of the space traveled, the latter pen being actuated by a series of contacts on a front wheel. From the experience thus gained an improvement of the Worcester chronograph was evolved which used an ignition timer driven like a speedometer from the front wheel and discharging a high tension spark through the moving chart every one-fifth revolution of the front wheels. The S. A. E. adopted this as the standard method of determining the performance of a car.

In 1918 the problem was again taken up and a new chronograph was built, with many of the details considerably improved, and a series of tests were made on a Dodge and a Ford car. One of the drawbacks of this method was the tedious counting of the small holes made by the spark and the fact that the spark would not jump in a straight line from one needle point, through the paper, to the other.

Early in 1921, with the cooperation of the Michigan State High-

way Department. the problem of determining the performance of a vehicle was attacked from an entirely different angle, in that the major part of the data was obtained in the laboratory by laboratory methods and merely a check was made on the road. By this method the characteristics of the power plant and the power transmission system were determined in the laboratory and only the rolling resistance of the running gear was determined on the road. The fuel consumption of the truck was determined on the road as a check on the results obtained in the laboratory. Four 3-ton trucks, all of the same model—gross weight, 16,000 pounds—were used to give a thoroughly dependable average result. In these tests the greatest difficulty was encountered in determining the efficiency of the transmission system. A hydraulic dynamometer of the recording type was also developed to measure directly the rolling resistance of the running gear. A formal report of this work was made in the "Proceedings of the Eighth Annual Conference of Highway Engineering," February, 1922.

There was considerable criticism among the state highway engineers to the effect that the truck was somewhat heavier than the average commercial vehicle on our roads; so that early in the year 1922 work was again begun on two high-speed 1-ton trucks, using methods considerably improved, as a result of the experience in the previous tests. Since the engines in the light trucks were not governed, a much larger range of speed was covered. In testing the transmission system, the engine was removed and the chassis driven by an electric dynamometer. The output at the rear wheels was measured by Prony brakes and checked by a reaction dynamometer on the rear axle itself.

In calibrating the large hydraulic dynamometer it was found that there was some friction in a stuffing box which might seriously affect our results on a very light pull, so a much smaller dynamometer was built which avoided the use of a stuffing box. Some of this friction still remained, however, and at present we are in the process of developing the reaction dynamometer used on the transmission system tests. Instead of using a piston and cylinder to change the drawbar pull into liquid pressure, a Fulton pressure element is adapted to that purpose. Since it is a combination of a diaphragm and a bellows, no leakage of the liquid can occur, and as there are no sliding surfaces, friction is reduced to a minimum. We intended to use both methods to determine the rolling resistance of the 1-ton truck. The reaction type dynamometer has a distinct advantage in that it is self-contained and the truck upon which it is mounted constitutes an excellent instrument for comparing the rolling resistance over various

types of road surfaces, rough roads, curves, etc. Since in determining the rolling resistance of the running gear it will be necessary to correct for grade resistance and acceleration or deceleration, a recording accelerometer will be used in addition to the recording reaction dynamometer.

TABLE 1.—*Inertia Tests. 3-ton Truck*

Group	Equivalent moment of inertia, M. ft. ²	Actual moment of inertia, M. ft. ²	Weight of parts in pounds	Radius of gyration, feet
Two front wheels.....	24.06	24.06	494	1.25
Two rear wheels.....	67.2	67.2	1304	1.28
Transmission main shaft with sliding gears, propeller shaft, universal joints, final drive and axle shafts.....	43.0			
Clutch drum and driven discs, clutch shaft and gear, transmission counter-shaft.....	<i>Gears</i> 4th 2.10 3rd 4.62 2nd 13.84 1st 44.23	.025		
All moving parts of the engine.....	4th 166.1 3rd 365.3 2nd 1094.0 1st 3491.0	2.05		

$$2 \text{ front wheels } r = \sqrt{\frac{24.00 \times 32.2}{494}} = 1.25$$

$$2 \text{ rear wheels } r = \sqrt{\frac{67.2 \times 32.2}{1304}} = 1.28$$

Gear ratio:

4th gear= 9.0
 3rd gear= 13.36
 2nd gear= 23.10
 1st gear= 41.3

While the truck performance tests were going on we became interested in the effect of storing energy in the rotating parts of a moving vehicle and the relation of this effect to acceleration and deceleration of the vehicle. If a car or truck is accelerated, kinetic energy of translation is stored in the moving vehicle. A large number of the parts have, in addition to their linear motion, rotative motion, and the connecting-rods and pistons have a very high reciprocating velocity. Thus they have an additional quantity of kinetic energy. By suitable methods the capacity of these parts to absorb energy was determined; also a quantity called the equivalent moment of inertia of all these rotating parts. It may be defined as the moment of

inertia of such an imaginary mass, located in the rear wheels and revolving with them, that would have at any speed the same kinetic energy as the actual rotating parts of the truck.

Thus, when accelerating the 3-ton truck in high gear, we find that 21 per cent of the stored energy will be found in the rotating parts, and in low gear we find over 75 per cent in the rotating parts.

TABLE II.—Comparison of Kinetic Energy of Translation vs. Kinetic Energy of Rotation in Various Gears. 3-ton Truck

	Gear			
	4th	3rd	2nd	1st
Linear speed of truck, miles/hour	12	8.1	4.7	2.6
And of wheel periphery, feet/second (<i>v</i>)	17.64	11.88	6.87	3.84
Angular velocity of rear wheel radians per second (<i>w</i>)	11.63	7.83	4.53	2.53
Equivalent moment of inertia of rotating parts, poundal foot: ²				
(a) Engine to clutch	166.1	365.3	1094.0	3491.0
(b) Clutch to neutral	2.10	4.62	13.84	44.23
(c) Neutral to rear wheels	43.00	43.00	43.00	43.00
(d) Rear wheels	67.20	67.20	67.20	67.20
(e) Front wheels	24.06	24.06	24.06	24.06
(f) Total—when accelerating	302.46	504.18	1242.10	3669.49
(g) Total—when coasting	134.26	134.26	134.26	134.26
Kinetic energy	Accelerating			
Of translation, foot-pounds	76,950	35,100	11,830	3,664
%	79.0%	69.5%	48.0%	23.8%
Of rotation, foot-pounds	20,380	15,375	12,800	11,720
%	21.0%	30.5%	52.0%	76.2%
Kinetic energy	Coasting in neutral			
Linear speed of truck, M. P. H.	12.0	8.1	4.7	2.6
Energy of translation, foot-pounds	76,900	35,100	11,830	3,664
%	89.5%	89.5%	89.5%	89.5%
Energy of rotation, foot-pounds	9,050	4,100	1,389	429
Per cent	10.5%	10.5%	10.5%	10.5%

$$\text{Kinetic energy of translation} = w v^2$$

$$\text{Kinetic energy of rotation} = \frac{1}{2} I w^2$$

Weight of loaded truck (*w*), 16,000 pounds.

Truck operating at governed speed (1000 R. P. M.)

When decelerating, this stored energy is used to drive the truck, so that when the truck is coasting with gears in neutral, 10 per cent of the driving energy is furnished by the rotating parts.

When using an accelerometer to determine the rolling resistance by the coasting method, this relation must be known. Of the above 10 per cent, 5 per cent was stored in the rear wheels, 1.8 per cent in

the front wheels and 3.2 per cent in the rotating parts of the truck between the rear wheels and the transmission neutral.

The method of determining the equivalent moment of inertia was to jack up the rear end of a truck with the rear wheels over a well. Ropes attached to weights were wound on the wheels. The weights were allowed to drop a given distance, using their potential energy to overcome the friction of the rotating parts, to give the falling weight kinetic energy of motion, and the rotating parts kinetic energy of rotation. If the velocity, distance and time relations are known, equations may be set up and solved for the equivalent moment of inertia of rotating parts. Tables I and II give some interesting data obtained from the 3-ton trucks. Table III gives a comparison of the results obtained so far on the 1-ton speed truck with those obtained on the 3-ton truck.

TABLE III.—*Comparison of Results Thus Far*

Engine characteristics	1-ton	3-ton
Number of cylinders	4	4
Bore, inches	4 1/8	4 1/2
Stroke, inches	4 1/2	5 1/2
Displacement, cubic inches	240.5	349.7
Maximum horsepower at 1000 R. P. M.	23.0	33.7
Speed of maximum torque, R. P. M.	600	825
Maximum torque, pound, foot	130	179
Torque per cubic inch displacement, pound, foot		538
Maximum mechanical efficiency, per cent	87	90
Maximum over-all thermal efficiency, per cent	16.9	16.8
Minimum specific fuel consumption, lbs./B. H. P. hr.	7.59	7.65
Minimum at 1/2 load, lbs. B. H. P./hr.	1.00	.84

Transmission System Characteristics

1-ton truck					3-ton truck						
Gear	Speed, M. P. H.	Max.	Full load	Half load	Gear	Speed, M. P. H.	Max.	Full load	Half load		
High	10	85.0	84.7	83.0	High	12.0	83	82	82		
	20	84.5	84.2	82.0		3rd	8.4	79	79	73.5	
	30	83.5	83.1	80.0			2nd	4.7	78	78	72.0
	40	80.0	78.8	75.0				1st	2.6	77	77	70.0
2nd	5	81.3	81.0	81.0	1st				2.6	77	77	70.0
	10	81.5	81.2	81.5		1st			2.6	77	77	70.0
	15	81.5	81.3	80.5			1st		2.6	77	77	70.0
	20	81.5	81.4	79.0				1st	2.6	77	77	70.0
1st	10	78.9	78.4	76.5	1st				2.6	77	77	70.0
	10	78.9	78.4	76.5		1st			2.6	77	77	70.0

NO. 3. RELATION OF ROAD TYPE TO TIRE WEAR

Report by Professor W. C. McNowin

Purpose.—In the selection of a type of surface for a road it is necessary to take into account not only first cost and cost of maintenance, but also the effect of that type upon the cost of vehicle operation. Inasmuch as tire wear causes one of the major items in motor vehicle operation cost, it is desirable to know the relation of road surface to it. Such is the purpose of the investigation, the progress of which is here outlined.

Review of previous work on the subject of tire wear.—The writer has made a diligent search for records of previous efforts in the direction of determining the relation of road-surface type to tire wear, not only in engineering literature, but among those research agencies of the country likely to interest themselves in such a problem. If such work has been done, the search made has failed to bring any record of it to light except in one instance, namely, that of three students working on a Bachelor's thesis at the University of Kansas in the spring of 1922. This work of H. A. March, W. B. Wells and F. W. Goodnow, done under the direction of Prof. C. C. Williams, was the forerunner of the present research. The record of this work may be found in the library of the University of Kansas, in the Bachelor's thesis entitled, "Relative Wear of Automobile Tires on Brick, Concrete, and Asphalt Pavements," by March, Wells and Goodnow.

A circular track 59 inches outside diameter was constructed and was surfaced successively with the three previously mentioned surface types. Upon this track, by suitable mechanism, were run four ten-inch wooden wheels. Around the circumference of each wheel was fastened a strip of rubber casing material one inch wide which had been cut from a standard automobile tire casing. This wearing strip was carefully weighed before and after a 100-mile run on each kind of surface and the loss recorded in per cent of total weight lost. Other details are omitted. It suffices to say that the work was done in a satisfactory manner, considering the attendant circumstances. The results are shown in the following table:

TABLE I. *Per Cent Loss in Weight per 100 Miles, Considering Wear of Rear Wheels on Concrete as 100*

<i>Surface</i>	<i>Rear wheels</i>	<i>Front wheels</i>
Asphalt	27.2	15.3
Brick	53.3	34.5
Concrete	100.0	80.6

The plan for the present cooperative test.—It was decided to conduct the test in two parts, one being accomplished on a specially devised piece of laboratory equipment and the other on a Dodge touring car especially equipped for the purpose. This plan was carried out, and what follows will be largely a discussion of the purpose, design, construction and testing of these two pieces of equipment. It became clear very early in the summer that practically the whole season would have to be given to such work, and that little could be accomplished in the way of running a testing program. The objective determined upon has been very nearly completed. Such additional work of getting ready as needs to be done will be pushed during the year and, as far as can be foreseen, all difficulties ironed out, so that a program of testing can be started promptly with the opening of next season.

The laboratory apparatus.—This apparatus was designed to handle certain features of the work which could be done only on stationary equipment, or could be done better, cheaper, or more expeditiously in such manner. The following are some of the necessary items of work thought to be best done on it:

- (a) Determining in a standardized situation the individual characteristics of the tires to be used as regards wear.
- (b) Testing the effect of under inflation on wear of tires.
- (c) Testing effect of moisture on wear of tires.
- (d) Testing the effect of traction on wear of tires.
- (e) Testing the relative wear of tires on such surfaces as could be reproduced on such laboratory equipment.

Description of the apparatus.—General views may be obtained by reference to Figures 1 and 2. A carriage carrying a 12 H. P. motor is supported by a single rear Dodge Bros. motor car wheel and balanced by four coiled springs. This motor drives the auto wheel by belt and pulleys and through it drives the concrete shod wheel which constitutes the road. The "road" is connected by belt and pulley to a generator which is wired to load racks. The attendant uses the wattmeter and the load racks to keep the traction between the auto wheel and the "road" at a predetermined constant. The carriage carrying the driving motor is carefully balanced by weights, and its weight plus the balancing weights plus the tension in the four stabilizing springs give a weight on the auto tire equal to the weight on a rear wheel on a Dodge touring car when carrying a normal load or 900 pounds.

The pulley combinations are such that the speed of the auto wheel is held nearly constant at 25 miles per hour. The shaft of auto

wheel and "road" were each fitted with revolution counters to check speed, and to be used in the determination of the mileage. The running unit was taken as five hundred miles, and this appears to be about the right amount.

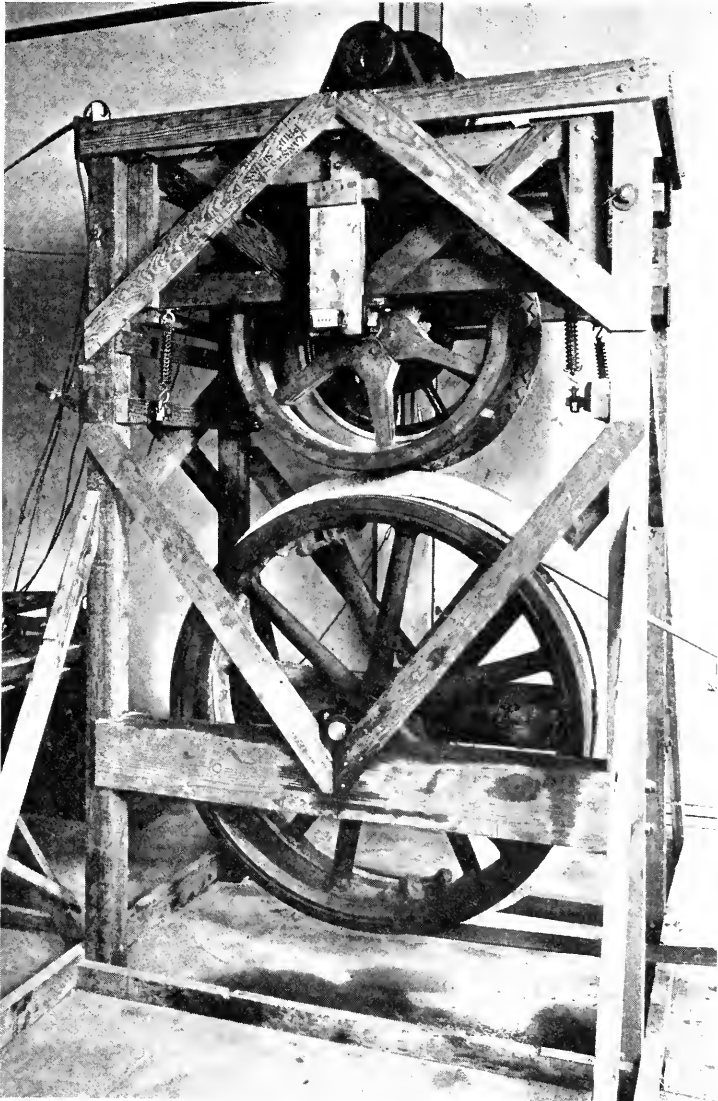


FIGURE 1. Tire testing apparatus used by Professor McNown.

The tires.—The tires adopted are standard for a Dodge touring car. The Kelly-Springfield Tire Company entered into cooperation on the

test to the extent of furnishing five of their standard BB 32"x4" cord tires.

The plan was to measure the wear in terms of the loss in weight for a given distance, and this, of course, pre-supposed getting the tires

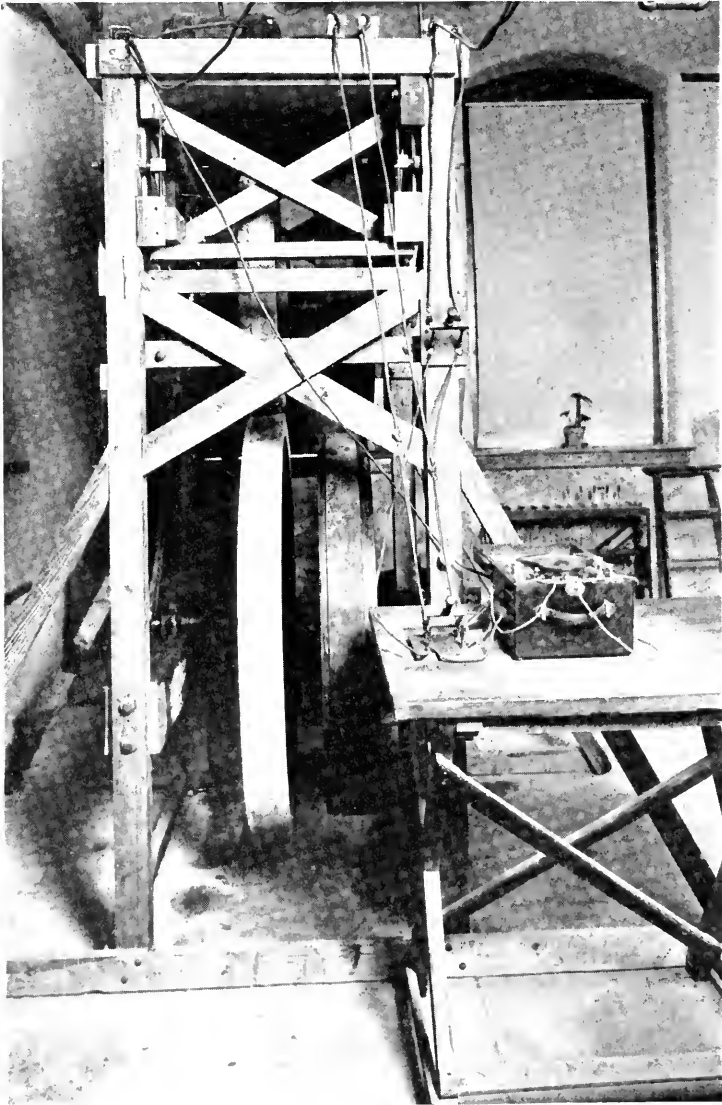


FIGURE 2. Tire testing apparatus used by Professor McNown.

into a condition of constant weight in all relations except that of wear. Such proved to be very difficult—in fact, we are not yet satisfied with

our solution of this problem. Rubber tires are more or less porous and readily gain or lose in weight by taking on or throwing off moisture. Within certain limits, their weight fluctuates with the degree of humidity of the air. Table II gives the history of such variation for one tire through a period of two months.

An attempt was made to dry the tires to a constant temperature in a specially devised container heated by a Freas electric oven. Table II shows the degree of success attained. It also shows that as soon as the tires were removed from the dryer they began to increase in weight, due to an accession of moisture. Such absorption doubtless continued throughout the twenty-hour period necessary to make a 500-mile-tire-wear run, affected of course both by the heating and the ventilating to which the tire was subjected during the run. The solution adopted was to take the tire from the dryer, expose it to the atmospheric condition of the room in which the test was to be made, ascertain its hourly rate of change in weight, and compute a correction.

Considerable thought and effort has been directed toward finding a moisture-proof coating to protect the tires. E. I. du Pont de Nemours & Company has furnished such a coating in their Viscolac. This, however, is a celluloid lacquer and not very suitable for use on rubber. It has not yet been given a trial.

The laboratory test.—It is well known that traction is an important factor in the wear of the tires on the driving wheels. For that part of the work which is to be done with the car on the various roads the traction will be a variable, chiefly on account of the different grades encountered on the roads and the different tractive efforts required for different road surfaces. For this reason it was thought necessary to plan for the development of a "Wear-Traction" curve through the use of the laboratory apparatus and the wheel shod with concrete, and possibly with brick and asphalt as well. Such work as has been done this season has been on a concrete-shod wheel and at a traction of 50 pounds per ton. This value was taken simply to develop one point on the curve.

In order to control the traction on the laboratory apparatus the efficiency curve of the upper or driving motor was determined: then the carriage was raised so that the auto wheel was clear of the road and the power necessary to run the auto wheel in this condition determined. Then the additional power needed to produce a given traction was computed and that traction maintained by the operator by the aid of the wattmeter and electrical resistance in the form of load racks, so called.

TABLE II.—*Tire Wear Test—Weighting Record—Kelly-Springfield 32 x 4 Cord Tire #509,721*

Date, 1923	Hour	Weight in kilograms	Difference	Hourly rate, grams	Remarks
Aug. 10	9:30 A.M.	10 442 2			
11	8:40 A.M.	420 6	-21 6	0 93	In electric dryer at temperature 108°-138° F.
12	9:40 A.M.	409 6	-11 0	0 44	In electric dryer at temperature 108°-138° F.
13	8:45 A.M.	399 4	-10 2	0 44	In electric dryer at temperature 108°-138° F.
14	7:00 A.M.	395 4	-4 0	0 18	In electric dryer at temperature 108°-138° F.
15	9:00 A.M.	390 5	-4 9	0 19	In electric dryer at temperature 108°-138° F.
16	9:00 A.M.	386 4	-4 1	0 17	In electric dryer at temperature 108°-138° F.
17	9:00 A.M.	385 9	-0 5	0 02	In electric dryer at temperature 108°-138° F.
18	12:30 P.M.	376 2	-9 7	0 35	Changed position in dryer
19	9:30 A.M.	373 8	-2 4	0 11	Changed position in dryer
20	8:30 A.M.	372 1	-1 7	0 07	Changed position in dryer
21	8:30 A.M.	370 3	-1 8	0 07	Changed position in dryer
22	8:30 A.M.	378 4	8 1	0 34	In warm closed room outside of dryer, temperature 77°
23	10:30 A.M.	380 3	1 9	0 07	In warm closed room outside of dryer, temperature 77°
24	3:15 P.M.	382 6	2 3	0 08	Before test #4
25	2:00 P.M.	351 6	-31 0		After test #4
26	10:00 A.M.	355 8	4 2		Standing laboratory temperature 77°
27	8:15 A.M.	358 6	2 8	0 21	Standing laboratory temperature 77°
28	8:30 A.M.	367 3	8 7	0 13	Standing laboratory temperature 77°
3	8:15 A.M.	356 5	-10 8		In dryer again 112° to 140° F.
4	8:30 A.M.	355 0	-1 5		In dryer again 112° to 140° F.
13	9:00 A.M.	345 2	-9 8		In dryer again 112° to 140° F.
18	4:30 P.M.	360 3	15 1		In laboratory
19	8:30 A.M.	361 6	1 3		Before test #9
20	5:00 P.M.	349 4	-12 2		After test #9
Oct. 10	11:30 A.M.	368 6	19 2		In laboratory

The inflation of tires was kept at the standard of the tire manufacturers, viz., 65 pounds.

Table III shows a typical set of running notes for one run of 500 miles.

Weighing the tires.—The weighing was done on an E. H. Sargent Company fine balance loaned by the Kansas Bureau of Weights and Measures, having a capacity of fifty pounds and a sensitiveness of one-tenth gram.

The results of the laboratory tests.—Table IV shows the results so far attained.

It was in the search for the reason for the discrepancy in Test 2 that it was found necessary to give the tires a drying treatment. At the end of Test 4 the first concrete wheel developed a weakness and had to be discarded. The results of Tests 5, 6, and 8 are remarkably concordant, considering that they were made on different tires. There is no explanation for the low value from Test 7. The purpose of Tests 5, 6, 7 and 8 was to prepare a set of tires to put on the car for a road test. The car apparatus, however, developed a mechanical weakness which has taken weeks to correct, and hence the road running was postponed until next season. Had a road run been made, it would have been necessary to re-run with the tire used in Test 7 for a check upon the value obtained. The plan is to put all tires over the laboratory apparatus before they are used on the car, in order to develop any individual characteristics or weakness. How frequently this will have to be repeated cannot be decided until results begin to come in from the road-testing with the car.

Inside temperature of tires.—One by-product of this test may be the determination of the inside temperature of automobile tires. A device has been prepared whereby a thermometer may be inserted into the inside of the inner tube through an inlet similar to that used in inflating a tire. The thermometer is protected from the air pressure inside the tire by a thin brass wall. Inasmuch as it may be left in the tire indefinitely, it will soon come to the heated condition which will permit it to register the inside temperature of the tire. On account of the pressure of more important preparation, no results have been taken with this apparatus. It may, of course, be used either on the road or in the laboratory.

Equipment for testing tires on the road.—A Dodge Bros. touring car was chosen on account of its moderate cost and because it seemed to represent fairly well an average size. The one secured is of the late 1921 model, had been run about eighteen months, and was in good mechanical condition. The local dealer at Lawrence, through

TABLE III—Laboratory Apparatus—Tire Wear Test

Date, 8-24-25—Test No. 6—Operators, McNowa, Bradshaw—Tire No. 509—Load 900#—Air pressure 65#—Traction = 50#/ton = 22.5#—One rev. of tire = .00163 Mi.—One rev. of wheel = .00268 Mi.

Time	Min.	Register No. 1	Revolutions	Miles	Comp. speed mi. hr.	Tachometer rev. min.	Tachometer mi./hr.	Input watts	Time	Register No. 2	Revolutions	Miles
5:00:00	60	18,542	15,863	25.86	25.86				5:00:00	2,623	9,663	25.90
6:10:00	17	34,405	4,470	7.29				2,170	6:10:30	12,286	2,620	7.29
6:27:00		28,875							6:27:00	14,906		
6:37:00		38,875							6:37:00	14,906		
7:38:00	61	54,965	16,090	26.23					7:38:30	24,710	9,804	26.27
8:37:00	59	70,576	15,611	25.45		262	25.5	2,170	8:37:30	34,137	9,437	25.29
9:37:00	60	86,133	15,557	25.35	25.35	265	25.8	2,170	9:37:30	43,546	9,399	25.18
10:37:00	60	107,063?	20,960	34.16		266	26	2,250	10:37:30	53,191	9,645	25.85
11:37:00	60	118,045	10,952	17.85		265	25.8	2,150	11:37:30	62,841	9,650	25.86
12:12:00	35	126,891	8,846	14.42		260	25.3	2,100	12:12:00	68,375	5,534	14.83
12:52:00	60	126,891	20,898	34.06		260	25.8	2,200	12:52:00	68,375	9,683	25.95
1:52:00	60	147,789?	11,064	18.03		265	25.8	2,200	1:52:30	78,058		
2:52:00	60	158,853	16,131	26.29	26.29	267	26.1	2,210	2:52:30	87,761	9,762	26.06

3:52:00	174,984	16,143v	26.31	26.31	266	26	2,180	3:52:30	97,523	9,758	26.15
4:52:00	191,127	16,112	26.26	26.26	266	26	2,180	4:52:00	107,281	9,743	26.08
5:52:00	207,239	15,971	26.03	26.03	266	26	2,150	5:52:30	117,024	9,666	25.90
6:52:00	223,210	16,027	26.12	26.12	266	26	2,170	6:52:30	126,690	9,701	26.00
7:52:00	239,237	15,913	25.94	25.94	266	26	2,180	7:52:30	136,391	9,707	26.01
8:52:00	255,150	15,869	25.87	25.87	260	25.3	2,190	8:52:30	146,098	9,513	25.49
9:52:00	271,019	15,999	26.08	26.08	264	25.8	2,180	9:52:30	155,611	9,682	25.95
10:52:00	287,018	15,995	26.07	26.07	264	25.8	2,190	10:52:30	165,293	9,673	25.92
11:52:00	303,013							11:52:30	174,966		
1:21:00	326,526							1:21:00	189,102		
19:	21:00	307,984	502.01	25.82			2,179			186,479	499.76

$$X \cdot r = 746 \times 5,280 \times 25.82 = 550 = 2,179 \quad \bar{X} = 23.6\# = \text{Tractive effort}$$

$$33,000 \times 60 \times .748$$

$$\bar{X} = 23.6\#$$

whom it was purchased, gave it a thorough overhauling, with especial attention to alignment of wheels and mechanical condition of steering gear.

TABLE IV.—*Results in Laboratory Tire Wear Apparatus*
Loss in grams in a 500-mile run

Test No.	Tire No.	Loss in grams	Cor- rected	Road wheel	Remarks
1	Q 513 562	17 6	.....	#1	Not previously dried
2	Q 513 562	6 0	.....	#1	Not previously dried
3	Q 513 562	20 2	.....	#1	Not previously dried
4	Q 513 562	24 2	.....	#1	Dried to a low hourly rate of loss
5	Q 512 990	32 9	34 8	#2	Dried to a low hourly rate of loss
6	Q 509 721	31 0	32 0	#2	Dried to a low hourly rate of loss
7	Q 523 538	20 4	22 1	#2	Dried to a low hourly rate of loss
8	Q M 6550	31 2	32 9	#2	Dried to a low hourly rate of loss
9	Q 509 721	42 2*	.....	#2	Brick shod wheel

*At the end of 144 miles the brick shod wheel developed weakness which required the discontinuance of the run. The loss in weight of 12.2 grams was raised by proportion to the 500-mile basis for comparison.

In order to measure traction, the car had to be equipped with some form of dynamometer or torque meter, together with autographic register. Prof. A. H. Sluss, Director of Fowler Shops at the University of Kansas, was perfecting a torque meter, and after seeing it tried out, we decided to adapt it to our purpose. An autographic register suitable to our needs, and much less costly than any that could be purchased, was made in Fowler Shops. Figures 3, 4 and 5 show the set-up of both torque meter and autographic register.

To adapt the torque meter to the car, it was necessary to cut the propeller shaft and put flanges on the two ends thus exposed. The torque tube also had to be cut and bridged around the space to be occupied by the torque meter. Roller bearings were inserted between torque tube and propeller shaft near each end of the torque meter. A housing over all to keep out dirt will probably be needed.

The autographic register is driven from the propeller shaft by suitable gears and a flexible shafting. The paper speed is about ten inches to the mile. Pressures are transmitted to the paper by a steam indicator gauge using a 50-pound spring. A clock-work, solenoid and pencil puts a mark on the paper at fifteen-second intervals.

Calibration of the torque meter.—We are at present engaged in calibrating the torque meter by the use of a Prony brake. The car

is mounted on a platform and the two rear wheels run on two wheels at each end of the Prony brake-shaft, according to the usual set-up. The many delays incident to ironing out mechanical difficulties have

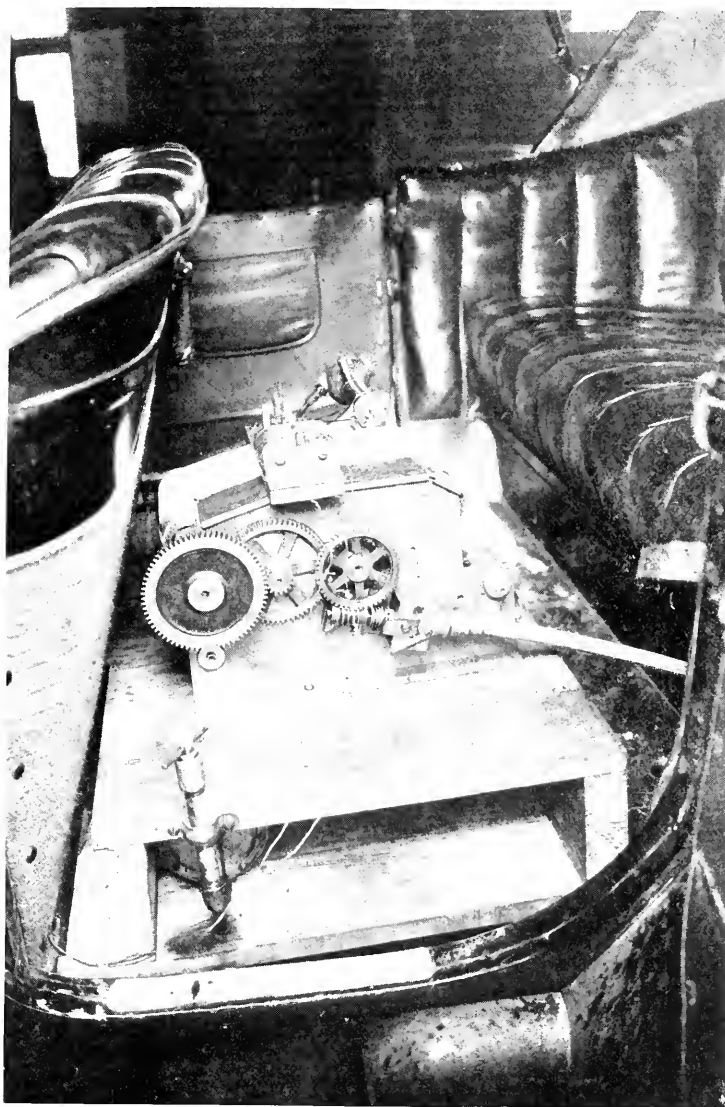


FIGURE 3. Torque meter.

so delayed this work of calibration that no results are available at this writing. It is hoped very soon to establish the relation between traction at the road and the ordinate of the indicator diagram.

No. 4. COST OF OPERATION OF MOTOR VEHICLES

a. Project organized by American Automobile Association. Report not yet available.

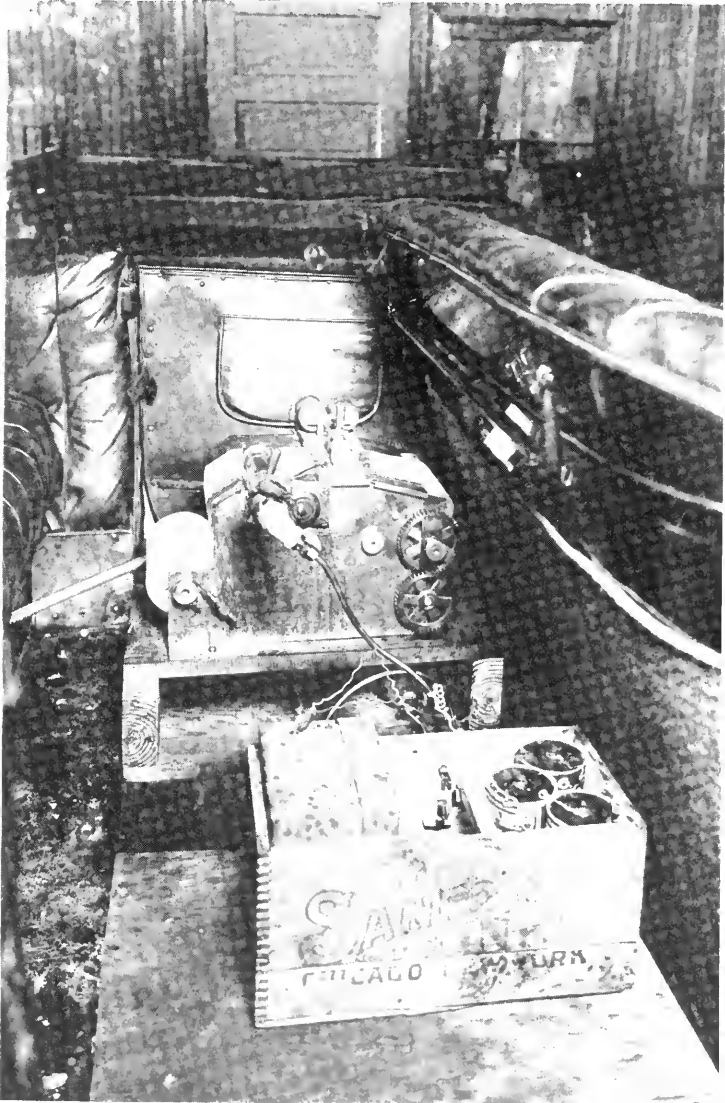


FIGURE 4. Torque meter.

b. Project organized by Iowa State College. This project involves not only a study of the various items that enter into the cost of

vehicle operation, but also a correlation of these costs with type and condition of highway. A small amount of work has already been done, but the project is practically a new one.

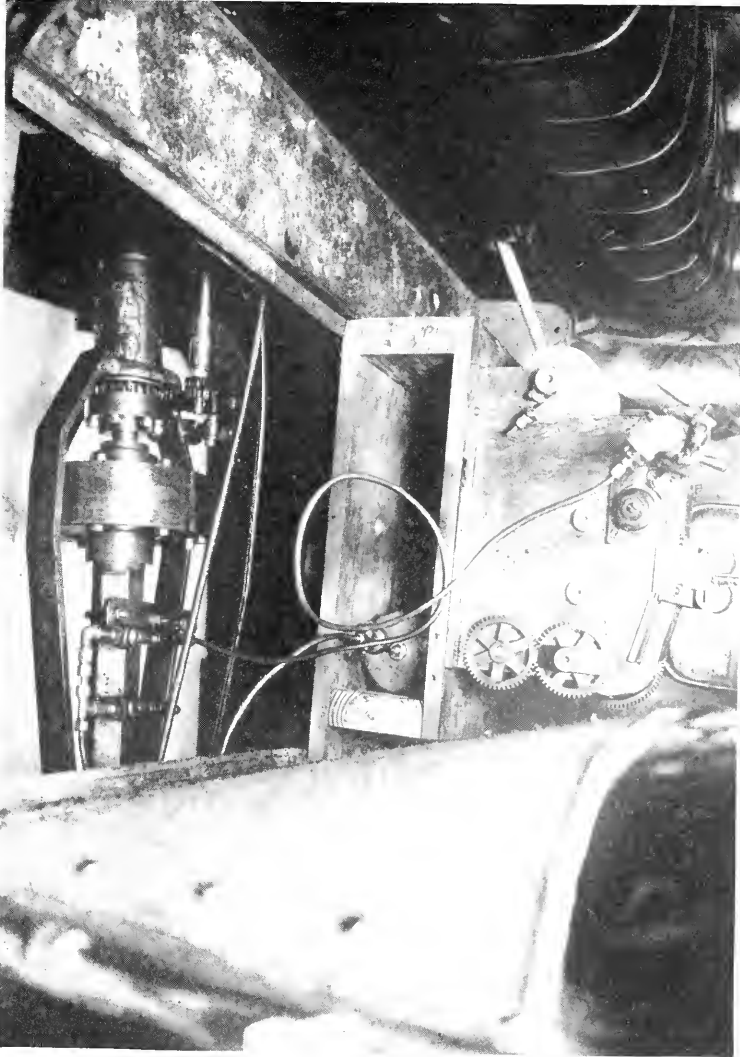


FIGURE 5. Torque meter.

NO. 5. ROLLING RESISTANCE AND RELATED CHARACTERISTICS OF ROADWAY SURFACES

It will be noted that a final report has been made on a project under this title. There remain a few factors of immediate impor-

tance to be investigated, and this work is under way at Ames at the present time. The most important is the determination of the change in rolling resistance with the thrust (or tractive effort) of the driving wheels. In this work we are using the transmission dynamometer designed by Mr. Beebe, of the U. S. Bureau of Public Roads, and I think that the desired information will be obtained shortly.

Prof. Agg: Prof. Manly, have you anything to report this year?

Prof. Manly: We are going on with the work on "The effect of tires and spring suspensions on maintenance of vehicles and roads" and attempting to develop reliable apparatus and methods of tests. The problem gets harder the further one advances. So far, I have no final results to report.

Prof. Agg: This is typical of this kind of problem. We work along for several years on a method of solving the problem. When methods are once determined, results come quickly.

Chairman Johnson: Prof. Agg's report is before you for discussion. Are there any questions?

Chairman Johnson: What factors are to be taken into consideration in the evaluation of the roadbed of highways?

Prof. Agg: That is a matter which we hope to take up at a future committee meeting—the question of exactly what factors should be included in the evaluation of the highway in the total cost of highway transportation. I have ventured to prepare a tabulation in which I have included the cost of the right of way, interest on cost of highway surface, cost of maintenance of right of way, cost of the roadway surface and maintenance of roadway surface; then the usual plan for an annuity whereby the cost of the roadway surface will be amortized at the end of the economic life of the roadway surface. These are items to be included in the cost of the highway itself and similar items for the vehicle. It is largely my own work and will be submitted to the committee before it is published as committee information. It seems logical to put in the cost of the right of way, but most people do not agree with me on this point. I charge the number of acres per mile in the right of way at \$250 per acre, and it amounts to about \$2,000 a mile.

Mr. Shirley: I find the cost runs about \$1,000 a mile.

Mr. Manly: Do you allow for appreciation of value in the right of way?

Chairman Johnson: Is it charged as an expenditure? The taxpayers having spent the money, should there be any further interest charge on money spent as cost of highway? There is no current charge in public ledgers.

Prof. Agg: We charge interest every year on \$2,000 at 4 per cent as a capital charge for the right of way. There was no charge in the first instance for right of way taken from adjoining lands. Today we do pay hard money for it.

Chairman Johnson: How far back should we begin or cease to make charge for interest?

Prof. Agg: If the scheme of evaluation I mention is carried out, payment of interest will not cease as long as the highway is used.

Prof. Tilden: In the evaluation of \$2,000 a mile, what was the original investment in right of way?

Prof. Agg: The value of the right of way.

Prof. Tilden: Suppose at the present time there is traffic over the right of way of, say, 1,000 vehicles a day. When that increases to 10,000 vehicles a day, is there any change in the capital charge?

Prof. Agg: No.

Prof. Tilden: The value of that mile of right of way to the community has unquestionably increased.

Mr. Blair: The original investment in Iowa roads was practically nothing, and I am wondering if the use of the road or the use of the abutting lands has developed their present worth. Will Prof. Agg evaluate the right of way in accordance with the fluctuating prices of land?

Dean Hughes: Does Prof. Agg intend to readjust this value every year or so? I found the cost of Iowa land a few years ago was less than \$50 an acre.

Prof. Agg: I do hope to get a unit of cost for transportation per ton-mile on public highways of any type that will be applicable at the time it is published. Whether it will be any good ten days after I cannot tell. It strikes me as being exceedingly important for the highway engineer to know what it costs him per ton-mile to transport over dirt roads, including cost accruing to the vehicle itself and to the road itself. When it has begun to cost him more to transport over a dirt road than over water-bound macadam, he should transform the road into water-bound macadam; and when it costs more to transport over bituminous macadam, he should put a high type pavement on the roadway surface. Above 300 vehicles a day, earth roads can be replaced by paved roads and money saved.

The road costs are insignificant costs. It is the vehicle costs that count. So far as Iowa is concerned, the total cost of vehicle operation, including capital and operating costs, will be this year about \$225,000,000, and the total expenditure for new construction and for maintenance of highways will be \$25,000,000, including every kind of highway. Vehicle costs entirely overshadow the road costs.

Mr. Lemon: I should like to ask whether rate of tire wear is to be determined by tread wear or by carcass failure. Also, after completion of the rotating concrete wheel tests, are the results going to be comparable with road service tests?

Mr. McNow: The scheme we are using for testing tires is to measure the loss by wear from the tread. We do not test carcass failure. That question has not been taken up. In measuring the wear, work has been done in the laboratory, but nothing as yet on the road. Whether the work done in the laboratory will correlate with that of the road remains to be seen.

The report of Committee No. 1 was accepted.

Mr. W. L. Holt, of the U. S. Bureau of Standards, presented a paper on

RESEARCH ON RUBBER TIRES

The various departments of the government spend in the neighborhood of a half million dollars per year for pneumatic tires. Inasmuch as these tires are purchased on a competitive basis, the setting of proper standards to be used as a basis of purchase is a very important consideration. The U. S. Bureau of Standards, in conjunction with the other interested departments and the tire manufacturers, has been instrumental in establishing a standard for purchases, and with the large volume of business it will be seen that a small percentage increase or decrease in the purchase price, or in the quality, means a considerable amount in dollars and cents.

I am going to outline some of the work which has been carried on at the Bureau with a view to establishing a better basis for tire purchases. The present specifications, which have been in use for some time, although revised from time to time, cover detailed requirements in regard to the material to be used, including certain chemical and physical tests, and also prescribe methods for putting the tires together. While such specifications serve a useful purpose and aid in sorting out the good from the bad, they are not foolproof, as it is possible to build tires of the best of materials while the resulting product will not give satisfactory service. On the other hand, tires have been found constructed of materials of mediocre quality which have yielded at least average service.

In an attempt to better such specifications a laboratory endurance testing machine has been installed. With this machine the tire is mounted on a wheel, free to revolve, which is carried on a movable carriage and pressed against a 5-foot flat-faced drum with a pressure corresponding to the axle load. The drum is driven at a surface speed of 30 m. p. h. and thus the tire is revolved and subjected to

flexing such as it would receive on the road. Cleats are bolted across the surface of the drum at intervals so as to give the effect of bumps in addition to the flexing.

Contrary to what seems to be the popular idea, the problem in tire-building is not to make a tread which will wear, but to make a tire in which the component parts—the plies, the breaker, the tread, etc.—will stay together, and at the same time distribute the various strains so that the strain will not be excessive at any point. As soon as any of the parts separate, chafing immediately sets in, blisters begin to appear at various places, and the life of the tire is about gone. Accordingly, in developing such a test the motive has been to produce primarily a carcass test, the question of tread wear to be taken care of as a separate test.

It has been found that the conditions under which a tire is run—that is, the air pressure used, the axle load, and the nature of the cleats—have a marked effect upon the mileage which a tire will give on this machine. By changing these conditions, different features of a tire can be tested. For instance, a high air pressure and small cleats seem to yield a particularly severe action on the tread portion, and failure is apt to occur, due to tread separation, unless that particular feature is especially well designed. Larger cleats seem to cut down the mileage considerably and are especially severe on the carcass, so that failure is apt to occur, due to ply separation or breaking of the carcass. If a set of, say, ten different tires is run under each of the two different test conditions such as I have mentioned, the order in which the tires will line up with respect to mileage will probably be quite different.

Accordingly, the problem has been to so establish the test conditions that the method of failure will be the same as would result from average road service. As I have stated before, such a machine does not determine the wearing quality of the tread, but rather is designed to pick out any carcass weakness which may exist. It has also been the aim to set the test conditions so that a test can be run in the shortest possible time.

From the present results, it appears that it will be possible to determine whether or not there is any weakness in the tire in about 1,000 miles of running. This means that, by operating a machine day and night, a test could be completed in less than two days. The Rubber Association of America is actively cooperating with the Bureau in this work and it is anticipated that such a test will be adopted in the near future.

Aside from the value of such a test directly to the government in making purchases, the numerous requests which are received from

manufacturers all over the country show the need for such a standard test for the tire industry in general.

In conjunction with such tests as I have outlined, power-loss tests of pneumatic tires have been carried on for the past two years. Over 100 tires of various makes and of sizes ranging from $3\frac{1}{2}$ to 5 inches have been tested. The equipment consists of two electric absorption dynamometers. One was operated as a motor and carried on its shaft a wheel and the tire to be tested, and the other operated as a generator and carried on its shaft a smooth flat-faced drum. The motor is mounted on a movable carriage, the arrangement being such that the tire can be forced against the drum with a pressure corresponding to the axle load. In this way the tire and drum constitute a friction drive by means of which the motor drives the generator.

Aside from the tire itself, four principal variables enter into the determinations: speed, tractive effort, air pressure and axle load. The method of determining the power loss is to mount the tire on the wheel on the motor shaft and force it against the drum by means of weights acting through a bell-crank lever. The axle load is varied by changing the weights. The air pressure may be changed in the usual way. In our case the tire can be inflated or deflated while running by means of a slip joint on the hub. This arrangement also aids in maintaining accurate pressures. Speed is taken care of with a variable speed motor and the tractive effort by cutting out generator resistance.

The power loss is the difference between the input to the tire by the motor and the output to the generator by the tire. It is measured by mechanical rather than electrical means, which eliminates the consideration of motor and generator efficiency, bearing friction, etc. Tests are made by running a tire under varying conditions and measuring the energy input and output under each. The difference between these figures after making a small correction for windage represents the loss in the tire. This loss is manifested by the generation of heat and a rise in the tire temperature.

Certain conclusions have been drawn as to the effect of each of these variables.

1. *Speed*.—The power loss is very nearly directly proportional to the speed—that is, at 40 m. p. h. the loss is approximately twice that at 20 m. p. h. This means that the resistance which a tire offers to rolling, or what will be referred to as the rolling resistance, is very nearly constant and is independent of the speed.

2. *Axle load*.—The axle load has a similar effect on the power loss unless excessive loads are used—that is, there is almost a direct proportion, and doubling the axle load doubles the loss.
3. *Air pressure*.—No simple relation exists between air pressure and power loss: there is a rapid increase in power loss under low air pressures. Under high air pressures the loss approaches a constant value.
4. *Tractive effort*.—The introduction of a moderate tractive effort does not seem to have much effect on the power loss. For instance, if the input to a tire is one horse-power, and the output zero horse-power, the loss is one horse-power. If there is a five horse-power input, the output will be almost four horse-power. Under higher tractive efforts, the effect on the power loss is more marked.

As a simple and quick means of comparing tires, the following were used: (1) Zero tractive effort. (2) The air pressure as recommended by the S. A. E. for the maximum recommended load. (3) The maximum recommended axle load for each particular size tire, the loss calculated as the rate per 1,000 pounds load. (4) Expressing the loss as pounds rolling resistance per 1,000 pounds axle load, which eliminates the item of speed.

The following figures are a summary of the rolling resistance of different kinds of tires.

TABLE I. *Rolling Resistance per 1,000 Pounds Axle Load in Pounds*

3½-inch fabric tires.....	14 to 20
Average	17
3½-inch cord tires.....	8.4 to 13.8
Average	11.5
4-inch fabric tires.....	14 to 17.5
Average	16
4-inch cord tires.....	8.1 to 13.1
Average	11.3
5-inch cord tires.....	9 to 14.5
Average	11

It will be noted that the average rolling resistance of cord tires, irrespective of the size, is a little over 11 pounds, while for fabric tires it lies between 16 and 17 pounds. This indicates that the performance of the different sizes of tires is about the same. In round numbers the rolling resistance of tires varies from 8 to 20 pounds

per 1,000 pounds load, with 14 as the dividing line between cords and fabrics.

At the present time fabric tires are rapidly becoming obsolete, except for the smaller sizes; but, taking the cord tires only, the one with the lowest rolling resistance is only 56 per cent of that of the highest. The popular idea is that these differences are due to the design of the tread. This has some influence, but it is not the deciding factor. Taking two tires, one with a smooth tread and one with a non-skid or bumpy tread, it is not possible to tell from outside appearance which will offer the most rolling resistance, although, other things being equal, the non-skid type of tire will probably show a slightly greater resistance. The real cause for differences lies in the carcass construction. While from appearances the two carcasses may be identical, small differences in the rubber compound, the lay of the cords, the amount of rubber, etc., will materially change the internal friction, and hence the rolling resistance. The fact that the carcass construction is the deciding factor is brought out by the differences between cord and fabric tires. It also emphasizes the statement made in the first part of this paper, that the problem in tire design is not to make a tread that will wear, but to make a tire that will hold together with strains reduced to a minimum.

As a check on laboratory figures, the losses in several sets of tires have been determined in the laboratory and then the same sets put on an automobile one after the other and the difference in the rolling resistance determined by towing behind another car. This test was carried out at various speeds and under different inflation pressures for each set of tires. While the results have not been completely compiled as yet, the differences in rolling resistance were apparent at once and the results seem to follow closely the laboratory determinations.

As to the significance which may be attached to such figures, the first thing which comes to mind is the effect on fuel consumption. Comparing the effect of a change in tire equipment on fuel consumption is simply a matter of measuring the loss in each case and finding the fuel necessary to generate the excess power. The difficulty of making an accurate statement as to what this difference will amount to is the big variation in fuel required per horse-power, not only in different engines, but in the same engine run under different conditions. Work is being carried on at the present time to make determinations such that some fair average values may be given.

A second value which may be attached to power loss determinations is their use by the tire designer to analyze the influence of details in

the tire construction. By this means it should be possible more closely to coordinate the different parts and reduce friction or wasted energy to a minimum, and at the same time prolong tire life. These investigations are being extended to solid and cushion tires. The latter tires in particular are coming quite into prominence at the present time, with many new kinds being put upon the market. The balloon, or air-cushion type, is also being taken up, but not enough data is yet available to draw any definite conclusions as to how the power loss compares with that of the usual type of tire. From the standpoint of absorbing bumps, there is no question but that balloon tires are superior.

In connection with reclaimed rubber, the use of a larger percentage in tire treads is being investigated. One hundred tires have been built, the tread of each consisting of sections containing different combinations of new and reclaimed rubber; these are being tested on post-office cars run over roads selected with a view to giving as many varieties of road wear as possible. In addition to the direct conclusions which may be obtained from these tests, an opportunity is afforded for obtaining some data as to the value of the various types of laboratory abrasion machines in use. Accordingly, a complete study is being made on the rubber compounds used in the treads, using as many types of abrasion testing machines as possible. These results in connection with the road tests should give valuable information for interpreting the results of laboratory tests.

Mr. Crane: Has there been enough work accomplished in the way of results to connect in any way the rolling resistance with tire life? Is there any indication that the tire with the least rolling resistance has longer life?

Mr. Holt: In that connection what is measured is the total energy lost in the tire which is made up of the sum of the losses in the unit parts. There may be a small part of a tire in which there is a high unit strain which would not show up as excessive compared with the total loss, and until such can be differentiated the tire with the lowest total loss will not necessarily show the greatest road mileage.

Prof. E. H. Lockwood, of Yale University, contributed the following description of a road seismograph for motor vehicles.

ROAD SEISMOGRAPH FOR MOTOR VEHICLES

This instrument was devised originally in an attempt to measure the value of shock absorbers, snubbers, etc., as applied to motor vehicles. It proved useful for the purpose mentioned, and since has found applications in measuring the relative roughness of different

stretches of road, the riding qualities of different vehicles over the same road, and the effect of tire inflation and the so-called balloon tires.

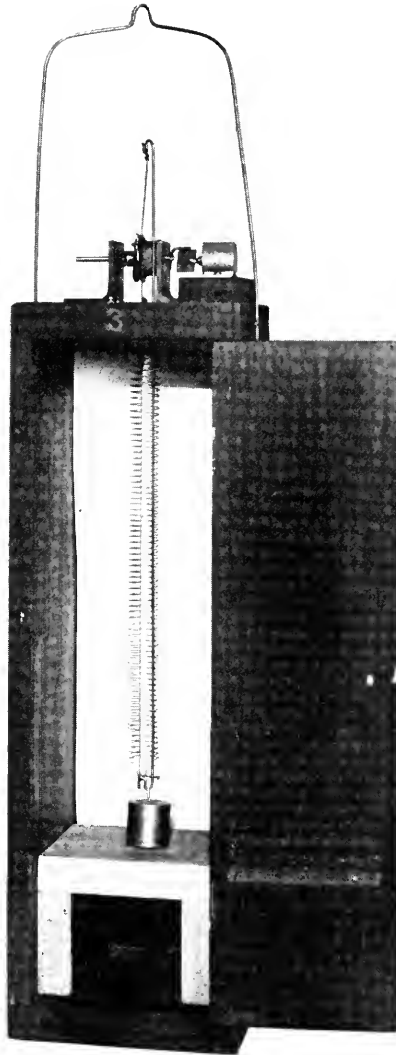


FIGURE 1. Lockwood road seismograph.

A photograph of the instrument shown in Figure 1 contains the usual suspended pendulum, with an attached mechanism for recording the relative motion between the pendulum and supporting frame in a *vertical* direction only. The recording device consists of

a reciprocating spool, actuated by a linen cord wrapped around the spool, and tied to the ends of a light vertical rod which forms part of the pendulum. A friction ratchet transfers the motion of the reciprocating spool, in one direction only, to a revolution counter, which therefore integrates the reciprocating motion by reading on the dial. In the instrument shown in Figure 1, the spool was made about 13-16 inch in diameter, giving a register of one revolution for about 2.6 inches vertical motion. In using an instrument of this type the counter is read at certain stations, or distances, by the speedometer, and comparisons can be made directly from the counter readings as an index of the vertical shaking.

One feature of the instrument deserves special mention because it is not a part of the usual seismograph. This feature is a supporting table under the pendulum, whose object is to prevent the periodic

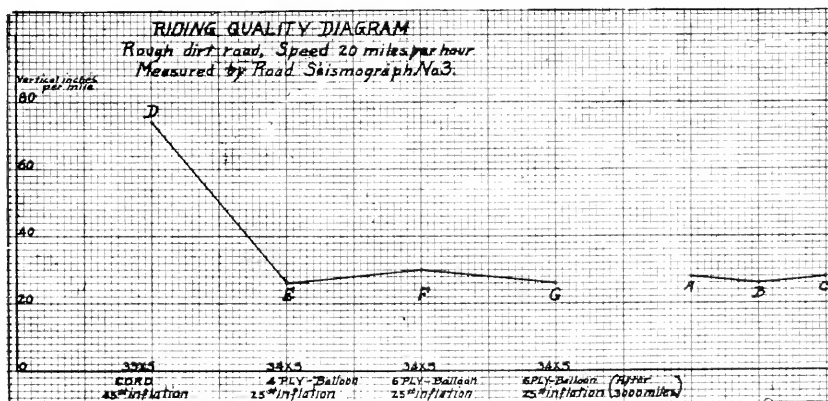


FIGURE 2. Record obtained by Lockwood road seismograph.

vertical oscillation of a free pendulum when carried on a vehicle. The motion of the supported pendulum consists of a rebound or jump from the table, of height dependent on the intensity of the shock. The motions of the pendulum may be quite small and frequent. In actual use the counter will read steadily, with no visible motion of the pendulum. The sensitiveness of the instrument to small shocks depends on the location of the table. In the instrument described, the table supported about 2 per cent of the pendulum weight, and as thus constructed will not register on a railway coach over a good roadbed, but will give a considerable reading with any automobile over the smoothest road.

An application of this seismograph to vehicle measurement is given in Figure 2. Tests A, B, C refer to the riding quality of three

closed cars with best forms of shock absorbers driven at 20 miles per hour over a rough dirt road. Test D gives a similar record of a heavy touring car over the same road, equipped with the usual form of cord tires. Test E shows the effect on car D of applying balloon tires with low inflation pressure. Tests F and G are for other forms of balloon tires, showing that different forms of balloon tires are about on a par for riding qualities. This diagram suggests some useful and practical applications that may be made of a simple instrument of this kind.

Mr. W. S. James, of the U. S. Bureau of Standards, gave an illustrated discussion on "Tests of Braking and Stopping Conditions of Motor Vehicles." This is not yet available for publication.

REPORT OF COMMITTEE NUMBER 2, ON STRUCTURAL DESIGN OF ROADS

The following report is divided into two main portions: first, that dealing with the facts that have been brought out by researches, and, second, that containing suggestions for additional research.

PART I

THE RESULTS OF RESEARCH ON HIGHWAY DESIGN

(a) SUBGRADE

Research work on the subgrade seems to have been under way by the State Highway Commission of North Carolina, the Department of Public Works and Buildings of Illinois, Iowa State College, American Society of Civil Engineers' Committee on Bearing Power of Soils, Ohio State University, and the U. S. Bureau of Public Roads, University of Texas and Michigan Agricultural College Experiment Station.

NORTH CAROLINA STATE HIGHWAY COMMISSION

The work of North Carolina is presented in a report, entitled "Summary of Results of Capillary Moisture Tests," by H. F. Janda, University of North Carolina, Chapel Hill, N. C.

Results: Briefly, the results indicate the efficiency of porous layers, such as sand, cinders, broken stone, etc., in preventing capillary moisture from rising into the overlying soil. It is likewise stated that tile drains are found to be inefficient in removing capillary moisture.

ILLINOIS DEPARTMENT OF PUBLIC WORKS AND BUILDINGS

A series of soil tests is under way, but no reports have been made upon them to date. New apparatus has been devised for testing soils under many subgrade conditions, including a new slaking test and a new method for making soil cylinders. Soil samples have been transplanted into the ground near the laboratory, in order that they might acquire their natural condition after having been disturbed.

Results: None reported.

IOWA STATE COLLEGE

Soil investigations have been carried on at Iowa State College since the summer of 1921. No published report has been made to date. The first year's work was reported to the special committee of the American Society of Civil Engineers on the Bearing Value of Soils for Foundation.¹

This investigation has the following aims:

The determination of the various physical properties of soils in their undisturbed state as found in nature, such properties as the tensile, compressive, shearing, transverse and other strengths, these to be determined upon various soils and at various depths and under various conditions.

Supplementary tests, such as true and apparent specific gravities, specific weights, capillarity, hygroscopic moisture, porosities, mechanical analyses, coefficients of friction, etc.

Chemical analyses.

Colloidality of clay.

To determine the laws of variation of pressure in earths under various loads and under differing seasonal conditions.

Results: *Tensile tests* gave an average value of 211.5 pounds per square foot for yellow clay and 255.0 pounds for blue clay. Tests were made on sections of two square feet area.

Shearing tests gave values averaging 312 pounds per square foot for sandy loam, 584 pounds per square foot for yellow clay, and 426 pounds per square foot for blue clay. Test pieces had 2 square feet cross-section.

Compression tests were made upon pieces from 6 inches to 9 inches in diameter by 6.5 inches to 14.5 inches long.

	<i>Lbs. per sq. in.</i>	<i>Tons per sq. ft.</i>
The average for yellow clay.....	28.5	2.05
The average for blue clay.....	17.2	1.24

¹ See March Proceedings of the American Society of Civil Engineers, 1922, page 557.

Some four tests, given in detail, appear to show that soils, or these two clays at least, have a slight elasticity and do recover shape to a small degree after removal of load.

No reports of the work of 1922 and 1923 are available.

A. S. C. E. COMMITTEE ON BEARING POWER OF SOILS

The Special Committee on Bearing Power of Soils of the American Society of Civil Engineers have gathered from various sources excellent information upon colloids in clays.

According to Searle, clay contains (1) colloidal silica, (2) colloidal alumina, (3) colloidal ferric hydroxide, and (4) possibly colloidal organic matter or humus. These colloids may modify the characteristic properties of clay, but Searle thinks those characteristic properties are not due to colloids. Van Bemmelen found that the fine suspensions of clay in water could be easily precipitated by adding a small quantity of acid, salt or alkali to the cloudy suspension.

In summarizing the discussion on colloids, the conclusion seemed to be that colloids are suspensions of very fine particles, as follows:

Suspensions—Particles over 0.1 micron in mean diameter.

Colloidal solutions—Particles between 0.1 and 0.001 micron in mean diameter.

True solutions—Particles under 0.001 micron in mean diameter.

The statement was made that the proportion of colloids that can be definitely separated from clays is less than 3.0 per cent.

Some properties of clay most satisfactorily explained by assuming the presence of colloids are:

1. The ratio of water absorbed to the plasticity.
2. The hygroscopic quality of clay.
3. The slaking ratio.
4. That to a certain extent pressure plays the same part as water in certain clays in producing plasticity.
5. That clays are remarkably sensitive to the action of electrolytes.
6. The swelling and shrinkage of clays under increase or decrease of water content.

Rohland suggests that this power of imbibing a definite quantity of water is due to the colloids in the clay, and that as soon as the clay

has absorbed sufficient water to convert its colloids into a colloidal sol, its saturation point has been reached.

Mellor, Green and Baugh have analyzed the substances likely to be present in or to be added to clays into five groups, according to their action on the viscosity of the clay. They are as follows:

1. Substances which *first* make the slip more fluid, while further additions stiffen the slip: sodium and potassium carbonates.
2. Small amounts thicken the slip; larger amounts make the slip more fluid: dilute ammonia, copper sulphate, etc.
3. Substances which make the slip thinner: magnesium, sodium sulphate, etc.
4. Substances which only stiffen the slip: grape sugar, humic acid, ammonium chloride, calcium chloride.
5. Substances which have no appreciable effect on slip: alcohol.

Note, then, that the plasticity of clay may be reduced by adding such substances as ammonia, caustic soda, caustic potash, lime, sodium carbonate, borax and water glass.

Ashley and Rohland conclude that the plasticity of clay is directly proportional to the amounts of colloids that they contain.

The final conclusion of the committee is:

“It seems evident, therefore, that ultra clay is the principal binding material of the soil, giving it plasticity, cohesiveness, or hardness, according to the moisture content. The recognition of these important properties shows the fundamental relation the material bears to certain engineering problems, including subgrades in road construction.”

Note.—The Committee on Structural Design of Roads feels that further research is necessary on the effect of mechanical properties of soils due to colloids before a definite conclusion can be drawn.

OHIO STATE UNIVERSITY

The Ohio State University reports data on thirteen clays from ten different counties in the state. These are given in the following table.

One of the promising series of investigations was made upon impact upon subsoils.

Four shapes of impact heads were used, with the idea of selecting one that would give results the most uniform and the easiest to measure the deformation of accurately. This impact test would then be

TABLE No. 1.—*Showing Various Properties of Subgrade Clays in Ohio*

Sample No. of clay	Color of clay	Texture or character of clay	Water content when sample was taken, per cent dry weight	Water absorbed by cap. in 4 1/2 hrs.	Soil dried	Water content air dried in lab. 2 years	Shrinkage value in sec.	Exp. soil per unit length due to cap. saturation	Per cent water retained for pen. of 10 mm.	Per cent water retained for pen. 20 mm.	Org. mat. in clay in per cent of dry weight	Silt and sand in 25 grams soil	Clay washed from 25 grams soil	Ultra clay not thrown down by centrifuge
6	Yellow		31.9	31.6	2	49	221	0.0470	38	41	20.4	17.76	6.38	0.86
13	Yellow		20.2	39.2	3.37	3.37	163	.0975	45	48	9.2	13.327	0.447	1.226
19	Yellow		24.4	21.7	2.40	2.40	160	0.119	37	50	6.4	13.932	0.30	0.768
22	Yellow		11.1	18.5	2.35	2.35	160	.....	36	37	8.0	7.544	15.497	1.959
27	Gray-blue	Dense with crystals	16.5	18.6	1.34	1.34	1,493	0.454	39	40	1.4	4.531	18.660	1.809
30	Yellow		15.5	29.2	2.28	2.28	.....	0.119	50	53	4.0	8.827	14.057	2.116
33	Yellow		20.8	28.5	1.45	1.45	.....	0.055	37	39	2.8	12.084	20.035	0.877
36	Yellow		18.8	26.6	1.61	1.61	227	0.286	29	31	4.8	4.984	10.925	1.091
38	White	Fire clay	20.2	27.2	1.33	1.33	.....	.....	29	31	0.8	17.452	6.705	0.845
44	Dark red	Dense	17.1	35.2	2.16	2.16	181	0.104	42	44	7.6	5.642	14.705	4.658
50	White	Fire clay	25.7	.....	2.25	2.25	1,291	.....	41	44	1.8	5.643	17.245	2.112
54	Yellow		.....	26.3	1.89	1.89	.....	0.184	39	41	.....	11.440	12.059	1.503
72	Yellow		.....	25.0	1.00	1.00	.....	0.030	26	26	.....	12.757	11.227	1.016

calibrated against static bearing power tests, and when calibrated could be used in lieu of the static test, the advantage being in the ease and celerity with which an impact test may be carried on.

The shapes used were:

1. The circular flat head similar to the ones used by the U. S. Bureau of Public Roads.
2. A flat cone 30 degrees with the horizontal.
3. A truncated cone 60 degrees with the horizontal, with a flat face $2\frac{1}{4}$ inches in diameter.
4. A segment of a sphere.

So far as tests have gone, numbers 2 and 3 seem to give the most even results and fulfil the requirements as to measuring deformations. No calibration tests have yet been made.

U. S. BUREAU OF PUBLIC ROADS

The U. S. Bureau of Public Roads tests aim:

1. At standardization of physical tests for subgrade material.
2. At determination of efficiency of admixtures.
3. At standardization of tests to determine the laws of moisture in the subgrade.

Physical properties of subgrade soils.—It is thought that the tests in the laboratory for determining the physical properties of subgrade soils have now been standardized reasonably well, with the possible exception of the bearing value test. These tests are discussed in a paper by J. R. Boyd.¹

In addition to the laboratory tests for the bearing value of subgrade materials, a field test has been devised and is described in the recent bulletin on Highway Research Equipment issued by the National Research Council.²

Field test for moisture equivalent.—Attention should also be called to a field test for moisture equivalent which gives results very closely checking with laboratory results and with very simple apparatus. This test was devised by Mr. A. C. Rose, highway engineer of the U. S. Bureau of Public Roads. It is described by Mr. Rose as follows:

Procedure: A 300-gram sample of soil is dried at 108° centigrade and prepared in an iron mortar (when no hard rubber is available) to pass a 1-millimeter screen. A 50-gram sample of this is placed in

¹ "Physical Properties of Subgrade Materials." See Proceedings of A. S. T. M., 1922, Vol. 22, pp. 344-347.

² National Research Council Bulletin No. 35, "Apparatus used in Highway Research Projects in the United States." C. A. Hogentogler.

a steel bowl. Water is added in small quantities from a burette and a tablespoon is used to mix the water and the soil sample. Care is taken to break up all of the lumps that develop. Water is added until the sample becomes uniformly of the consistency of putty and can just be compacted by the spoon without any free water appearing on the surface.

The moisture equivalent equals (the weight of water added divided by the dry weight of the soil) x 100 plus 0.8.

A check run is made and the average of the two used as the final result.

This test was made on 29 samples of soil taken from Oregon Federal Aid Project No. 51. Portions of the same sample were taken to the Oregon Agricultural College and the moisture equivalent was determined in a centrifuge (1,000 times the force of gravity) by the standard method. Results obtained by the use of the field method outlined above were found to compare very favorably with laboratory results when the constant of 0.8 was added.

It has been stated by Mr. Rose that the moisture equivalent value of twenty is somewhere near the dividing line between a poor and good subgrade. This is probably approximately correct, judging from the results of the analyses of a large number of samples of the Bureau of Public Roads Laboratory, but needs further verification.

Effect of admixtures upon some of the physical properties of subgrade soils.—In many sections of country the subgrade materials are of a very plastic nature, and when road surfaces are built on such subgrades the inadequacy of the subgrade must be compensated for either by thickened design or possibly by alteration of the subgrade material, which will change a soil of plastic nature into one having more granular characteristics and higher supporting value. It was with this idea in mind that the following investigation was undertaken:

In this investigation a soil was treated in the laboratory with Portland cement, high calcium and high magnesium hydrated lime. In each case 5 per cent of the aforementioned adulterants was thoroughly mixed with the soil.

Upon each treated sample the capillary moisture test, the volume test under capillary moisture conditions, and the bearing value test under capillary moisture conditions were made. The results of these tests are shown in Chart I.

The conclusions obtained from this chart are as follows:

1. The addition of 5 per cent of high calcium and high magnesium hydrated lime increased the capillary moisture of the soil

about 4 per cent, whereas the addition of 5 per cent of Portland cement decreased the capillary moisture about 1 per cent.

2. In spite of the slight increase in capillary moisture of the two lime-treated samples, the per cent of volumetric change of these two samples was very much lower than that of the untreated soils (about 10 per cent). The same phenomena took place in the case of the Portland cement treated samples.

3. The bearing value of the three treated samples was materially increased over that of the untreated soil. Admixtures of sand and other granular materials accomplish similar results.

Therefore it may be said that, from a purely laboratory point of view, the physical properties of a soil can be materially improved by the addition of hydrated lime or Portland cement and granular materials. Further research looking into the economy of this procedure should be brought about.

The effect of heat treatment upon the physical properties of subgrade soils.—In this investigation two different soils were heated at temperatures varying from 200° centigrade to 600° centigrade in steps of 100° centigrade. On the soil resulting from each heat treatment the mechanical analysis, volumetric change under capillary moisture conditions, and adsorption number were determined. The results of this investigation are shown on Chart II.

The conclusions may be stated briefly as follows:

1. A temperature of 600° centigrade seems to be necessary to materially change the above-mentioned physical properties of the soils treated.
2. If this temperature is used, the mechanical analysis of the soil is materially changed, in that the clay content is decreased and the sand content increased.
3. The adsorption number (character of clay) is decidedly decreased, producing a much less active material.
4. The volumetric contraction was decidedly decreased.

It may therefore be said that heat-treating a soil at a temperature of 600° centigrade materially improves the physical properties of the soil, but the cost of this process seems to be prohibitive.

Status of drainage and moisture in the subgrade.—Experiments on drainage and waterproofing road subgrades were begun during the summer of 1920 at the Arlington Experiment Station for the purpose of determining, if possible, suitable methods which would promote dryness and stability in this part of the roadway. Both lateral and transverse ditches were cut to a depth of 30 inches below the center line of the finished pavement and kept open during the first winter.

Later, these ditches were obstructed and water allowed to stand in them. During the dry season lawn-sprinklers kept the roadway as wet as it was possible to make it.

Results: During the winter months, and especially near the approach of spring, all of the sections contained rather high percentages of moisture in the subgrade. In some cases the attempts to waterproof, especially by impervious walls, seemed to trap water under the pavement rather than keep it out. Tile drainage did not in this case decrease the amount of water, except at a depth level with the drain. At that depth the decrease was only about 1 per cent. It seems, then, that drainage of the types used was only effective in removing water in excess of the capillary moisture.

The maximum upward movement of the pavement was approximately three-quarters of an inch, which occurred at the time when there was the greatest volume of moisture in the subgrade. This was at a time when there was the greatest depth of freezing. The minimum movement at this time was under the section having the greatest depth of gravel base.

Influence of vibration: Experiments of this sort were made on a 4 feet x 4 feet concrete slab with free water standing at 12-inch and 6-inch depths below the subgrade. For the purpose of permitting the water to have easier access to the subgrade immediately under the pavement, 4-inch pipes were laid all around the slab at a depth of 18 inches under the subgrade.

During the summer of 1922 a 120-pound rubber-faced hammer was allowed to pound almost continuously on the pavement after the subgrade had reached its maximum moisture content by capillarity, but there was no perceptible increase in moisture due to vibration. These experiments will be repeated under heavy pressures.

Effect of temperature on soil capillarity and moisture capacity: There is every evidence to show that temperature has a very marked influence on the water capacity of soils. The colder the soils, the greater the capacity for holding moisture. Dr. Bouyoucos, of the Michigan Agricultural Experiment Station, has done much work in this field, and his results have been checked at the Arlington Experiment Station. These effects are very clearly shown in Figures 1 and 2, which are typical of conditions in many other charts and curves on file in the Bureau of Public Roads.

From many examples available with shallow depths of frost, it is roughly true that frost action affects moisture content at approximately twice the depth of the freezing. There is an increase in moisture in the frozen earth and a decrease in the soil just below the

frozen section. This is due to the cold soil having a stronger capillary pull than the moisture-retaining power of the warmer soil.

The following figures show typical capillary moistures for soils indicated at temperatures of from 0 to 5° centigrade and from 25 to 30° centigrade.

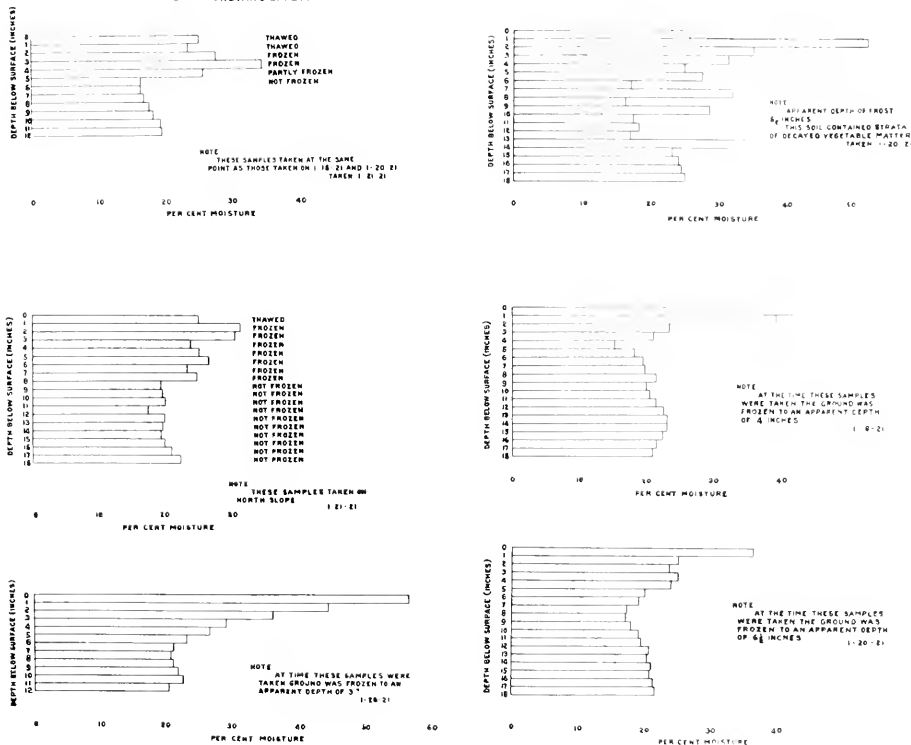
Soil No.	Temperature, 0-5° C.		Temperature, 25-30° C.	
	Per cent		Per cent	
20	29.2	25.8	3.4	
44	34.5	29.7	4.8	
61	36.6	32.6	4.0	
74	43.6	37.7	5.9	
Ottawa	25.8	26.1	-0.3	

By comparing the curves on Figure 7, it will be observed that much greater differences than these are found under actual field conditions.

Influence of the quality of soil particles on moisture content, bearing value, etc.: This influence is particularly well indicated in

FIGURE 1

CHART SHOWING EFFECT OF FROST ACTION ON CAPILLARY MOISTURE AT VARIOUS DEPTHS



Figures 3, 4, 5, 6 and 7. The highest moisture content here will be observed in sponge-like materials like cinders and granulated slag; the next highest will be seen in clays having admixtures of hygro-

FIGURE 2

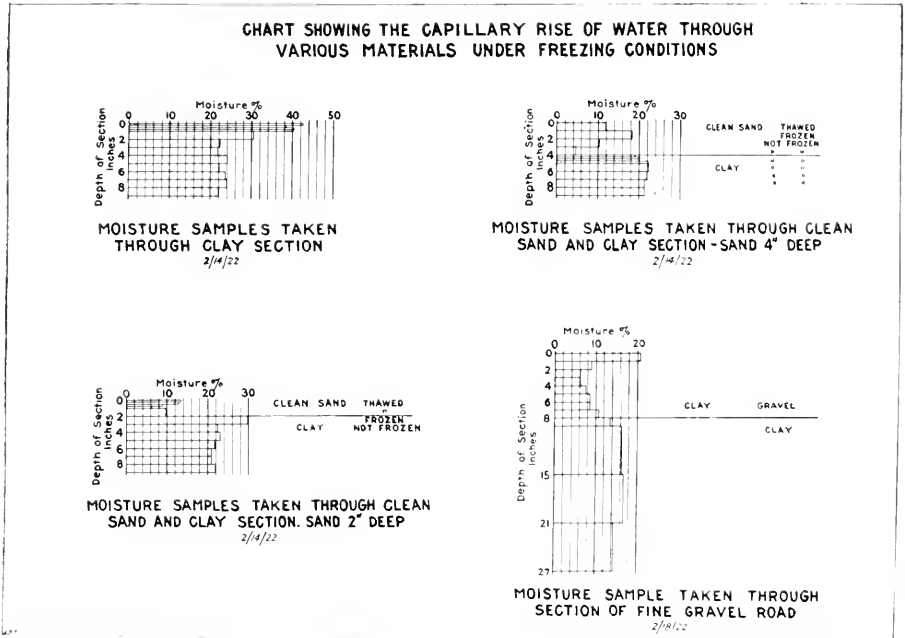
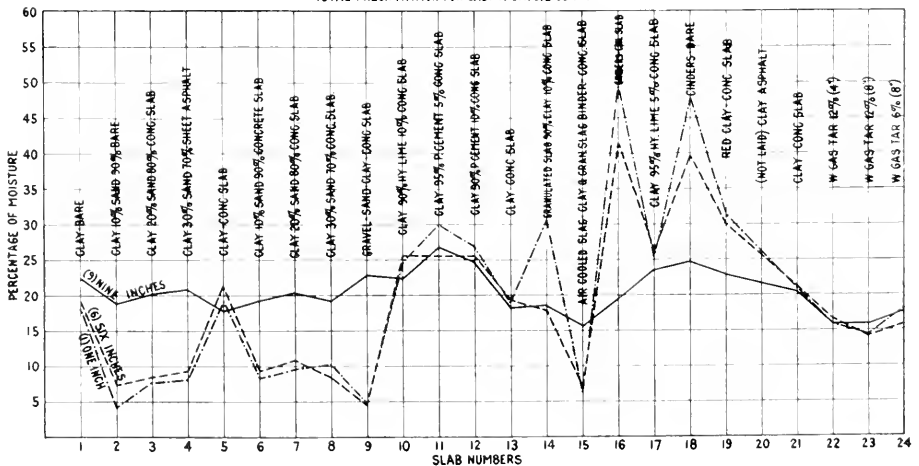


FIGURE 3

CHART SHOWING MOISTURE CONTENT OF SUBGRADES ON JAN. 18-19, 1923

AVERAGE TEMPERATURE OF AIR FOR LAST 10 DAYS. 35°F.
TOTAL PRECIPITATION FOR LAST 10 DAYS. 2.02 INCHES



scopic materials like lime and Portland cement. Some materials, such as the many types of clays, take up considerable quantities of moisture when it is available and expand in volume, while other materials, like sand, gravel, crushed slag, etc., take up only enough

FIGURE 4

CHART SHOWING MOISTURE CONTENT OF SUBGRADES ON FEB. 12-13, 1923
 AVERAGE TEMPERATURE OF AIR FOR LAST 10 DAYS, 33°F.
 TOTAL PRECIPITATION FOR LAST 10 DAYS, 0.93 INCH

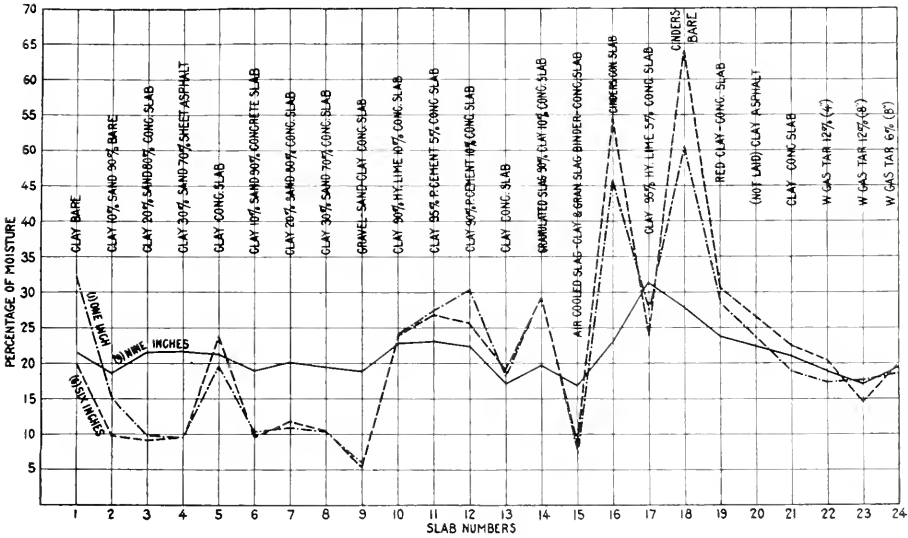
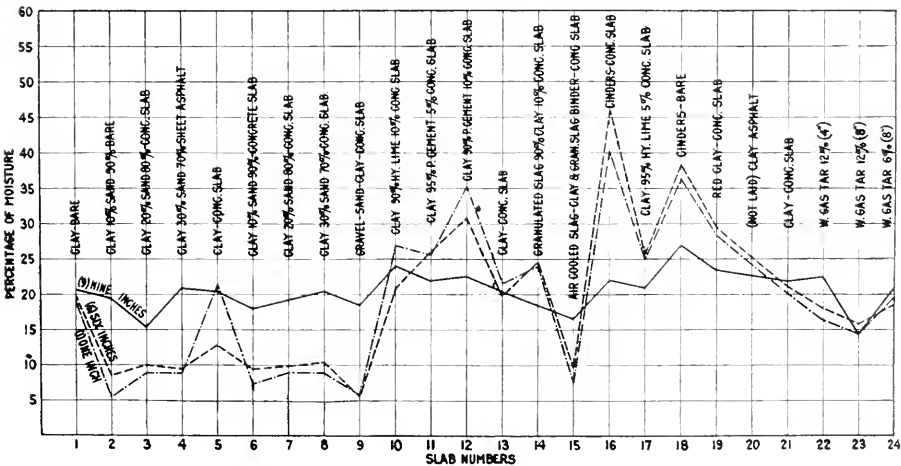


FIGURE 5

CHART SHOWING MOISTURE CONTENT OF SUBGRADES ON MARCH 27, 1923
 AVERAGE TEMPERATURE OF AIR FOR LAST 10 DAYS, 45°F.
 TOTAL PRECIPITATION FOR LAST 10 DAYS, 1.44 INCHES



moisture to coat the surfaces of the particles and show little expansion. In these charts it is shown that sand- and other kindred materials take up less moisture than any other material studied. These materials also have much higher bearing values, because moisture

FIGURE 6

CHART SHOWING MOISTURE CONTENT OF SUBGRADES ON JUNE 1, 1923
 AVERAGE TEMPERATURE OF AIR FOR LAST 6 DAYS 75°F.
 TOTAL PRECIPITATION FOR LAST 6 DAYS 1.75 INCHES

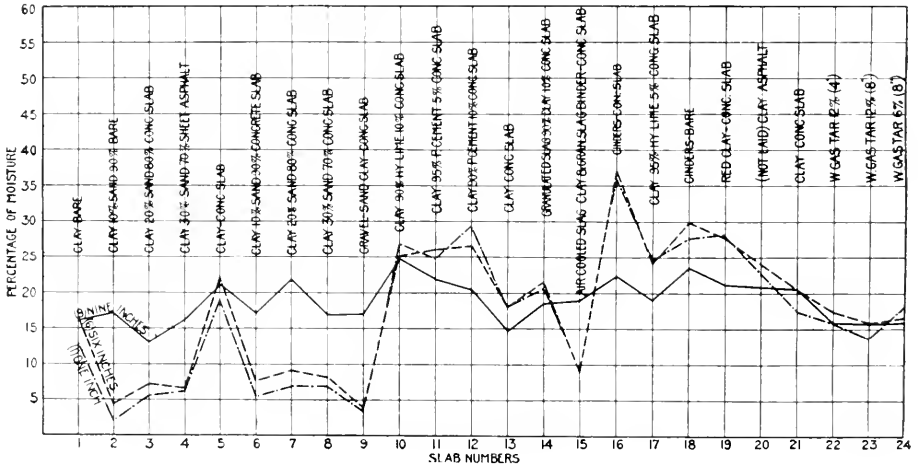
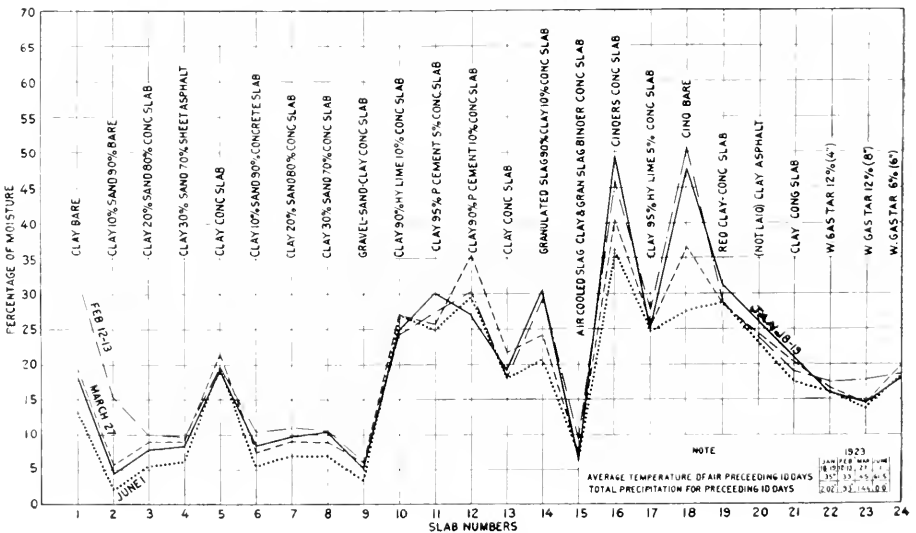


FIGURE 7

CHART SHOWING MOISTURE CONTENT OF UPPER INCH OF
 SUBGRADE ON DATES INDICATED



(capillary moisture) does not decrease their bearing values to any marked extent.

It seems to be evident that the characteristics of any soil are dependent on the relative percentages of the particles of different characteristics present, and for this reason clay soils having high expansion, high moisture capacity and low bearing value when moist may be greatly improved by sand admixtures, resulting in a soil of lower moisture-holding capacity, lower volume change and higher bearing values. Such admixtures might be used to create an artificial subgrade over bad soils. The necessary depth of such artificial subgrades for various road types has yet to be determined.

When macadam or broken stone bases are used over a heavy clay subgrade, it often happens that the clay is forced up through the voids in the stone and renders the broken stone layer much less resistant to loads and much more liable to damage through the expansion action of frost. Experiments, both of a laboratory nature¹ and by actual use in roads², show that a blanket of sand or similar material interposed between the subgrade and the broken stone is effective in preventing the clay from working up through the overlying stone layer. This statement is borne out by the experience of railroad engineers who have used cinders under broken stone ballast over bad subgrades.

Freezing of moisture in soils: The principal apparatus for freezing soils artificially is shown in Figure 8. All other apparatus has been abandoned long since and no mention will be made of this equipment. In no case have we been able to check results with any apparatus for freezing except the one shown in Figure 8. With this apparatus we are able to check to within 0.2 per cent. This shows that the method is satisfactory for measuring the expansion of the frozen moisture in the soil being tested.

It is now definitely known that the soil itself does not expand on freezing, but the expansion occurs in the moisture alone. This is proved in this way: We determined the expansion of distilled water by actual measurement and found that 1 cubic centimeter of distilled water expands 0.1 cubic centimeter. This is the same value as that obtained by Dr. George J. Bouyoucos, of the Michigan Agricultural College Experiment Station. Bunsen's data show an expansion of 0.09073 cubic centimeter per gram of water frozen, while Foote and Saxton, of Yale University, obtained a value of 0.09325. The factor of 0.1 is sufficiently accurate for our purposes, as the method for de-

¹ Bureau of Public Roads experiments.

² Rhode Island practice.

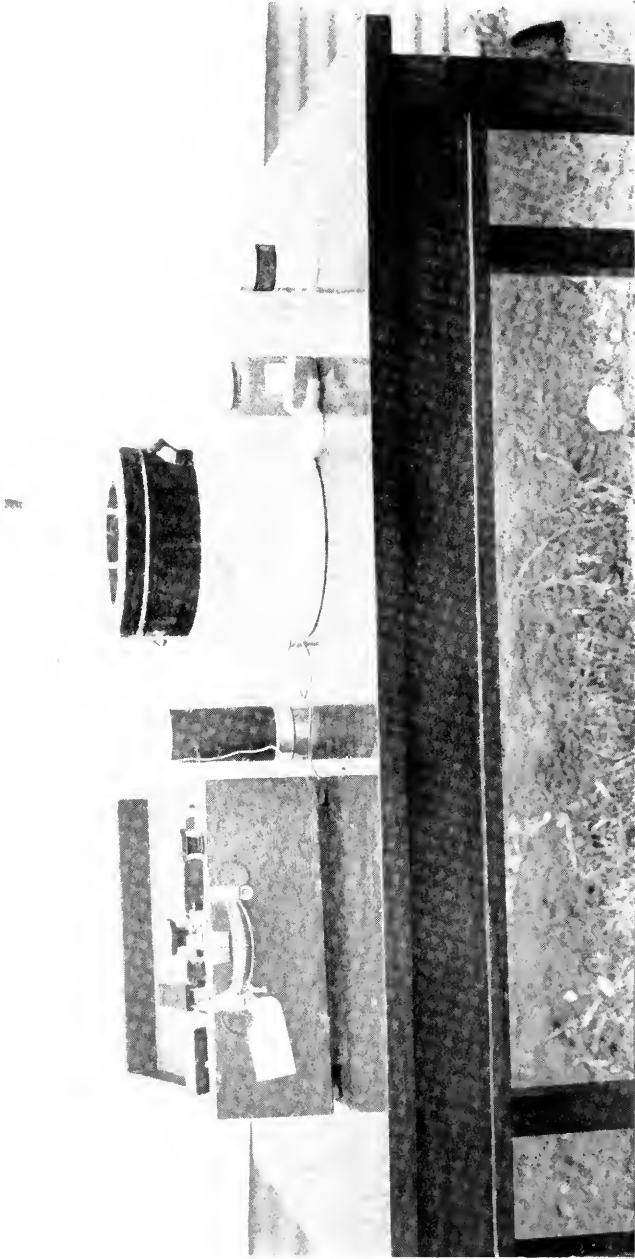


FIGURE 8

termining the frozen moisture in soil is vastly more precise than the uniformity of the soil. Checks are made only by the most accurate method of mixing and sampling.

We are able to freeze 100 per cent of the added moisture in Standard Ottawa sand, which is clean and free from dirt, but this same sand when reduced to silt which passes a 200-mesh sieve will permit of only 71.47 per cent being frozen. This phenomenon is mentioned to show what it means to have the water existing in a finer capillary state.

It was hoped that some relation might exist between the adsorption number and the percentage of moisture frozen, but it seems that this relation is rather remote. It is highly probable that a chemical analysis of the soil would indicate why there seems to be no such direct relation and would possibly furnish "the missing link" in this work.

The table on page 82 gives typical comparisons between moisture frozen, adsorption and percentage of clay content for various soils.

It will be observed that in no case have we been able to freeze all the moisture in any soil, and by applying the factor of 0.1 it is possible to determine the volumetric expansion of the moisture frozen.

(b) PRINCIPLES AND METHODS FOR SAND-CLAY, TOP-SOIL AND SEMI-
GRAVEL ROADS

The following methods and principles are submitted by Dr. Strahan, of Georgia, as the result of a number of years' investigation; with which, after discussion, the Committee on Structural Design agrees.

1. These materials are to be classed as mixtures of loose aggregates wherein the larger sizes and particles (sand and gravel) have a stability due chiefly to mechanical interlocking or bond, and wherein the finer particles (silt and clay) increase the mechanical stability by filling voids and by greater or less adhesion, usually with the aid of moisture, to the larger particles.

2. The adhesion of the silt and clay to other aggregates and their own internal cohesion are due in part to the nature of the silt and clay, but are also largely influenced by the amount of moisture present and acting in a colloidal state on the finely divided particles thereof.

3. The resultant strength under traffic of these materials is dependent upon mass action. The slabs must have adequate thickness and monolithic consolidation. Packed in thin layers, weakness and early raveling may be expected.

4. Mass action in such slabs takes advantage of—
- a. Internal arching of the materials.
 - b. Resistance to direct compression.
 - c. Resistance to internal shears.
 - d. Resistance to diagonal tension when the silt and clay are adhesive.

A Comparison between Moisture Frozen and Adsorption in Certain Soils

Soil No.	Moisture frozen	Adsorption	Per cent clay
290	84.0	6.3	16.0
293	81.0	7.5	14.4
158	75.6	2.5	5.2
188	75.0	15.0	15.9
29	74.5	25.0	29.3
13	74.1	17.5	46.0
5	70.0	7.5	11.6
200	70.0	57.5	40.4
201	70.0	15.0	20.4
59	69.3	40.0	34.8
56	69.4	18.8	28.0
294	69.0	7.5	13.6
202	67.2	25.0	18.0
28	67.0	45.0	34.0
119	66.3	20.0	45.6
27	63.8	127.5	52.0
60	63.5	87.5	....
80	62.3	22.5	41.8
36	61.7	31.3	36.4
14	61.4	55.0	48.8
19	61.4	15.0	29.6
25	60.8	150.0	45.7
11	60.0	8.3	22.4
6	60.0	22.5	32.0
12	59.3	17.5	36.8
291	59.1	7.5	19.2
120	57.5	50.0	76.5
55	57.2	55.0	36.0
92	57.0	35.0	32.0
161	56.7	....	*
50	55.0	38.8	38.8
54	55.0	52.5	....
24	54.3	90.0	52.8
186	53.8	35.0	35.0
15	53.8	22.5	41.6
67	53.4	130.0	....
157	52.5	110.0	45.6
23	50.7	57.5	40.8
26	50.7	154.8	60.4
22	47.7	90.0	56.8
392	47.7	32.5	....
32	47.5	42.5	33.2
42	43.0	120.0	82.0
44	33.1	140.0	71.6
161	22.9	....	*

* Burned.

5. Full bearing and impact resistances are not developed near the edges of the uncurbed slabs. Weakness may be expected for a distance about twice the thickness of the slab from the outside edges if unsupported. Usually these materials are deposited in trenches with supporting shoulders.

6. Such slabs show some degree of elastic reaction, but not according to quantitative laws. Laboratory specimens for transverse break yield by tension for spans longer than twice the vertical depth of the specimen. For shorter spans the yield is by diagonal tension from the load point downward toward the point of support.

7. Successful roads require—

- a.* Graded mixtures capable of making a dense mass on consolidation. The best mixes run as low as 20 per cent porosity.
- b.* Uniform composition, secured by thorough mixing.
- c.* Heavy compacting from the bottom upward. This is usually done by traffic. There is need for a type of multiple-rim roller to hasten and unify the degree of compactness imparted to these roads during construction.
- d.* Mixtures with a liberal amount of coarse material above No. 60 sieve.

8. The detailed classification, percentage limits, and methods of laboratory analysis and tests are to be found in U. S. Department of Agriculture Bulletin No. 555, issued by the Bureau of Public Roads; and in University of Georgia Bulletin Vol. XXII, No. 5*a*, June, 1922.

The procedure is to separate the original sample as follows:

(1) The well-pulverized sample is weighed and passed through a No. 10 standard sieve. The residue on the sieve is called "coarse material."

(2) The material passing through the sieve is regarded as a "soil mortar" and is analyzed as follows:

Fifty grams are thoroughly shaken and rubbed with about 250 millimeters of water, adding 5 millimeters of a 4 per cent solution of ammonia; allowed to stand 8 minutes and siphoned to a depth of 8 centimeters from the surface. Operation repeated until a clear supernatant liquid is obtained.

The fine sediment thus removed is called "clay" or "total clay." The total clay can be further separated by centrifuge into "suspension clay" and coarse clay. The washed residue is dried on a water bath and separated through a nest of sieves—Nos. 20, 60 and 200. All residue above the No. 200 sieve is classed as "sand." The residue

passing No. 200 and caught in the pan is called "silt." The sand coarser than No. 60 sieve is a most important criterion. Unless it reaches or exceeds 30 per cent, it is hopeless to expect a satisfactory soil mortar.

CLASSIFICATION OF SOIL MORTARS

	Class A <i>Per cent</i>	Class B <i>Per cent</i>	Class C <i>Per cent</i>
Clay	9 to 18	15 to 25	10 to 25
Silt	0 to 15	10 to 20	10 to 20
Total sand.....	65 to 80	60 to 70	55 to 80
Sand above No. 60 sieve.....	45 to 60	30 to 45	20 to 30
	Hard	Medium	Soft

For further details see bulletins referred to above.

Coarse material, above No. 10 sieve, has a decided influence on the durability, hardness and smoothness of the surface. Ten per cent of such hard, gravelly material, with a Class B soil mortar, justifies reporting the whole as a Class A material.

9. Extensive experience in the field and in the laboratory support the following comments:

(1) As to soils having no coarse material above No. 10 sieve:

- a.* Classes A and B give respectively admirable and adequate traffic service for the expense involved. It is doubtful whether Class C soil mortars should be used except on secondary roads with very light traffic and when the material is close at hand.
- b.* The most important factor is the presence of coarse sand in liberal amount. Of course, clays and silts differ markedly, but roads built of many different clays have shown excellent durability. It will be noted that the total clay present in the best samples rarely exceeds 18 per cent. Efforts are, however, being made to differentiate between clays by laboratory tests, and some tentative progress has been made.
- c.* It may be accepted that the sand below No. 60 sieve has little supporting value. It has some value in filling voids when coarser sand is present.
- d.* Highly organic silts have binding value and strengthen the mixture, so long as the organic matter persists, but such silts lose the organic matter quite rapidly by decay and dusting.
- e.* The more adhesive or highly colloidal clays give effective bond with as little as 9 per cent present. Less plastic clays

are needed in larger amount up to a maximum of 25 per cent, but the mixtures with 20 to 25 per cent clay are apt to be slippery and cut into mud in long spells of wet weather.

- f.* Laboratory tests indicate that the adhesive values of clays are largely dependent upon the colloidal state of the material and the moisture present. Metal plates cemented together with thin films of clay show markedly greater adhesion when containing 5 to 10 per cent of water than when dried at 212°.
- g.* In general, it is believed that inorganic silts tend to diminish the strength of road soils, and noticeably so when present above 15 to 20 per cent of the soil mortar.

(2) As to soils containing 10 per cent or more of hard coarse material above No. 10 sieve:

- a.* It is a matter of assured experience that such coarse material adds greatly to the durability of the mixtures. Such soils are found in many places and give rise to a series of semi-gravels reaching from 10 per cent up to the 50 or 60 per cent in a full gravel road.
- b.* A good Class A soil mortar with from 20 to 30 per cent coarse material gives a fine surface of marked durability. This is especially true of the iron-silica gravels in southwest Georgia, with from 25 to 40 per cent of a nodular iron-impregnated gravel, ranging from one inch downward. These nodules are not nearly so hard as true silica gravel, but are sufficiently strong to give most excellent service and very smooth travel.

The effect of wet weather

a. Moderate ground moisture increases the strength of all classes of these roads.

b. Long and heavy rains influence them as follows:

Class C. Soften the surface so that wheel ruts two or more inches deep may appear under heavy vehicles, and when the sand is fine considerable material is washed down the steeper grades and into the side ditches. They do not show deep mud and are not slippery. Repairs are readily made with drags and road machines.

Class B. Soften only after very long and continued wet weather, wheel ruts rarely as deep as two inches, not much

washing into side ditches. Easily repaired with road machines. Dry out promptly and are usually too hard for any but the heaviest metal drags and light road machines.

Class A. Do not materially soften except where water stands for a long time in depressions. Wheel ruts rarely deeper than one inch. The slab below this surface mud is generally hard and firm, and will require the heaviest road machines to reshape the surface. Dries off rapidly and soon becomes too hard for the heaviest road machines to cut.

e. Laboratory tests show that the road soils are of marked density, are not readily penetrated by rain on the surface, and when made into briquettes with varying amounts of water they retain the larger part of their tenacity until 15 to 25 per cent of water is added.

Thickness and crown

The thickness used is designed to supply mass action and to provide ample shearing resistance against traffic pressures and impacts. The usual specification has been ten inches when packed in place. On weak subgrades, especially those subject to ground water saturation or capillary lift from below, this should be increased to 12 or 14 inches. There seems little or no advantage in exceeding the above, for the following reasons:

1. Examination of the packed road slab shows that the hard pack rarely extends more than 6 inches deep. The material below this, while firm, is easily penetrated by a pick and comes up in small pieces rather than as a large clod.

2. The lower portion is thus functioning less actively in bearing resistance, but most probably it serves usefully as a drainage layer and also as a cut-off plane against capillary lift of water from the subgrade.

3. The surface wear of the better soils is not so rapid as to demand a large margin of extra thickness. The roughness which comes under wear after five to eight years will require scarifying and reshaping. The most expensive part of this process is pulverizing the clods, and the addition of new soil saves the necessity of much fine pulverization. It also restores the thickness of the original slab.

As to the proper crown, the earlier view advocated a high crown, even as much as 1 inch per foot, but later experience has shown that one-fourth inch per foot is adequate and much more acceptable to the traffic.

Research investigations

With the valued cooperation of the U. S. Bureau of Public Roads, there is in progress in Georgia, under its State Highway Department, an important and state-wide study of the effective life and economic results of 29 Federal Aid Projects built of these materials and under constant maintenance. The program embodies:

- a. Samples taken at frequent intervals on each project at specified points and careful analysis of same. New samples are taken each year, and will continue to be taken until the surface must be reconstructed.
- b. Traffic counts 8 days per month for one year, repeated in alternate years.
- c. Careful field inspection (with photographs taken) made in summer and winter.
- d. Taking of cost data on maintenance.

Thus far, after 18 months, all but two of the projects show very satisfactory stability. These two were constructed of poor soils, not recommended by laboratory tests. Some of the projects have been under traffic for more than four years.

Incident to the above economic research, the laboratory is seeking to solve the very intricate problem of the specific interaction and influences of the gravel, sand, silt and clay in such mixtures. A great variety of tentative tests have been tried out. Attention is called to several of the more promising ones, as follows:

a. The Adsorption Test for Distinguishing Clays: This test was first devised and promulgated by the Bureau of Public Roads, using standard solutions of crystal violet filtered through and adsorbed by the material. Special filter tubes are used. (See Proc. A. S. T. M., 1922, Vol. 22, Part II, pp. 344-7.)

The possible value of this test as applied to original samples, to the separated ingredients, to the clay in particular, is easily seen. Further, the total clay itself can be further fractionally separated in a centrifuge and the adsorption of these fractions studied. This test has been followed on the soil samples from the 29 Federal Aid Projects with interest in this laboratory. It is noted that the soils and clays of this state show markedly lower adsorption values than the subgrade materials reported by the Bureau.

Change of the color medium to methylene blue has been tried out. In general, samples at this laboratory adsorb somewhat larger amounts of the latter than of crystal violet. Methylene blue also

has certain advantages of stability of color, and is not apparently influenced by acid or basic condition of the sample. Crystal violet is thus influenced in color. Further, the pure blue color is free from pronounced overtones, and a test by adding excess color, agitating vigorously or boiling can be applied and the excess determined in a colorimeter. Less time is required for this test than for the very slow filtration incident to the filter-tube method. This modification of the test is being fully tried out.

b. The Disk Shear Test: Results fairly consistent have been obtained by this test, conducted as follows:

Three disks, 2 inches in diameter and 1 inch high are prepared from each sample. The soil is moistened to stiff mud consistency and compressed under 3,000 pounds. A thin tin collar is used inside the mold, which aids the removal of the disk. The disks are dried in air or on the water bath. For test, the disk is inserted into the test cylinder and broken through in shear by the 1-inch steel plunger.

Conclusions by Committee.—1. Laboratory tests and procedure for determining physical properties of subgrade materials seem to be well developed.

2. Tile drainage and ditches remove only moisture in excess of capillary moisture in the soil.

3. Difference of temperature in soils tends to cause motion of moisture from the warmer to the colder layers.

4. Undesirable, plastic and finely divided soils are improved by admixtures of granular materials and small percentages of Portland cement and hydrated lime.

5. A blanket layer of granular material beneath the base course of macadam or gravel roads is effective in preventing settlement and penetration of the subgrade into the base course and tends in general to reduce heaving and displacement of subgrades.

(c) FORCES ON PAVEMENTS RESULTING FROM TRAFFIC

The following is reported by Mr. E. B. Smith as a result of the Bureau of Public Roads' tests. They are to be regarded as preliminary results and are now being verified in a large series of tests in cooperation with the Rubber Association and the Society of Automotive Engineers.

Before strength designs may be definitely made, it is first necessary to determine the loads or forces which must be sustained. This applies no less to the design of a concrete road slab than to any other structure. The loads and forces to be sustained by a road are those

resulting from the action of traffic, and those most severe are mainly from heavy motor trucks.

A former series of tests were run about two years ago to determine the value of impact of different trucks, and these investigations indicated quite a wide range of values. (See Mar. and Dec., 1921, "Public Roads.") The tests were run over a selected stretch of road on which were placed different types of obstructions. Under the condition of having an obstruction 1 inch high and with a 7½-ton truck fully loaded, running at 15 miles per hour, an impact value of 28,000 pounds was secured when using worn solid tires. Higher impacts were obtained when using higher obstructions.

A later series of tests was run to determine the average impact that may be expected from different trucks traveling over a certain selected stretch of road. The trucks selected were a 2-ton Mack and a 5-ton Pierce-Arrow, both trucks being constructed with the usual rear-axle differential. An accelerometer of the new type was attached to the rear axle, which gave deceleration values of the unsprung weight, to which should be added the sprung weight on one wheel. The conditions of the tests and results are as follows:

1. 2-ton Mack Truck, No Cargo: Static Rear Wheel Load, 2,285 Pounds

a. Gravel road—bad ruts—high speed (15 to 18 m. p. h.), 12,500-18,500 pounds maximum impact force.

b. Gravel road—smooth—slow speed (5 m. p. h.), 7½-inch obstruction, 3,000 pounds maximum impact force.

Gravel road—smooth—slow speed, 2-inch obstruction, 5,600 pounds maximum impact force.

Gravel road—smooth—moderate speed, 7½-inch obstruction, 3,300 pounds maximum impact force.

Gravel road—smooth—moderate speed, 2-inch obstruction, 8,000 pounds maximum impact force.

2. 2-ton Mack Truck, 3,000-pound Cargo: Static Rear Wheel Load, 3,735 Pounds

a. Concrete road (Columbia pike) running over one experimental section at a time at about 8 miles per hour, the impact values varying from 6,600 pounds to 13,235 pounds, most of the thirty-two sections giving impact values around 7,500 pounds.

b. Concrete road—maximum impact value at maximum speed (about 15 m. p. h.), 20,100 pounds.

3. 2-ton Mack Truck, 4,000-pound Cargo; Static Rear Wheel Load, 4,285 Pounds

The increase in cargo seemed to reduce the tendency of the rear end to jump, so that the accelerations obtained for this cargo load were consistently a little lower than for the smaller cargo loads and gave impact values which were slightly lower.

4. 5-ton Pierce-Arrow, 10,000-pound Cargo; Static Rear Wheel Load, 8,875 Pounds

a. *Gravel road*—smooth— $\frac{7}{8}$ -inch obstruction.

8 miles per hour	—13,000 pounds maximum impact force.
10 do.	15,000 do.
12 do.	16,800 do.

Gravel road—smooth—2-inch obstruction.

8 miles per hour	—22,500 pounds maximum impact force.
12 do.	28,700 do.
15 do.	33,700 do.

b. *Concrete road*— $\frac{7}{8}$ -inch obstruction.

8 miles per hour	—16,800 pounds maximum impact force.
10 do.	19,600 do.
12 do.	21,250 do.
15 do.	27,800 do.

Concrete road—2-inch obstruction.

6 miles per hour	—22,600 pounds maximum impact force.
10 do.	34,000 do.
12 do.	36,800 do.

- c. When running at full speed over $\frac{1}{2}$ -mile to 2-mile stretches of typical concrete pavement at maximum speed (sometimes reaching 20 miles per hour on downgrades), impact values ranging from 28,300 pounds to 38,700 pounds were obtained.

These preliminary tests indicate that when driving over a typical concrete road at high speed with a fully loaded 2-ton truck, we may expect impact values of approximately 20,000 pounds, or over five times the static load on one rear wheel. With a fully loaded 5-ton truck at high speed, we may expect forces of 35,000 pounds to 40,000 pounds, or over four times the static load on one rear wheel.

The impacts as shown in the table represent the values usually ob-

tained, but the maximum value of the force sustained by the road may at times be much greater, owing to the oscillating action of the truck body. If a downward movement of the loaded truck body occurs at the same instant as an impact, the two forces are, of course, additive, and the result may be possibly double the impact. Therefore, under certain bad surface conditions a total force of 40,000 to 60,000 pounds may be obtained at each rear truck wheel. The committee feels that the facts above stated were ascertained by careful test methods and concurs in the tentative conclusions.

(d) GENERAL CONCLUSIONS FROM FIRST SERIES OF TESTS ON PAVEMENT SLABS AT THE BUREAU OF PUBLIC ROADS

The following report is submitted by Mr. C. A. Hogentogler, of the Bureau of Public Roads:

These tests were conducted on slabs 7 feet square laid directly on the subgrade. They were subjected to impact of a specially constructed machine designed to simulate the blow struck by the rear wheel of a motor truck. Essentially, the machine consisted of an unsprung weight shod with a rubber tire and a sprung weight supported on the unsprung weight by means of a 5-ton truck spring. Repeated blows were struck in the center of the test specimens, increasing impacts being obtained by raising the height of fall.

First tests of impact on pavements of the Bureau of Public Roads, carried on at the Arlington Experimental Station in 1920, a report of which was published in "Public Roads" for October and November, 1921, indicated that:

1. Resistance of 1:1½:3 concrete slabs 7 feet square to impact blows increased consistently with increase in thickness. Beginning with 4-inch thickness, which resisted 14,000 pounds equivalent static load, the resistance of slabs increased 5,000 pounds with each inch of additional thickness. Specimens tested as beams, however, indicated that resistance to static loads varies as the squares of the depths.

2. The monolithic brick slabs (concrete base, ¼-inch sand cement cushion, cement-grout-filled brick tops) in most cases showed less resistance than 1:1½:3 concrete slabs of the same depth. The resistance of the eleven slabs on this particular subgrade was equivalent, on the average, to that of the concrete slabs having thicknesses of but 82 per cent of those of the monoliths.

3. Semi-monolithic slabs (concrete base, 1-inch sand cement cushion, cement-grout-filled tops) showed less resistance than the monoliths. The average of the resistances of four slabs was equivalent to that of concrete slabs having thicknesses of but 68 per cent of those of the semi-monoliths.

A second large series of impact tests is just being completed by the Bureau of Public Roads, but results are not available for the present report.

(c) RESULTS ESTABLISHED BY THE PITTSBURG TEST ROAD INVESTIGATION

The following conclusions are stated by Mr. Lloyd Aldrich as a result of the studies of the Pittsburg Test Road investigations:

Note.—Reference should be made to page numbers in "Report of Highway Research at Pittsburg, California, 1921-1922."

1. The method of constructing the subgrade on adobe soil, as described, so reduced the objectionable features of this material that a reliable foundation for the pavements resulted.

Reference (page 141; title, "Discussion"; subtitle, "Subgrade").

2. This subgrade was not injured by the water which filled the side ditches for three months.

Reference (page 141; title, "Discussion"; subtitle, "Subgrade").

3. The unsurfaced concrete completely resisted all surface wear due to solid rubber-tired traffic. The limited metal-tired travel indicated that it would cause, with sufficiently heavy loads, an early failure of surface.

Reference (page 141; title, "Discussion"; subtitle, "Surface Wear").

4. Early morning travel was more injurious to the pavement than the day traffic.

Reference (page 143; title, "Discussion"; subtitle, "Deflections under traffic loads").

5. The observed deflections of the pavements are very nearly directly proportional to the loads.

Reference (page 95; title, "Special Tunnel Studies"; also, page 94, Plate 36).

6. Those sections that had steel placed in such positions as enabled it to resist the tension flexural stresses were more durable than those sections of the same dimensions that did not contain steel so placed.

Reference (page 145; title, "Discussion"; subtitle, "Deflections under traffic loads"; also, Table 17, page 143; also, page 146, subtitle, "Effect of traffic on corners of plain and reinforced concrete").

7. The rock ballast, as constructed under Section A, was less efficient than the earth subgrade.

Reference (page 145; title, "Discussion"; subtitle, "Deflections under traffic loads").

Note.—Further reference in entire body of report.

(f) GENERAL CONCLUSIONS FROM THE BATES ROAD TEST

Mr. Clifford Older has submitted the following conclusions as a result of the Bates Test at Bates, Illinois, conducted by the Illinois State Highway Department:

1. The endurance limit of concrete when subjected to repeated tensile stresses may safely be taken as not less than 50 per cent of the modulus of rupture of the material.

2. That the resistance to structural failure of plain concrete pavement slabs of uniform thickness and laid on a uniform subgrade, when subjected to highway traffic loads, is in proportion to the square of the thickness of the slab.

3. That in plain concrete pavement slabs overloaded by ordinary traffic, structural failure normally first appears at corners formed by open cracks or joints, which either intersect each other or the edge of the pavement slab.

4. That corners formed by intersecting cracks or joints which are held in close contact, either by compression set up by temperature expansion or artificial means, may be expected to resist structural failure under loads much greater than those required to cause failure where the cracks or joints are open.

5. That in concrete pavements having widths up to 18 feet, a center joint may be so designed and constructed as practically to eliminate the formation of longitudinal cracks and to insure a close contact along at least one edge of all interior corners.

6. That the contraction of concrete pavement slabs concentrated at transverse joints or cracks, thus causing the formation of corners unsupported along either edge, makes necessary the strengthening of the edges of ordinary rural pavements in order that such corners, as well as the edge of the pavement, may afford at least approximately the same resistance to structural failure as the interior portion of the slab.

Another conclusion reached was that soft tops, such as sheet asphalt, asphaltic concrete and bituminous-filled brick, may add slightly to the resistance of the rigid pavements to structural failure when laid on good subgrades by minimizing the effect the daily warping of the slab has on subgrade support; but that this advantage over uncovered concrete pavement slabs which are divided by center joints is so slight that it can be practically neglected.

The committee has discussed with interest and submits the conclusions suggested, respectively, by Mr. Aldrich on the Pittsburg road and Mr. Older on the Bates road. The committee will suggest under Part II further research endeavors, which include some problems arising in connection with the above reports.

(g) THEORETICAL ANALYSIS OF STRESSES IN ROAD SLABS

A theoretical investigation of the mechanics of concrete slabs is now being undertaken by Dr. H. M. Westergaard for the Bureau of Public Roads. The following note is contributed by him:

"A contribution to the understanding of the mechanical behavior of concrete roads should be obtained by application of the mathematical theory of elasticity. This theory has methods available for determining the distribution of stresses in an elastic slab resting on an elastic subgrade and carrying given loads. The resemblance of a structure of this kind to the road slab, with its subgrade, is sufficient to warrant the assumption that exact information concerning the perfectly elastic slab, when its dimensions and physical constants are chosen properly, may serve as approximate information concerning the road slab. Since it is possible by the theory of elasticity to investigate rather completely a wide range of cases, it appears to be a reasonable plan to obtain theoretical data for use as a basis for interpretation of experimental data and as a means for interpolating between the results of one test and another.

"A rather extensive literature deals with the theory of flexure of elastic slabs. Two papers deal with the subject of slabs on elastic support: one, by Hertz, was published in 1884; the other, by Happel, appeared in 1920.¹ Notable contributions to the general theory of elastic plates have been made during recent years, especially by Nádai, Mesnager, and Galerkin.²

"A theoretical investigation of the mechanics of stiff road slabs is in progress at present at the Bureau of Public Roads. So far, the assumption has been used that at each point the subgrade reaction is proportional to the deflection of the slab. Diagrams of deflections and bending moments have been obtained for various cases."

¹H. Hertz: Über das Gleichgewicht schwimmender elastischer Platten, Wiedemann's Annalen der Physik und Chemie, Vol. 22, 1884, pp. 449-455, or in the Complete Works, Vol. 1, 1895, pp. 288-294. H. Happel: Über das Gleichgewicht von elastischen Platten unter einer Einszellast, Mathematische Zeitschrift, Vol. 6, 1920, pp. 203-218.

²A. Nádai: Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, 170-171, 1915; Zeitschrift des Vereines deutscher Ingenieure, 1914, p. 487; 1915, p. 169; 1922, p. 848; Schweizerische Bauzeitung, Vol. 76, 1920, No. 23; Der Bauingenieur, 1921, p. 11, p. 299; Zeitschrift für angewandte Mathematik und Mechanik, 1922, p. 1, p. 381; Physikalische Zeitschrift, 1922, p. 366. A. Mesnager: Annales des Ponts et Chaussées, Mémoires, 1916, 111, p. 313, and a series of short papers in Comptes Rendus, 1916-1919, Vols. 162-165, 168, and 169. B. G. Galerkin: a series of comprehensive papers in Russian, Annals of the Polytechnic Institute of Petrograd, 1915-1919, Vestnik Engeneroff, 1915 and 1917, and Bulletin of the Russian Academy of Science, 1919.

PART II

PROBLEMS FOR FURTHER RESEARCH

It is suggested by your committee that research should be conducted on the following problems in order to obtain further information leading to the establishment of principles of design:

1. Study of elastic properties of subgrade soils. Investigations should include observations on the flow of soils if they are only partly elastic. Research should also take into account that highway loads are moving loads of short duration many times repeated.

2. The transmission of pressure by various thicknesses of macadam and gravel to subgrade soils. Such an investigation would call for an observation of pressures for a period of several years following the original construction of the surface. Such an investigation should cover a wide variety of methods of construction and materials on different types of subgrade.

3. The mathematical analysis of stresses in rigid slabs (now under way).

4. Exhaustive measurement of stresses in rigid slabs to confirm the mathematical analyses (now under way).

5. Ascertain if the same or similar treatment of other heavy soils will make them impervious and good subgrade material as it did the heavy black adobe at the Pittsburg tests; also, determine if such treatment will retard or eliminate frost action.

6. Determine the comparison or relationship, in a pavement slab, of deflections and stresses under different loading conditions, with observations taken longitudinally *versus* transversely.

7. Comparison of vertical and horizontal movements of a concrete pavement due to moisture *versus* temperature.

8. Establishment of a basis of comparison of various asphaltic pavements *versus* Portland cement concrete. Conditions: (a) Subgrade as nearly uniform in every respect as is possible to attain; (b) Pavement slabs of equal dimensions; (c) Identical atmospheric temperature and moisture conditions; (d) Identical loading and traffic, and (e) The same installation of recording apparatus to measure the direct comparison.

9. The effect of longitudinal reinforcing on transverse temperature cracks in a Portland cement concrete slab.

10. The effect of an asphaltic top course on a Portland cement concrete base in changing the magnitude or rate of vertical motion due to temperature changes.

11. To determine the proper ratio of transverse steel to longitudinal steel and the maximum amount of each necessary in a reinforced concrete pavement slab to safely withstand unlimited repeated

applications of, say, single axle loads of ten tons, without impact (this in conjunction, of course, with fair average subgrades).

12. To conduct further practical studies of the effects on pavements of various types of motor vehicles, including tires, springs and various accessories now on the market.

13. To evolve some simple means of predetermining the usefulness of a finished subgrade made of the various soils, if it be properly prepared to get the best known results. (This is quite aside from the present method of determining bearing power.)

14. To confine our highway research, for the present at least, to pavement slabs between the limits of five and seven inches in thickness. The balance of the study can well be spent on the preparation of soils in securing proper subgrades for such pavements which would then safely carry any present-day traffic.

15. Need of dowels in two-section pavement.

16. The increment of strength added to pavements by thickened edges.

16a. Are thickened edges along center joints necessary?

17. The effect of crown subgrade on drainage.

18. To devise a method of surfacing sand-clay, top-soil and gravel roads similar to veneer surface as being carried on by North Carolina.

19. More definite information as to the average and maximum value of the load and impact force that have to be considered for each type of road.

20. The relative destructive effect of different types of vehicles (this with reference to types and weights of axles, chassis, and load distribution).

21. Importance of proper tire equipment.

22. A simple and definite method of testing tires to determine relative cushioning quality.

23. Relative stress effect of static and impact forces on materials.

24. Deformation and modulus of elasticity of materials under impact.

25. Investigation of merits of reinforcement and special joints in carrying loads across adjacent slab.

26. Study of methods of compaction of fills of various kinds of materials.

27. Distribution of pressure intensities under road slabs.

28. Further studies on effect of climate and snow on moisture in the subgrade.

29. Further study of beneficial effect of admixtures on plastic subgrade and the depth required.

Note.—Subgrade treatment, 8 inches thick.

Dr. H. M. Westergaard, University of Illinois, gave an illustrated progress report of investigations on the "Mechanics of Stiff Road Slabs." This report is not yet available for publication. A brief summary by Dr. Westergaard is given:

This work was carried on during the summer of 1923 by the Bureau of Public Roads and is being continued at present at the University of Illinois for the Bureau of Public Roads. The method of the investigation is that of the mathematical theory of elasticity. The nature of the problem is as stated in the note on theoretical analysis, embodied in the report of the Committee on Structural Design. The problems yet to be solved are the problem of local stresses in the immediate neighborhood of a wheel load, and the problem of the effect of a non-uniform subgrade. When the results of the investigations are plotted in the manner of test data, they should furnish a means for interpreting the results of tests.

REPORT OF COMMITTEE NUMBER 3, ON CHARACTER AND USE OF ROAD MATERIALS

In the absence of the chairman, Dr. Hatt gave an outline of Mr. Mattimore's report. The report follows:

A meeting of this committee was held at Harrisburg on October 4 for the purpose of receiving and acting on reports pertaining to problems which had been assigned to individual members of the committee. Those present were B. A. Anderton, R. W. Crum, F. C. Lang, C. S. Reeve and H. S. Mattimore; or an attendance of five out of a total membership of seven.

The twelve problems assigned to individual members of the committee for investigation were considered to be subjects upon which no definite conclusions have been drawn by research workers in the highway field. Their importance is recognized by highway research workers and it is considered that a solution of many of them would be a step forward in quality control of both concrete and bituminous surfacing, and may result in correcting many defects in both types of highway surfacing. These research problems are as follows:

Problem	Assigned to
1. Soundness Test for Aggregates in Concrete.	M. O. Withey.
2. Soundness Test for Concrete.	
3. Effect of Grading of Fine and Coarse Aggregate in Concrete.	R. W. Crum.
4. Determination of the Amount of Cement in Hardened Concrete.	

5. Significance of Modulus of Rupture Tests for Concrete in Road Slabs. H. H. Scofield.
6. Significance of the Jones Talbott Rattler as Tests for Concrete in Road Slabs.
7. Absorption of Concrete as Effected by Aggregate, the Ultimate Effect of this in Expansion of Road Slabs. F. C. Lang.
8. Significance of Ball Test (Penetration of 1½-inch Steel Ball under Pressure in Concrete and Mortar).
9. Strength of Cast Concrete *versus* Drilled Specimens. H. S. Mattimore.
10. Strength of Hardened Concrete in Wet and Dry Condition.
11. Effect of Grading of Mineral Aggregates on Sheet Asphalt and Bituminous Concrete Construction Relative to Deformation of Surface under Traffic. B. A. Anderton.
12. Recovery of Bituminous Materials from Road Surface Mixtures in Original Condition. C. S. Reeve.

PROBLEM NO. 1. SOUNDNESS TEST FOR AGGREGATES IN CONCRETE
PROBLEM NO. 2. SOUNDNESS TEST FOR CONCRETE

So far as the committee can ascertain, very little research work has been done on these problems. The committee is of the opinion that accelerated tests, both on aggregates and concrete, endeavoring to duplicate atmospheric action, are one of the vital needs in this field. The Sodium Sulphate Test¹ might prove to be valuable for this purpose, and it is recommended that research workers give consideration to it.

PROBLEM NO. 3. EFFECT OF GRADING OF FINE AND COARSE
AGGREGATE IN CONCRETE

The report submitted gives the present status of research on this subject. Several theories for proportioning concrete, devised by research workers, have been compared, and the following are some of the conclusions taken from the full report:

Established facts and principles.—"As a result of the work of the various authorities, the following fundamental fact has been practi-

¹"Proposed Soundness Test for Concrete Aggregate," United States Department of Agriculture, Bulletin No. 949, page 62.

cally established. The strength of Portland cement concrete varies with the amount of actual solid material present in a given volume and with the relative parts of this volume that are cement and aggregate. Different experimenters have expressed this relation in different ways, but appear to be in substantial agreement as to the underlying principle."

"The fact having been established, that for the same amounts of cement and aggregate, other conditions remaining the same, the strength of concrete varies with the amount of mixing water, it readily follows that concrete should be mixed with as little water as will yield a workable mixture for the use at hand. It has also been reasonably well established, other conditions being the same, that the grading of the aggregate has a decided effect upon the amount of water that may be used to yield a workable mixture. We have here, therefore, an explanation of the benefit of using well-graded aggregates."

Controversial factors.—"The various suggested methods of evaluating the sieve analyses of aggregates have not yet been reconciled or the fundamental laws fully established. Concrete has been designed and made both experimentally and in actual construction, with success, by each of the various methods. The 'Fineness Modulus,'¹ and the 'Surface area'² methods depend upon a complete sieve analysis. Prof. Talbot's mortar void method³ depends upon the characteristics of the mortar portion of the concrete. The Iowa Highway Commission⁴ has used mixtures based upon the ratio of fine to coarse aggregate.

"It can be shown that with materials from a given source these various functions have definite relations with each other, but that with random materials from different sources no such definite relation obtains. It is probable that equivalent concrete mixtures can be designed by each method for aggregates generally similar, but varying in grading."

Recommendations.—"The committee recommends that research tending to coordinate the data now available be encouraged, and that research to develop methods of making more uniform concrete upon a large scale be strongly urged upon all interested agencies as prerequisite to making effective use of the information already available on the design of concrete mixtures."

¹ Bulletin No. 1, Structural Materials Research Laboratory, Lewis Institute.

² Proceedings A. S. T. M., Vol. 18, 1918, page 236.

³ Proceedings A. S. T. M., Vol. 21, 1921, page 940.

⁴ Bulletin No. 60, Eng. Exp. Station, Iowa State College.

PROBLEM NO. 4, DETERMINATION OF THE AMOUNT OF CEMENT IN
HARDENED CONCRETE

This report should be a valuable guide to research workers in this field, as it takes up the present status of the problem, with tabulation of the past work and the work at present under way.

No report has been submitted on Problems Nos. 5 and 6, but a sub-committee is engaged in this work and expects to submit some data at the next meeting.

PROBLEM NO. 5, SIGNIFICANCE OF MODULUS OF RUPTURE TEST FOR
CONCRETE IN ROAD SLABS

The committee considers Problem 5 a very important subject. There are considerable data at the present time on this subject, the importance of which for the testing of concrete road slabs is recognized.

PROBLEM NO. 6, SIGNIFICANCE OF THE JONES-TALBOTT RATTLE AS
TESTS FOR CONCRETE IN ROAD SLABS

The committee does not consider that data obtained at the present time indicate that this is a reliable test, and they question that it should be placed in the status of an important or essential test for concrete when used in road slabs.

PROBLEM NO. 7, ABSORPTION OF CONCRETE AS AFFECTED BY AGGREGATE:
THE ULTIMATE EFFECT OF THIS IN EXPANSION
OF ROAD SLABS

The full report on this subject gives the status of the research to date. The committee considers that this is a very important problem and that research along this line should be encouraged. An investigation of the absorption of concrete, combined with temperature changes to which it is exposed, may result in some solution of the cracking and rupturing of concrete bases and road surfaces.

PROBLEM NO. 8, SIGNIFICANCE OF BALL TEST (PENETRATION OF 1/2-
INCH STEEL BALL UNDER PRESSURE IN CONCRETE AND MORTAR)

The research on this problem, so far as the committee is informed, has been limited—in fact, confined to one agency;¹ but it is the opinion of the committee that if the test proves to be a reliable indication of the compressive strength and effect of fatigue on concrete slabs, further development should be encouraged. The weak feature

¹"Ball Test Applied to Cement Mortar and Concrete." Bulletin No. 12, Engineering Experiment Station, Purdue University, Lafayette, Indiana.

of this test in its present state seems to be that the penetration of the ball in a concrete mix is affected when coarse aggregate is encountered.

PROBLEM NO. 9. STRENGTH OF CAST CONCRETE VERSUS DRILLED SPECIMENS

Considerable data on this subject have been secured and compiled. The data to date have not shown any direct relation between cast and drilled specimens, but it is the opinion of the committee that, while some such relation should exist, lack of control and absence of detailed data on the field concrete make it difficult to trace the relation. For guidance of research workers on this problem, a research outline is given ("Strength of Concrete as Determined from Moulded and Drilled Specimens").

PROBLEM NO. 10, STRENGTH OF HARDENED CONCRETE IN WET AND DRY CONDITION

The general conclusion that could be drawn from this report is that concrete when tested in a wet condition shows a decrease in strength over that which is tested dry.

The moisture content of concrete specimens when tested may be a large factor in the variables present in concrete testing; therefore, it is considered that this is a factor that should be taken into account by research workers in the concrete field.

PROBLEM NO. 11, EFFECT OF GRADING OF MINERAL AGGREGATES ON SHEET ASPHALT AND BITUMINOUS CONCRETE CONSTRUCTION, RELATIVE TO DEFORMATION OF SURFACE UNDER TRAFFIC

The report gives the present status of this problem. It is surprising that so little conclusive research has been carried on in this field. All investigators emphasize the need of more information. The committee considers this a very important field for research.

PROBLEM NO. 12, RECOVERY OF BITUMINOUS MATERIALS FROM ROAD SURFACE MIXTURES IN ORIGINAL CONDITION

The full report on this problem discusses several methods now in use for the recovery of bituminous materials from mixes. Conclusions are also drawn regarding the efficiency of the various methods, and a suggested line for further research is presented. The committee considers this an extremely important subject, in that if we had an exact method for recovering bituminous materials in their original condition we might be in a position to determine some of the factors which cause the pushing and cracking of bituminous road surfaces.

In endeavoring to compile research data upon bituminous mixes, the committee found that very little work of a broad research nature had been carried on. This field should be a fruitful one for highway research workers. The following concise statement is given in an endeavor to impress upon highway research workers just how important this field is:

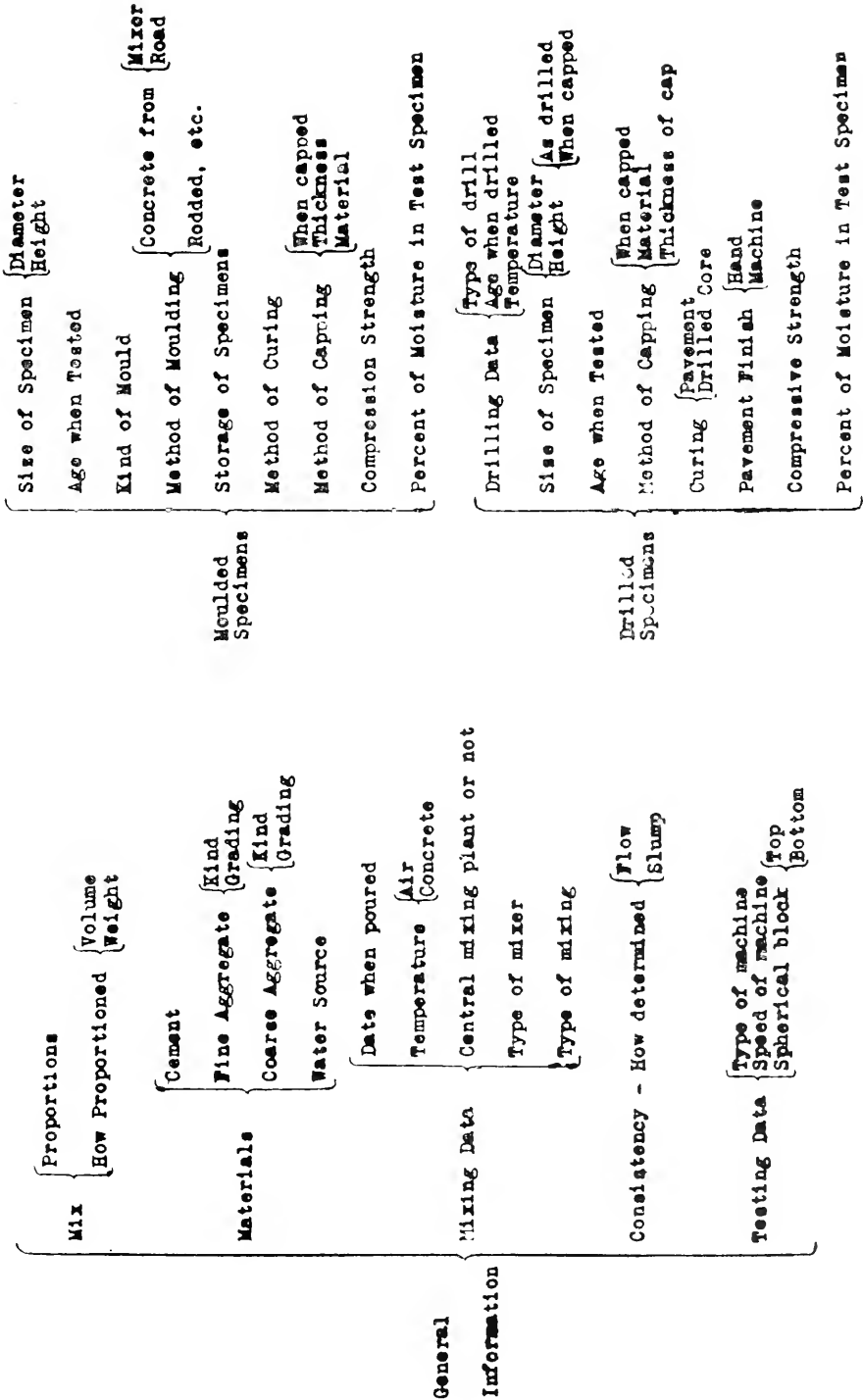
"Research upon bituminous materials, particularly as used in paving mixtures, includes a number of problems upon which it would be desirable to have much more comprehensive information than is available at present. Discussions in recent years as to the causes of instability of bituminous pavements emphasize strongly the need for investigating the properties of mixtures of this nature. The problem is difficult of attack on account of the great variety of materials, proportions, methods of preparation and construction, and because of the interdependence of many factors to be controlled and measured simultaneously. Such research requires special equipment, development of testing apparatus and methods, thorough investigation in a broad field of possible combinations of materials, and will probably necessitate considerable time and expenditure for the obtaining of comprehensive data. It is worthy of the most extensive and best thought which may be brought to bear on investigation of road materials."

Research outlines, entitled "Outline Investigation of Stability of Bituminous Surface Mixes" and "Strength of Concrete Determined from Moulded and Drilled Specimens," are attached for the guidance of the workers in this field.

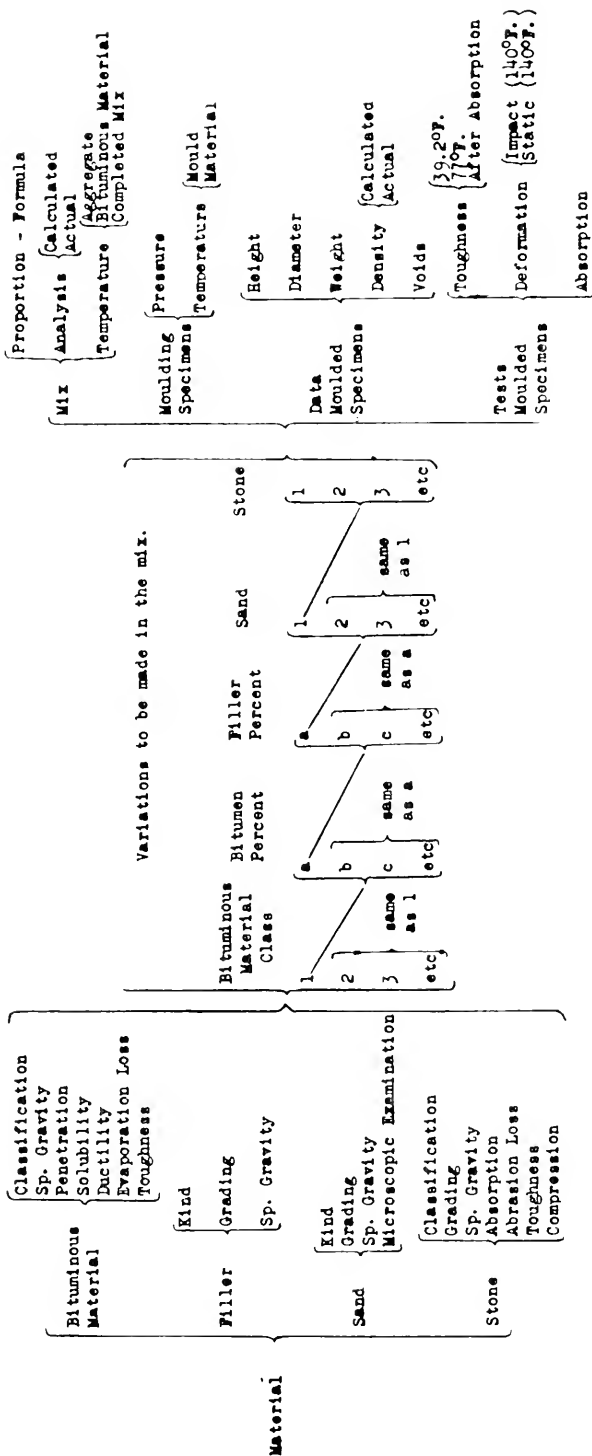
Chairman Johnson gave the meeting over to a general discussion of the various reports and papers.

Mr. Older: Results obtained by repeated soil-bearing tests on the Bates Road subgrade may be of interest in connection with Dr. Westergaard's report. Loads of varying amounts were applied to concrete slabs, cast in place on the subgrade, ten to fifteen times at short intervals, followed by rest periods. The first load applied after a rest period invariably resulted in a marked permanent depression of the subgrade soil. This permanent depression always seemed to appear, even although the rest period amounted to only a few minutes. Further, the repeating of a number of loads at frequent intervals seemed to result in continued permanent depressions, although apparently on a decreasing scale as the number of repetitions of load increased. As might be expected, there is some indication that as the moisture content of the soil increases approximately to the point of saturation, the permanent depression caused by each application of load increases quite rapidly.

STRENGTH OF CONCRETE AS DETERMINED FROM MOULDED AND DRILLED SPECIMENS.



OUTLINE OF INVESTIGATION OF STABILITY OF BITUMINOUS SURFACE MIXES



The observations so far made indicate that at least one other item may have an extremely important bearing upon the behavior of a clay subgrade soil when subjected to repeated loads. This relates to the effect produced by freezing and thawing of the soil. During the summer and fall months, when the moisture content was about 28 per cent, ten repetitions of a load amounting to 6 pounds per square inch might result in a total permanent depression of perhaps not more than 1-100 inch. Later, when the moisture content had increased under the same slab to about 33 per cent, in the meantime the ground having frozen and thawed a few times, ten applications of a load of the same magnitude produced a permanent depression of 16-100 inch. Still later, after another period of freezing and thawing, during which the moisture content had again decreased to about 28 per cent, ten applications of the same load produced a permanent depression of about 6-1000 inch. It would seem that north of the latitude where freezing and thawing of the subgrade may be expected this phenomenon would have an important bearing upon the subgrade problem.

Dr. Westergaard: It is possible that ruts can form under the pavement, provided the traffic follows definite tracks. I believe, then, that one of the particular problems that should be dealt with theoretically is the matter of the flexure of the slab having less support along two different lines. I believe that problem can be handled. Now, as to the matter of permanent sets in general, a committee on stresses in railroad tracks has been confronted with that same thing.

Second Session

The meeting was called to order at 7:30 P. M. The Chairman introduced Thomas H. MacDonald, chief of the U. S. Bureau of Public Roads, who made an address on

THE OBJECTIVES IN HIGHWAY RESEARCH

The United States is now carrying on a highway improvement program which, measured in terms of expenditures, approximates a billion dollars annually. As in nearly everything else of concern to the general public, we have gone in for quantity production. A large yearly mileage of new roadways has been demanded, that a place might be found upon which to operate the quantity production of the motor vehicle. So large are the annual programs of new construction in many states that even minor modifications in specifications or designs have a very large financial aspect.

In the face of large annual increases in the mileage of improved

roads, handicaps exist and have existed continually to the satisfactory and economical use of the motor vehicle because of insufficient mileage of highways improved to even reasonably acceptable standards. Very recently a well-known manufacturer stated that four million new vehicles would be placed on the highways in 1924. Even allowing for the retirement of a large number of those now in service, the net accrement is such there is the certainty that much greater service will be required from highways already seriously overloaded structurally and congested to the point of discouraging the reasonable and desired use of the motor vehicle.

All this has occurred without warning and without precedent. The whole development of highway transport is in the making, bringing with it hundreds of problems—social, economic and engineering. This condition must be recognized, accepted with just weight, and solved. Much greater reason exists for doubting whether the condition now existing will be correctly measured than for doubting the ability to apply proper remedies, once the individual problems are correctly analyzed. In no other development, ancient or modern, affecting in so major a degree the whole structure of our social and economic life has the engineer been given so commanding an opportunity for leadership and for carrying into effect policies formulated by his profession.

The opportunity is real. Will the engineer succeed or fail? If he is making progress, if he is succeeding, if he finally proves beyond all doubt the ability of the engineer to master, and thus to lead in a new and major translation in our national life, it will be through research—research that is as big and broad, as sympathetic and intelligent, as the present existing conditions and opportunities for advancement and progress justify.

A satisfied confidence in present practices and a lack of interest in engaging in and supporting broad highway research is not only a failure of a public duty, but it is the worst possible betrayal of the engineering profession itself. But past history is not entirely reassuring. One question for years has been to me a most perplexing one, and I may add it has not been an entirely happy one. This same question has been active in the minds of a great many, if not most, of the engineering profession, and common reference is made to it in engineering literature.

It is this: Considering the study, preparation and experience required to fit one adequately to practice the profession of engineering, the hard work, both mental and physical, usually involved in the practice of the several branches of engineering, the sincerity and persistency of purpose required for any successful accomplishment,

and the responsibilities of all kinds imposed, why has not the engineer been accorded more readily and more consistently leadership and the rewards of leadership, not necessarily material, which generally accrue to recognized authority?

And the answer, which is reasonably sufficient to me, but which I do not insist that any one else shall accept, is this: the lack of engineering research. As we review engineering history, this lack and often entire absence of anything approaching adequate research has been until very recent years characteristic of both individuals and institutions.

For example, agricultural experiment stations have been established through federal and state legislation and have been supported for many years to promote the development of the science of agriculture. These experiment stations are established in every state, but only a very few educational institutions have established engineering experiment stations, and most of these have had serious trouble to maintain a meager existence. Why research in engineering has not been more fully developed is most difficult to understand. Undoubtedly our great natural resources have lulled us into the belief that it was not necessary to use them with the economy which ought to follow proper research: yet this certainly cannot be the only reason, when we consider the tremendous fertility of the lands which have been ours for the taking: and yet we find a widespread and persistent extension of agricultural research in the states where there has been no engineering research developed.

I am fully convinced that engineers have been so busy with the day's work that they have not insisted upon the development of an adequate engineering research until the fact was accomplished, and that this reason is, to a greater degree than any other, responsible for the failure of engineers up to this time to secure that degree of recognition justified. Very hopeful indications now exist that this recognition is coming slowly but surely: and without doubt the motivating reason behind this changing attitude of the public toward the engineer is the greater interest, activity and insistence of the engineers in the establishment and conduct of engineering research.

You will find in this statement no striving for effect, no unfriendly criticism, but rather an expression of the deepest concern that the great needs and great opportunities for research that are presented shall receive full recognition from the engineer. And what is true of the necessities and fruitful potentialities in the field of engineering research is equally true in that of other professions; for example, the economist, who is concerned with the economic and social development of this nation.

Consider the highway transport field. The civil, the mechanical, the automotive, the transportation engineer, the economist, and the chemist—all have presented to them broad opportunities for direct research, while, although more indirectly and perhaps somewhat more removed in time, there are other professions that may very conceivably find worthy phases for research endeavor.

Highway research offers two major objectives: First, the isolation and definition of each problem; and, second, the solution of the problem. These objectives are supplemental and sequential. All too frequently the first is neglected to the undoing of the second. Perhaps I may even be justified in saying that engineers have frequently in the past made grave errors, and, judging the future by the past, will continue to make grave errors in big enterprises or in the solution of big problems in one of the following ways:

- a.* Insufficient and inaccurate fundamental data.
- b.* Limitations in scope of data secured.
- c.* Limitations imposed by legislation or other authority.
- d.* The misapplication or maladjustment of data in itself correct.

Examples might be multiplied of failure or lack of obtainable success in engineering projects through an incorrect or inadequate analysis of the whole problem involved. More specifically, failures might be catalogued under one of these four reasons. It might be urged that engineers are not responsible for the limitations imposed by legislation or other authority; but are they not responsible when, as is frequently true, they cut and trim estimates and designs below safe practice to meet these limitations? More than this, it matters not what the reasons are or what handicaps exist, the engineer in charge will be held in the court of public opinion for any failures.

There are these two groups of highway research objectives: First, those having for their purpose the correct analysis of each problem, and, second, those having for their purpose the finding of the remedy or the solution when the problem shall have been correctly isolated and analyzed. Just at this time, of the two, the first is the more important. Real progress is always slow. Consider the years of research required to isolate the yellow-fever germ, and in the meantime the lives that were lost from this cause, unknown and unchecked. The cause once known, the remedy has followed swiftly—to the everlasting credit of the medical profession. So, too, the opportunity is offered in the highway field to do a big work now in research. Much progress has been made, but we have only started. Nor can the research worker stop when he shall have reached both of these objectives, for he must then insist upon the practical appli-

cation of the solutions he finds in the field of highway transport. The most perfect solution is only valuable when applied. After all, the real objective of highway research is the most economical, in every sense of the word, and the most efficient highway transport service possible for the use of the public as a whole. The opportunities are unlimited. There is not a single phase in which there is not the necessity for major research. In the field of finance, no rational policies of providing the funds have been worked out. We have only fairly started upon the improvements in the design of road surfaces. We need to develop better materials—cement, asphalt, aggregates, and particularly sands.

Field control of processes to insure uniformity of product is still almost untouched. Adequate provision for, and the control and regulation of, traffic must be solved. These unsolved problems, and many more, present a wide, almost unexplored, field for highway research.

Anson Marston, Dean of Engineering, Iowa State College, was unable to be present. Dr. Hatt read Dean Marston's paper on

HIGHWAY RESEARCH WORK OF AMERICAN ASSOCIATION OF LAND-GRANT COLLEGES

In another report the writer of this paper is giving a summary account of engineering research at the land-grant colleges of the United States. In a word, they constitute the greatest single organized agency for engineering research in the country. The status of the land-grant colleges is especially favorable for organized highway research conforming to a national program, such as that of the Advisory Board on Highway Research.

- a.* The land-grant colleges are the only nationally endowed and supported educational institutions of higher learning in the country. Hence, each of these land-grant colleges should cooperate with the National Government in its highway research (conducted by the Bureau of Public Roads) and with the Advisory Board on Highway Research, itself (through the National Research Council) a creation of the National Government.
- b.* Each of these land-grant colleges also is officially established and supported by the government of the state in which it is situated. Hence, it is especially fitting that the land-grant college in each state should cooperate officially and systematically with the State Highway Commission in the same state, since they constitute two branches of the state government.

Furthermore, the land-grant colleges are by organic law devoted to education and research in the industries, including especially agriculture and mechanic arts. No line of research, therefore, could be more fittingly developed at each land-grant college than highway research. The planning, the construction and the maintenance of good roads, their use and the economics of highway transportation have the most vital relation to agriculture and to every branch of mechanic arts; in fact, to every line of work for which the land-grant colleges were established.

Under these conditions it is not surprising that the land-grant colleges, without any particular organized effort, already have engaged extensively in highway research. It appears that in 29 of the 48 states highway research has been undertaken at the land-grant colleges. In some states, as notably in Illinois, Indiana, Iowa, Kansas, Maine, Maryland, Minnesota and Wisconsin, a large number of highway research projects are in active progress at each institution.

However, the highway research undertaken so far by the land-grant colleges is not yet so extensive or so effective as it might be, because of lack of effectively organized cooperation with each other and with the Advisory Board on Highway Research. The Association of Land-Grant Colleges maintains a Standing Committee on Engineering Experiment Stations, which publishes quarterly the "Engineering Experiment Station Record," distributed to each of the land-grant colleges, giving definite and comprehensive accounts every three months of the engineering researches in progress at all land-grant colleges. Upon the initiative of this Engineering Experiment Station Committee, the Association of Land-Grant Colleges is now a constituent organization of the Advisory Board on Highway Research, with a personal representative on the Board. The writer, as such representative, hereby offers the assistance of the Association of Land-Grant Colleges in promoting highway research in the land-grant colleges in accordance with the program of the Advisory Board on Highway Research. I would suggest a conference of representatives of the Advisory Board and of the U. S. Bureau of Public Roads to meet with the Engineering Experiment Station Committee of the Association of Land-Grant Colleges.

It should be the part of the Advisory Board on Highway Research to suggest definite lines of research in which each of the land-grant colleges might engage. These suggestions should be specific rather than general, and should be based partly upon the resources at the

various land-grant colleges and partly upon the local needs of the several states.

Each of the land-grant colleges in its highway research should establish very close relations with the U. S. Bureau of Public Roads, and most friendly and active relations with the state highway commission in the same state.

Finally, I should say that in my judgment the character of highway research which should be undertaken by the land-grant colleges should be fundamental and theoretical, rather than purely practical in character. For example, I believe that the testing of road materials, to determine their acceptance or rejection, in general should fall to the state highway commissions.

Another extremely important function of the land-grant colleges in highway research should be to train the research men. The writer believes that a census of highway research men in the United States would show an extremely large proportion who have been trained at land-grant colleges.

Dr. J. G. McKay, Chairman, presented the

REPORT OF COMMITTEE NO. 6, ON HIGHWAY FINANCE

Principles of highway finance.—The economic and social advantages resulting from highway improvements are now generally accepted. The transportation of freight and passengers, the opening up of new areas for agricultural production, the savings in motor-vehicle operating costs, the increased values of rural and urban lands, the lowered cost of marketing agricultural produce, and the social influence of improved highway transportation are but a few of the many far-reaching results of an improved system of highways on our national life.

The method of raising revenue to finance highway improvements is typified by a lack of uniformity among the states, an unscientific distribution of the burden among the principal sources of revenue and a distribution marked by a lack of adherence to fundamental principles of sound public financing.

The financing of highway improvements today, as well as in the future, requires relatively fixed amounts of highway revenue each year. Highway expenditures are not irregular or periodic disbursements of public funds. The financing of a state system of highways involves a continuous expenditure and not high and low periods of disbursements. The amount of highway revenue necessary for new highway improvements decreases as a highway system as a whole approaches completion. This decrease in new construction expendi-

tures, however, will probably be absorbed in the growing amount necessary each year for maintenance, reconstruction and betterments. The yearly highway budget represents a relatively level and continuing expenditure of public funds and the methods of producing highway revenue to meet the yearly costs must be placed on a sound financial basis which permits highway officials to plan construction and maintenance of highways over a longer period of years.

A budget system as a definite part of the highway program is essential. Under the budget system a fixed amount of highway revenue is necessary for the construction of a relatively fixed amount of new mileage each year, the balance of the revenue being used for maintenance, reconstruction and betterments.

The sources of highway funds.—There are six so-called sources of highway revenue which promise highway funds—property taxation, vehicle license fees, bond issues, gasoline taxes, federal aid and a miscellaneous group such as legislative appropriations and income and inheritance taxes.

Today, as in the past, the taxation of property produces the larger share of highway revenue. Motor-vehicle license fees, the second main source of highway funds, are becoming of increasing importance. The practice of pledging vehicle license fees to meet the principal and interest of highway bond issues endangers the source of highway maintenance funds and usually results in diverting construction funds to maintenance. The third main source of highway revenue is from the sale of highway bonds. Highway bonds are credit instruments sold to make highway funds immediately available and are not in themselves a source of highway revenue. Real property taxation and vehicle license fees, when pledged to meet the principal and interest of highway bonds, are the true sources of funds obtained through the sale of bonds. The fourth method of raising funds, gasoline taxation, is now being used as a source of revenue by a considerable number of states and its importance is steadily increasing. Federal aid is a fifth source of highway funds. The sixth, or miscellaneous group, is not as important as the preceding ones and produces but a relatively small part of the total amount of highway funds. The primary sources of highway revenue, then, are as follows:

1. Property taxation.
2. Vehicle license fees.
3. Gasoline taxation.

As a general rule, states rely upon a combination of property taxation, vehicle fees, and in a number of states gasoline taxation, to

produce highway funds. Though the sale of highway bonds is a common practice of both state and county units, it is not a legitimate source of highway revenue. The true source of highway bond funds is that revenue which is pledged to meet the payment of the bond, principal and interest.

The principal criticism of present methods of raising highway revenue is that the per cent of the revenue raised from property and from the highway user is not based upon the benefits received by either source of revenue from the highway improvement nor upon the ability of either source to contribute to the improvement. In those states where real property provides the larger share of highway funds, there is an unfair burden on property which does not benefit in proportion to the amount of taxation. On the other hand, it is unfair to tax the highway user beyond the actual value of the highway service rendered. Between these two extremes lies a middle ground of highway financing which can produce revenue equitably from both sources.

The second major criticism of modern highway finance methods is the use of credit in highway improvement programs. The excessive use of state or county credit is dangerous. If a state can carry on a normal highway improvement program without resort to the sale of highway bonds, it is a sounder and less costly method of financing than state or county credit.

Any plan of state or county highway financing should conform as closely as local conditions permit to the fundamental rules which govern the raising of public revenue: (1) Distribute the burden equitably among the contributing sources according to the benefit derived from the improvement and the differences in the ability to pay for the improvement. (2) Provide a definite amount of highway revenue yearly. This implies the highway budget system.

The highway program of a state should be limited to the ability of the state to carry on economically a long-time improvement program. It is economically unsound to set as an objective the completion of a large yearly program of new construction as a mark of achievement. The result of this practice is to unduly increase the demand for labor and materials above normal, which increases the per-mile cost of highway improvement. Unfortunately, the increase in cost resulting from this practice is not confined to state limits, but reacts on the labor and material markets in adjacent states, increasing the cost per mile of neighboring states that may be operating on a normal yearly construction program. Whenever the demand for highway labor and material exceeds the market supply,

the available fund of highway revenue actually constructs a smaller amount of highway mileage. An excess volume of highway construction is also reflected in an increase in the construction costs of other industries which use the same type of labor and materials. This disturbing element in highway construction can be largely avoided by carefully planning the state highway improvement program extending over a period of years and adjusted to the yearly highway budget. Under a budget system the sources of revenue should produce an amount sufficient to handle normal construction, maintenance and betterments. The highway budget should be sufficiently flexible to take advantage of periods of low prices.

Two distinct problems are involved in discussing the financing of highway improvements: (1) An equitable distribution of the cost of highway improvements among the several sources of highway revenue. (2) Whether or not the use of credit is necessary in financing highway improvements by the sale of bonds. The theory underlying bonding is twofold: (*a*) To make immediately available a large amount of revenue, and (*b*) To shift a share of present improvement costs to future generations which will benefit from the improvement.

The answer to the first major problem is found largely in an analysis of the benefits accruing to the several sources of revenue from the highway improvement. The answer to the second major problem depends largely upon the ability of the present sources of revenue to provide sufficient current funds to complete the highway system without unduly burdening the sources of revenue.

It should be emphasized that the use of credit, which, in my judgment, is second in importance to the problem of equitable distribution of the costs, does not solve the problem of distributing the highway costs among the several sources of revenue. The same sources of revenue which finance highway improvements when credit is not used must also provide the revenue to meet highway bonds when funds are borrowed. It is quite often the case that when highway bonding is utilized it is impossible to distribute the costs fairly among the normal sources of revenue, due to the fact that the providing of the source of funds to retire the bonds may be covered by constitutional or legislative enactment, or that the ability to market the bonds at a fair price may dictate that only one source, usually real property, shall furnish the revenue to amortize the bonds.

The fundamental problem is to determine in any given state the type of financing necessary to produce sufficient highway revenue to carry out a normal highway improvement program.

The physical part of the highway improvement is an asset that remains in existence over a period of years and may be called the permanent investment. The larger the amount of permanent highway investment in existence in a state, the less the real need for the use of credit in financing the improvements. This situation is more the case in the older states whose road systems are well defined and a considerable portion of whose highway mileage is completed. The next factor in determining whether to use present sources of revenue or to make use of credit depends upon the wealth of a state and the ability to produce highway revenue from this wealth without unduly burdening it or decreasing the revenue raised for purposes other than highway improvements.

Using the amount of basic highway investments already completed in a state and the amount of wealth available for revenue purposes, we may classify state highway finance into three main groups:

(1) States in which the permanent highway investment is substantially completed. States of this type are the older states, with a large amount of completed highway mileage and with sufficient taxable wealth to provide a constant yearly source of funds for highway construction and maintenance work. It would appear logical that in states within this group the use of credit is not desirable except as an emergency measure.

(2) States in which the permanent highway investment is partially completed. The type of financing necessary in states in this group is determined largely by the ability of present taxable wealth to produce sufficient yearly highway revenue. If the sources of highway revenue can produce funds sufficient to carry out the yearly highway improvement program, the use of credit is unnecessary. It is entirely possible that states within this group may find it necessary to plan their financial program on a basis of financing from current revenue supplemented by the use of credit.

(3) States in the early stages of highway development with a small percentage of completed permanent highway investment. The use of credit as the major method of financing is essential in states in this group.

In order to justify the construction of a highway with funds raised from the taxation of real property, the benefit to the property must at least equal the burden. Both the burden and the benefit will be reflected in land values; if the benefit is the larger, land values will increase; if the burden is greater than the benefit, land values will decrease. In this way we can arrive at a maximum above which taxation of real property for highway improvements is un-

justifiable. The benefit to the user of the road can be measured by the amount he is willing to pay for this use, the maximum being the highest possible rate which will not result in a restriction of traffic. The benefit to the general public is much harder to measure; we meet here the difficulty which the benefit theory of general taxation has constantly encountered. It is safe to say that the benefit to the general public, after excluding the general as well as the special benefit to the user of the road and to the land-owner, is a comparatively small part of the total benefit. Our problem then resolves itself largely into the question of a just distribution between the burden on land and the burden on the highway user. The benefit to land must be determined by a study of the effect of various types of highway improvements on land values; the benefit to the user must be determined by a study of the value of the service.

Sources and expenditures of highway funds in four Wisconsin counties.—Before making any decision as to the justice or expediency of the methods of highway financing, it is necessary to make a complete study of the sources of highway revenue—local, county and state—in typical states. Most of the previous investigations have been limited to a study of the sources of state revenue for highway purposes and have disregarded the county and local expenditures for highway construction and maintenance. The following results are based on an analysis of all sources of revenue and expenditures in four Wisconsin counties from 1915 to 1921. Wisconsin was selected as a state whose system of highway financing represents a fair average of methods of raising highway revenues in other states. Four Wisconsin counties—Dane, Outagamie, Rusk and Waukesha—were chosen for the purpose of determining the percentage of revenue for highway purposes which is provided by each of the several sources of revenue. These counties were selected as typical counties, representing the highway development in different sections of the state.

Dane County is a well-populated, rich agricultural county, with no highway bond issues. Madison, the capital city of the state, is located in the center of this county.

Outagamie County is a good agricultural county. It has financed a large portion of the construction of its highway system through bond issues since 1916.

Rusk County is located in the newer section of the state. It is a purely agricultural county, with soil of average fertility, but as yet largely undeveloped. No highway bond issues have been made and its highways are, with the exception of the state trunk highways, largely unimproved.

Waukesha County lies west of the city of Milwaukee and is a rich dairying and manufacturing county. It has floated large bond issues during the past three years.

To determine the total expenditures for highways in each of the counties in which the analysis was made, it was necessary to consolidate the expenditures made by the local units within the county, the expenditures made by the county, and the expenditures of state and federal funds within the county. The expenditures by the different governmental units have been carefully analyzed and all expenditures appearing in the records of more than one unit have been eliminated in all except the unit which actually raised the funds for highway construction or maintenance. In the local units the expenditures made by cities have been eliminated, as their expenditures are almost exclusively for streets rather than for highways.

The following tables show the total expenditures for highways within each county—Tables I(a) to I(d). From these tables it is evident that the proportion of the burden of all highway expenditures which rests upon real property varies from 55 per cent to 70 per cent in the four counties. The highest proportion is found in Rusk County, a relatively undeveloped county, while the lowest proportion is found in Waukesha County, a very rich section, both agriculturally and industrially. This variation is due largely to differences in revenue derived from the income tax. In the richer counties the income tax furnishes a larger portion of the total revenue, and, as a result, in so far as funds for highway expenditures are taken from general revenues, the income tax furnishes a larger portion of revenue for highway expenditures. It will be noticed that real property taxation and "other revenue" taken together furnish almost the same proportion of revenue for highway expenditures in all counties, the figures being as follows:

Dane County, 76.82 per cent.
Outagamie County, 79.86 per cent.
Rusk County, 81.35 per cent.
Waukesha County, 78.68 per cent.

A comparison of the proportions furnished by each source of revenue in any one county for the different years substantiates the conclusion that the contribution of real property varies inversely as the contribution of "other revenue." "Other Revenue," as the name indicates, is made up of all sources of revenue except the sources listed separately in Table I, but the principal part of it is made up of revenue derived from the income tax. The other sources of revenue

TABLE I (a).—Sources of Revenue of Total Highway Expenditures, Dane County, Wisconsin, 1915-1921

	Amounts				Percentages					
	Total	Local	County	State	Federal	Total	Local	County	State	Federal
Total	\$4,395,782.43	\$1,814,125.79	\$1,442,325.23	\$902,688.76	\$236,642.65	100.00	100.00	100.00	100.00	100.00
Real property taxation	2,650,263.62	1,343,556.57	966,152.43	340,554.62		60.29	74.06	66.99	37.73	
Personal property taxation	492,317.87	218,870.85	194,922.04	78,524.98		11.20	12.06	13.51	8.71	
Other revenue	726,864.33	171,772.45	277,803.94	40,645.29	236,642.65	16.53	9.47	19.26	4.50	100.00
Automobile license fees	442,963.87			442,963.87		10.08			49.06	
Special assessments	79,925.92	79,925.92				1.82	4.41			
Miscellaneous contributions	3,446.82		3,446.82			.08		.24		

TABLE I (b).—Sources of Revenue of Total Highway Expenditures, Outagamie County, Wisconsin, 1915-1921

	Amounts				Percentages					
	Total	Local	County	State	Federal	Total	Local	County	State	Federal
Total	\$3,072,597.82	\$1,071,774.83	\$1,524,983.57	\$368,847.63	\$106,991.79	100.00	100.00	100.00	100.00	100.00
Real property taxation	1,943,975.63	713,491.92	1,095,246.96	135,236.75		63.27	66.57	71.82	36.67	
Personal property taxation	415,907.45	125,483.83	261,387.77	31,035.85		13.54	11.52	17.14	8.41	
Other revenue	599,882.60	219,986.54	168,348.84	14,555.43	106,991.79	16.59	20.53	11.04	3.95	100.00
Automobile license fees	188,019.60			188,019.60		6.12			50.97	
Special assessments	14,812.54	14,812.54				.48	1.38			

TABLE I (c).—Sources of Revenue of Total Highway Expenditures, Rush County, Wisconsin, 1915-1921

	Amounts				Percentages					
	Total	Local	County	State	Federal	Total	Local	County	State	Federal
Total	\$1,254,937.64	\$604,905.44	\$381,056.96	\$192,783.55	\$76,191.69	100.00	100.00	100.00	100.00	100.00
Real property taxation	876,316.81	496,240.81	311,245.27	68,830.73		69.83	82.04	81.68	35.70	
Personal property taxation	128,460.47	61,526.71	51,383.01	15,550.75		10.23	10.17	13.48	8.07	
Other revenue	144,531.38	45,149.27	18,428.68	4,761.74	76,191.69	11.52	7.46	4.84	2.47	100.00
Automobile license fees	103,640.33			103,640.33		8.26			53.76	
Special assessments	1,988.65	1,988.65				.16	.33			

TABLE I (d).—Sources of Revenue of Total Highway Expenditures, Waubesa County, Wisconsin, 1915-1921

	Amounts				Percentages					
	Total	Local	County	State	Federal	Total	Local	County	State	Federal
Total	\$2,484,831.50	\$983,058.28	\$734,354.28	\$540,561.22	\$226,857.72	100.00	100.00	100.00	100.00	100.00
Real property taxation	1,373,964.27	630,912.28	535,193.60	207,858.39		55.29	64.18	72.88	38.45	
Personal property taxation	253,235.89	104,128.16	102,110.36	46,997.37		10.19	10.59	13.90	8.70	
Other revenue	581,121.43	242,440.44	97,050.32	14,772.95	226,857.72	23.39	24.66	13.22	2.73	100.00
Automobile license fees	270,932.51			270,932.51		10.90			50.12	
Special assessments	5,577.40	5,577.40				.23	.57			

included under this head, such as fees, fines, etc., form a very small proportion of the total in this class. The annual expenditures by counties from each source of revenue show that in the years 1917 and 1918, when the receipts from the income tax were highest, the proportions of revenue derived from real property taxation were smaller than in the years when the receipts from the income tax were smaller.

TABLE II. *Percentage of Total Revenues for Highway Expenditures Raised by Various Governmental Units*

County	Local funds	County funds	State funds	Federal funds
Dane	41.27	32.81	20.54	5.38
Outagamie	34.88	49.63	12.01	3.48
Rusk	48.20	39.37	15.36	6.07
Waukesha	39.56	29.55	21.76	9.13
Average	39.92	36.43	17.89	5.76

Table II indicates the importance of funds raised by the local units (townships and villages) for highway purposes, as compared with state and federal funds. It will be noted that the funds raised by the local units and counties furnish from 69 per cent to 84 per cent of the total highway expenditures. While this analysis is based on only four counties, it is safe to assume that these proportions are reasonably correct for the State of Wisconsin, since the counties studied were selected as representative of the various counties within the state. In other states the proportion raised by the various governmental units may vary to a considerable extent from those shown in Table II, but in those states organized on the township basis the funds raised by the local units and counties will approximate the percentages shown in Table II. The percentages shown in Table II are derived from the total expenditures within the different counties for the period 1915 to 1921, inclusive. It should be noted that this period includes a few years before the period of federal aid, and also that the activity of the state in the highway field has increased greatly during the later years; so that had the period been made to include only the years 1918 to 1921, the percentages derived from state and federal funds would probably have been larger.

Although the proportions of highway expenditures contributed by local, county, state and federal units, as indicated in Table II, may vary to a considerable extent in different localities, nevertheless the figures are conclusive evidence that any discussion of highway finance treating exclusively of state and federal expenditures omits local and county expenditures, which constitute the major portion of the total highway expenditures. While it would be advantageous

to have more of our highways entirely financed and constructed by the state, the fact remains that *at the present time local and county highway expenditures absorb the major portion of funds raised from all sources for highway improvement.*

TABLE III. *Percentage of Total Revenue for Highway Expenditures from Real Property Taxation Levied by the Various Governmental Units*

County	Local taxation	County taxation	State taxation	Federal Government	Total
Dane	30.56	21.98	7.75	.....	60.29
Outagamie	23.22	35.64	4.41	.....	63.27
Rusk	39.54	24.81	5.48	.....	69.83
Waukesha	25.39	21.54	8.36	.....	55.29
Average	28.42	25.94	6.71	.....	61.07

While the general property tax is the most important single source of revenue for highway expenditures in all units—the township, the county and the state—its importance as a source of highway revenue is much greater in the township and county than in the state. As will be noted from Table III, real property taxation by the local units furnishes from 23 per cent to 39 per cent of all highway expenditures, and county real property taxation provides from 21 per cent to 35 per cent of the total highway expenditures, while state real property taxation provides only from 4 per cent to 8 per cent of the total highway expenditures.

TABLE IV. *Percentage of Real Property Revenue for Highway Expenditures Levied by the Various Governmental Units*

County	Local	County	State
Dane	50.70	36.45	12.85
Outagamie	36.70	56.33	6.97
Rusk	56.62	35.52	7.86
Waukesha	45.93	38.95	15.12
Average	46.54	42.47	10.99

Table IV shows the proportion of real property taxation revenues for highway expenditures raised in each county by the various units. An average of 46.54 per cent is raised by local units, 42.47 per cent by county units and 10.99 per cent by the state. *The real property revenue for highway expenditures raised by the state in comparison with local and county real property revenues is but a small share of the total real property revenue raised for highway improvement.*

TABLE V. *Sources of Highway Revenue for Total Highway Expenditures*

Source	Average percentage
Real property taxation.....	62.17
Other revenue (largely income tax funds).....	17.01
Personal property taxation.....	11.29
Vehicle license fees.....	8.84
Miscellaneous .....	.69

It is to be noted that real property taxation produces seven times as much of the total highway revenue as that derived from motor vehicle license fees, while the taxation of incomes (other revenue) produces approximately double the amount raised by vehicle license fees. Since local funds are expended on purely local roads, it is fair to compare the amount of county and state real property tax funds produced for expenditures on state and county highways with the amount raised by vehicle license fees used on the same highways. County and state real property taxation produce 32.65 per cent of total highway revenue, vehicle license fees 8.84 per cent. Real property, which contributes 61 per cent of all highway expenditures, produces for county and state highways four times as much of the total expenditures as that produced from vehicle license fees.

Conclusions Based on Analysis of the Sources and Expenditure of Highway Funds in Four Representative Wisconsin Counties:

1. The major portion of the total of highway funds in Wisconsin during the seven-year period from 1915-1921 was raised by township and county units rather than by the state.
2. Real property taxation was the chief source of highway revenue, producing an average of 61.07 per cent of the total local, county and state highway expenditures.
3. Vehicle license fees produce 8.84 per cent of the total highway expenditures.
4. Real property taxation for highway purposes bears too large a portion of the burden of highway expenditures, producing from 55 per cent to 70 per cent of the total highway revenue.
5. The major portion of the burden on real property is due to local and county taxation of real property for highway purposes. The local units produce 46.54 per cent; county units, 42.47 per cent; and the state, 10.99 per cent of the real property revenue for highway expenditures.
6. Real property contributes a larger share of highway revenue during periods of depression, when the revenue from other sources decreases. This results in an excessive levy on real-property owners, since the tax levy on real property is paid from income derived from the property, and in periods of low prices this income is reduced at least as much as income from other sources.

7. When income-tax funds increase within a county, real property taxation for highway purposes decreases.
8. As a county develops and grows richer, the relative burden on real property for highway purposes decreases. When a county or state is in the developmental stage, the cost of the permanent features of highway improvements can be economically financed by issuing a limited number of deferred serial highway bonds. By this method the burden on property is lightened during the early years of the improvement, increasing with the ability of property to produce more revenue as a result of the highway improvements.
9. A reduction or elimination of state taxation of real property for highway purposes in Wisconsin would not materially reduce the total of real property taxation for all highway purposes.
10. Reduction of real property taxation for highway purposes in Wisconsin would result largely in a reduction of local and county taxation of real property for township and county highway expenditures.

The problem of reducing real property taxation for highway improvements.—The two logical sources of highway revenue are real property taxation and vehicle license and gasoline taxation. When real property taxation produces too large a share of highway revenue in comparison with the share produced by vehicle license and gasoline taxation there are three courses which may be followed:

1. The elimination of inefficiency and waste in the expenditure of highway funds by the local and county units. Eighty-nine and three-tenths per cent of all real property tax funds for highway expenditures are raised by the local and county units. Any reduction in expenditures by eliminating the waste of highway funds will result in a reduction of the burden on real property for highway expenditures. This may be accomplished as follows: (1) Provide for strict supervision by the State Highway Department over the construction and maintenance of purely county highways. (2) Provide for close supervision by the county units over township highway expenditures, possibly limiting the maximum expenditures by the local units for highway expenditures to a fixed percentage of the township property valuation.

2. A reduction in the total yearly highway expenditures—township, county and state.

It is obvious that the present county and state expenditures for

highway improvements lags behind the need for improved highways and is not a desirable solution of the problem.

3. Shift part of the burden of highway improvements from real property to other sources of revenue.

By substituting other sources of revenue for a portion of the real property revenue, we cannot decrease the total revenue raised by the various units necessary for purposes other than highway improvement. A reduction in the amount of highway improvement revenue raised from the taxation of real property without raising a like amount from some other source of revenue would result in a reduction of the total highway funds below a necessary minimum. The logical solution is to increase the total revenue raised from old or to create new sources of revenue for highway improvement to replace the revenue lost by the lowered taxation of real property. The source of this increased revenue is the highway user, whose demand for highway service is largely responsible for highway improvements.

Charles M. Upham, State Highway Engineer of North Carolina, gave an illustrated discussion on

RESEARCH PROGRAM OF THE NORTH CAROLINA STATE HIGHWAY COMMISSION

The immediate necessity in research work is the practical application of our present knowledge already obtained by research. We now have vast funds of knowledge that have been obtained through research, but the benefits obtained by the present knowledge have not been developed to an extent commensurate with the labor and money expended. The reason for this is the non-application of the knowledge already supplied. Therefore, our problem is not necessarily a problem of research alone, but also a problem of application.

Probably there is nothing new in the fact that North Carolina has a research program, because every state, county or municipality that is carrying on the construction of highways has, to some degree, at least, a research program. In addition to this, laboratories scattered throughout the United States are also carrying on various researches. A survey by the Highway Research Committee disclosed the fact that many hundreds of projects are in operation. Some of them, of course, were duplicates, but the fact was disclosed that a great amount of research is being carried on.

The difficulties of a research program are numerous, but probably no more important problem exists than that of keeping research within practical limits and carrying it on in such a manner that when completed it may have a practical application and serve as a

step in working out economically some of the highway problems. Already a vast amount of research knowledge has been acquired, and this information is written into bulletins and distributed; but, unfortunately, many times the bulletins are of little practical value, because they do not reach the proper persons, nor are they written in a manner that will serve the busy official who generally organizes programs. Our research problems are still unsolved because the important step—the application of highway research work—has not been accomplished.

The problem of research seems to divide itself into two minor problems—research of the problem itself and the application of the research results. The application of the results obtained is such an important step that it could almost be considered a research problem in itself, and a proper study of this application would be well worth while. We find that a great amount of research has been carried on, but as yet a vast amount of the knowledge gained has not been applied to road-building, and consequently the economical value of the research has been lost.

In North Carolina every attempt has been made immediately to apply the results of research. Almost every step in construction is being studied in detail, and when anything of value is discovered it is immediately applied to construction on a large scale.

Not only does research include problems that may be carried on by the laboratory, but it includes transportation problems, problems that will ultimately render road service to the user of the highway. The great research problem is to render road service to the public so that transportation may be more economically carried on. These major problems of transportation and road service are, of course, influenced by other problems, such as the problems of construction, maintenance and operation. In all highway research there should be constantly kept in mind the question of how the results of this research can influence the road service rendered to the user of the highway.

Sand asphalt pavement.—One research that has recently been carried on has been the development of progressive type roads. Certain localities in North Carolina furnish practically no road-building material, with the exception of sand. The problem in this instance was to devise some means whereby these large quantities of sand could be used in road construction. The answer came in the construction of the sand asphalt road, which is made up of approximately 88 per cent sand and 12 per cent asphalt. These roads may be constructed in either single or double track, according to the needs of the traffic, and are generally constructed 4½ inches in depth. This method of construction affords a moderately low cost road, which

renders very satisfactory road service to the locality. It is not expected that this type of road will stand up under a large amount of heavy truck traffic, but it is a development road and is satisfactorily rendering road service to the user of the highway. Though this type of road is, of course, the result of laboratory research, it is more particularly the result of the proper application of laboratory research.

Marl rock base.—Another locality in North Carolina furnishes no stone for road aggregate, but it does have an underlying strata of marl rock, the result of a large deposit of shells. Although at some time this deposit must have been on the seashore, at the present time it lies some 8 or 10 miles back from the ocean and about 4 or 5 feet underneath a swamp. This marl rock is being quarried and crushed and is furnishing an excellent base for a sand asphalt surface. While the details of this construction were taken from earlier road work, still the use of this marl rock means the practical application of investigative research.

Subgrades.—The studies of subgrades have been demanding considerable attention during the past few years, but there seems, even at this time, to be a lack of proper application of the findings. It has already been determined that different soils are affected differently by the varying amounts of moisture. In some cases, however, no attempt is made to select the best soils for subgrade purposes. In many localities a proper selection of soils will not only furnish an ideal subgrade, but will serve as a road, a subgrade highway, to take traffic up to as high as 400 vehicles a day. These selected soil roads may be maintained for a period and then used as an excellent subgrade for the next better step in construction.

Capillarity.—Recent research has brought to light considerable information regarding the capillarity of different soils. For a long period it seemed as though a poor subgrade or a clay condition might be best remedied by the construction of a Telford foundation. Now it appears that the Telford foundation served as a drain to carry away the free water, but was of little, if any, value in taking care of the capillary moisture. Recent experiments have shown that a layer of material similar to sand is more effective as a means of cutting off capillary moisture. This explains why excellent results have been obtained in the construction of macadam roads on clay subgrades when screenings have been spread on the subgrade. It also explains the excellent results obtained with bituminous roads constructed on a gravel and sand foundation.

Research has shown that capillary moisture in the subgrade is not cut off from the overlying road surface as efficiently by coarse material as it is by ordinary sand. The reason probably is that the

subgrade material finds its way into the interstices of the coarse material and the capillary tubes of the subgrade material continue to act through the interstices of this coarse material; whereas, in the case of the sandy material, the subgrade material of high capillarity is excluded, and therefore the capillary action of the sand is not so great. This is an important point and one that can be taken advantage of and easily and economically applied to road work on a large scale much more so than is commonly done.

Veneer surface.—Another important application of research work is in the construction of stone veneer on earth roads. In the south there is an exceptionally large mileage of earth roads, consisting mainly of the sand clay, topsoil and gravel types. The bearing power of these roads is high and the strength is great; yet maintaining these roads is a problem, since they offer little resistance to abrasion. Thus the problem in this particular instance is to secure some means of protecting the surface against abrasion and to abate the resulting dust nuisance. The answer seems to be the stone veneer surface in which the quality of an asphalt wearing surface is combined with the strength of an earth road. Several attempts have been made in applying bituminous material to earth roads. The results, in general, have been unsuccessful because, even though the bituminous material was sufficiently light to penetrate the surface, it had no binding power or strength whatever, and if the bituminous material was sufficiently heavy to have a binding value, it would congeal on the surface and peel off, owing to a dust mat that formed underneath the bituminous material. With the veneer surface, a layer of stone of approximately three inches in size is applied to the earth road and rolled partly into the surface, after the surface has been scarified or loosened. This veneer surface of stone is then penetrated with a bituminous material having a consistency to give sufficient strength to hold the stone in place and afford resistance to wear. This bituminous material is then covered with proper sized stone, is rolled, and then opened to traffic. The stone is held in place from below by the earth road and has become an integral part of it. The bituminous material holds the stone in place on the surface and affords resistance to traffic abrasion. Thus we have a combination of the strength of an earth road and the wearing qualities of an asphalt pavement—another instance of the practical application of research work.

Hard surface types—coarse aggregate.—Another problem in construction is the ideal construction of hard-surfaced roads. Much laboratory research has determined that the aggregates must be of certain qualities and properly graded. Recent experiments in con-

crete work have shown that much depends upon the grading of the aggregate. Although the early tests indicate that a large aggregate gives a higher strength value, long-time tests seem to show that the aggregates below an inch and a half give higher strength values. In this instance we have a research giving one result, yet it is impossible to apply this result in its entirety, since the present arrangement of crushing plants and aggregate production machinery does not furnish economically an aggregate that gives the highest ultimate strength. Therefore the proper application of this research demands a compromise approaching the ideal conditions.

Core drill.—Considerable research is being carried on attempting to correlate the laboratory tests of materials to the final product as found in the pavement by the core drill. At the present time it seems there are so many variable factors that it is impossible to control all of them, and, as a consequence, the final product varies considerably.

Not only have studies of the coarse aggregate been made, but a new test for fine aggregate has been developed, which seems to permit a wider range of fine aggregate to be used, or, in other words, aggregate that would be condemned under the standard test can now be used with safety. This test consists essentially of testing the aggregate in compression and transversely rather than in tension, as is done in many of the present-day standards.

Investigations in cement also show that this material varies considerably, and that the final strength of the road depends primarily upon the quality of the cement used. It seems that individual brands may vary considerably. This may not be only a question of manufacture, but also one of handling and storage until the cement is used.

Surface finish.—Possibly no single demand on a pavement is so great as that of impact of traffic. Impact depends entirely upon the smoothness of the road surface; therefore considerable study has been given to obtaining smooth surfaces. This has been put into practice by devising various means of finishing the surface.

In the case of concrete, it is found that the smoothness of the surface depends upon many factors, chief among them being the consistency of the concrete and the character of the subgrade. The subgrade, after being wet by the concrete, expands or contracts and the green concrete in the road surface does the same. Various types of check templates are being used to check the surface before it sets up, so that it may be corrected while still plastic. In the case of the bituminous roads, test-boards and straight-edges are used during construction. After the road has been opened to traffic it is again

tested. Recently, experiments have been carried on with the vialog, an instrument devised for measuring unevenness of road surfaces.

There has been much discussion relative to the detailed construction and maintenance research problems, but probably the most pressing problem and the most immediate need is a solution of the proper methods for taking the research work that has already been done and giving it practical application. This leads us to the problem of organization and personnel; the varying results obtained in the work show the influence that personnel has on any undertaking. Research in construction and maintenance problems deals with definite quantities, but research in organization and personnel, since it deals with varying factors of the human mind, is more difficult so solve. The proper and economical application of research work still involves research in the matters of personnel and organization. It is useless to spend time, money and effort in carrying on research unless the results are applied in such a way that our highway problems will be more economically solved than they otherwise would be. In order that the facts may be used to the greatest advantage, they must be presented to the proper persons in a way that is definite, concise and easily understandable.

Third Session

The meeting was called to order at 9:30, Friday morning.

Chairman Johnson: The Board has received a report of cooperative work being carried on in Iowa on "Impact in Highway Bridges," by Prof. Fuller, Chairman of the Subcommittee of the American Society of Civil Engineers on Impact in Highway Bridges. His report is upon the cooperative program between the U. S. Bureau of Public Roads, Iowa State College, and the Engineering Experiment Station of Iowa State College. Dr. Hatt will read this report.

Dr. Hatt: Mr. Fuller's report is as follows:

Cooperative work was begun in the summer of 1922. An important item at that time was the adaptation of existing instruments or the development of new instruments for measuring dynamic stresses. A number of instruments were tried out, with the result that only those best adapted to the purpose were used in 1923.

A description of the 1922 work, discussion of the various instruments used, and a portion of the results have been published as Bulletin No. 63 of the Engineering Experiment Station of Iowa State College. The greater portion of this bulletin was included in the 1922 report of the Committee on Impact in Highway Bridges of the American Society of Civil Engineers and published in its Proceedings for March, 1923.

The general scope of the work for the summer of 1923 is indicated in the following:

Structures investigated:

1. One-hundred-and-fifty-foot span, 20-foot roadway, through curved chord steel truss, with concrete floor on steel stringers, known as the Skunk River Bridge, on the Lincoln Highway, located about three-fourths of a mile east of Ames.

2. Thirty-three-foot span, 20-foot roadway, consisting of concrete floor on steel stringers. This is an approach span to the main Skunk River Bridge.

3. Seventy-foot span, 24-foot roadway, through plate girder, with concrete floor on steel stringers. This is known as the Squaw Creek Bridge, on the Lincoln Highway, and is located within the city limits of Ames.

4. Forty-foot Pony truss bridge, 18-foot roadway, with reinforced concrete slab resting directly upon transverse floor beams, located on county road near Roland, Iowa, about twenty miles from Ames.

Loads:

1. Two 15-ton trucks with solid rubber tires, with about twelve tons on the rear axles and three tons on the forward axles.

2. A 10-ton Holt caterpillar tractor (on structures 1 and 2 only and only for about two hours).

Range of work:

Floor.—Rather complete work was done on the stringers of structures 1, 2 and 3 and on the floor beams of 1, 3 and 4. This includes impact on smooth floor, over one-inch obstructions and over two-inch obstructions, and also distribution data for static loads which show the actual unit stresses on all of the stringers for one and for two trucks.

Trusses.—Readings have been taken upon the greater portions of the web members of structures one and four, of the chords in structure four, and of the girder flanges in structure three.

Time.—Field-work was started on July 1 and ended September 15.

Instruments:

1. Three Turmeaure recording extensometers.
2. Five West direct reading extensometers.
3. One photographic mirror recording extensometer developed by the U. S. Bureau of Public Roads; available after August 1.

4. Six electrical remote reading and recording strain gages, in which records of all six instruments are photographed on one roll of paper—developed by U. S. Bureau of Standards and made available for one week in September through courtesy of that Bureau.

Calibration of instruments:

Before the field-work was begun the instruments were calibrated for static stresses. No suitable equipment was then available for dynamic calibrations. Two more or less impromptu devices have since been developed which have given, within reasonable limits, positive as well as comparative calibrations under rapidly changing conditions. These have been, first, an impact machine in which a weight was dropped upon a tension bar to which the instruments were attached; and, second, a vibrating device which produced known changes in length in very short but known increments of time. The work of calibration, while yet not complete, has been carried far enough to insure a reasonably accurate interpretation of results, which will be compiled as soon as practicable.

Chairman Geo. E. Hamlin presented the

REPORT OF COMMITTEE NUMBER 4, ON HIGHWAY
TRAFFIC ANALYSIS

During the year many states have carried on, to a greater or less extent, highway traffic censuses. Attached to this report is an analysis of the characteristics of such surveys, with data obtained. The detailing of this data shows that the various states realize the importance and value of traffic information and are each year increasing the census records to specify additional information of movement, commodity and length of haul.

In this connection, the chairman wishes to call particular attention to Prof. Blanchard's recommendation, that this committee strongly differentiate between a highway traffic census and a highway transport survey. The traffic census will give information pertaining to the traffic using the highway at the time the census is taken; the purpose of the highway transport survey is to determine the probable amount and character of the future traffic which will use a given highway during the lives of its several component parts. Up to the present time, the information collected by the various states has given traffic census information, but as far as the chairman has been able to determine, no state has extensively taken up the highway transport survey.

A highway traffic census is of value only for determining conditions which exist at the time the census is taken. It may be that by the construction of a new section of road the general trend of traffic may be radically changed in any particular locality. After an extended highway traffic census, it is recommended that additional counts be taken at critical periods of the year in succeeding years, from which, after a number of counts have been taken, curves of natural increase can be plotted from which in turn an estimate of increased traffic for a reasonable period of years can be roughly determined. This estimate should also include the curve of increase of motor vehicle registration which can be determined at the present time in every state. It is questionable if such a curve can be applied to other than the locality in which it is developed. In fact, even in a state of small area, different curves will have to be developed for different sections of the state, rather than to utilize a general curve for all of the main highways. Up to the present time, it has been found impracticable, with the data available, to develop a formula of this character.

The value of an extended traffic survey in determining the allocation of construction and maintenance funds in the development of a highway system is unquestioned. Such traffic survey, however, should be utilized for type and strength of surface rather than for location of expenditures, inasmuch as the development of new territory within a state is as much a demand upon the expenditure of highway funds as is the taking care of traffic already developed. This point cannot be stressed too strongly, for, if the allocation of funds depends wholly upon the volume of traffic, only a few of the roads in any particular state would ever receive a construction allotment. This is where the decision of the engineer in charge is valuable, and this decision must be based on potential as well as present traffic conditions. In other words, he must minimize any particular locality to consider the value of transportation in the whole state, and each construction unit must be based on his vision of the value of such unit.

To carry out a traffic survey successfully, much planning must be done preliminary to the actual field-work. Stations must be chosen which will give the average condition along each highway, and these must be located at a sufficient distance from the congested centers to eliminate as far as possible the strictly local traffic which will not enter into the construction program. Care should also be taken to establish stations where traffic is divided, so that the value of each section as well as each road may be determined. Each station should be occupied at least one day each month, for an eight to twelve-hour

period. This should be arranged so that the same station will be occupied successively on different days of the week, and on a different hourly basis, to determine daily as well as seasonal variation of traffic. Blank forms where check-marks may be used will reduce the time required for gaining information and names of cities; character of loading and make of truck or car may be coded, thus simplifying the actual compilation of the records in the office.

The personnel require a certain amount of special training, although courtesy has been found to be the largest asset. A special sign at the census station giving the reason for the questioning is the greatest factor in reducing the time required to pass a car or truck through the station. The enumerator can check many of the questions on the card by observation—the number of questions asked the driver in the case of the pleasure car covering only origin, destination and business or pleasure use. In the truck census other necessary information will require a longer period and larger party, where weights are actually taken on a platform scale installed for this purpose. A platform pit type scale of 25-ton capacity can be installed, with automatic dial and the necessary covering house, for \$2,500 to \$2,800.

The chief of survey should be thoroughly acquainted with the entire district, both in regard to road and traffic conditions, and be able to detect any seeming discrepancy in the records sent in. Abnormal conditions due to a particular event, such as a football game, must be previously discounted, so as not to congest traffic on that day, even if the stopping of the cars for questioning is omitted. Each party may consist of from three to six men, the number varying with the importance of the station occupied, each party having a designated head, who reports to the chief of survey and under whose direction the party operates.

In the State of Connecticut the cost of three parties operating over a year's period with varying numbers, including necessary automobile transportation, board allowance, etc., has been about \$27,000.

It will not be a function of this report to determine results obtained from the Connecticut traffic census, which are being compiled and tabulated under the direction of J. G. McKay in the U. S. Bureau of Public Roads. The survey was carried on for a full year, ending in September, 1923, with 56 stations and operated by three parties. The tabulation is still in progress and the full report is being prepared, so that the entire cost cannot be given at this time. It is, however, believed that the tabulation cost, including the printing of the reports, will not exceed \$10,000.

Dean Johnson, of this committee, in addition to continuing the

traffic count of the Maryland highway system, from which a revised traffic map of the state will be compiled, has, in cooperation with the U. S. Bureau of Public Roads, established an experimental traffic counting station where weights and numbers of vehicles are automatically recorded. This installation was in operation for two months during the late summer, but progress was not made past the experimental stage, and in September the apparatus was removed for changes. Dean Johnson notes, in commenting upon this work, that there is "sufficient promise of results to make it worth while to spend considerable more time experimenting."

A self-recording device of this kind, which can be installed and operated at minimum cost, should solve, to a large extent, the objection in many localities to the expense of a traffic census for a period of time sufficiently long to obtain accurate results.

The committee believes that, while a traffic count is of value, more details should be considered than has been customary in the past, so that an analysis of present and probable future traffic may be made, as stated in a previous paragraph. This census must include enough detail and be taken over an extended enough period of time to determine the seasonal traffic, which varies greatly in certain parts of the country and which is a maintenance rather than a construction problem. The construction type must be based on the heaviest travel rather than on average or seasonal travel. A determination should also include the effect of slow-moving vehicles upon the general situation and the consideration of the possibility of legislation which will remove such vehicles to secondary roads during high peaks of traffic. This may include a recommendation for legislative act to govern the minimum speed permitted upon Class A roads during certain hours of the day or times of the year. It is believed that the slow-moving vehicle is often the cause of congestion upon a main highway, that the importance of this fact is not at the present time understood, and that the capacity of the road can be largely increased by restrictive regulation.

Mr. Hamlin: Without question, the design of road must cover peak conditions rather than average conditions. Probably the most abnormal conditions we have in Connecticut are during the football games at New Haven. Two years ago we took a census of vehicles at the Yale-Princeton game. Usually about 77,000 people attend the most popular games, and several years ago many special trains were run. There may have been special trains at the Yale-Army game this year; but, if so, they were not extensively advertised. Quite a number of people come the night before, stay at New Haven, and go back the second day; so this figure does not represent the entire

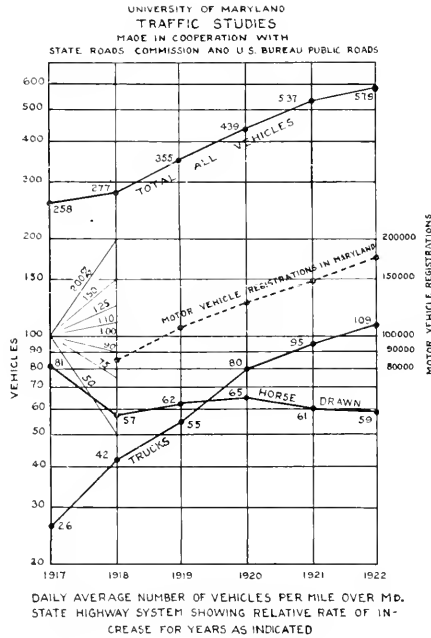
traffic. Two years ago we took a census from 8:00 a. m. to 8:00 p. m. At that time there were counted 26,016 cars on seven different roads which cover, to a large extent, the highways into New Haven. This year there were counted for the Yale-Army game 35,981, or approximately a 3,000 average per hour. The maximum recorded traffic for one hour, at Station 5, on the Derby Road, was 1,393 vehicles between 6 and 7 p. m., or 23 vehicles per minute—more than one vehicle every three seconds. At Station 5 the maximum passenger-car traffic was 1,385, showing that out of 1,393 cars only eight were other than passenger motor cars. The figures show an increase of about 40 per cent in all traffic in two years attending one of the major games. This is one of the conditions to be met on the Boston Post Road. We are building a 24-foot highway of 10-inch concrete, with shoulders varying from 8 to 10 feet—the maximum shoulder we can obtain. The plans for the future comprehend the construction of 36 feet of concrete, or four 9-foot travel paths, giving two lines of travel in both directions.

In the material received at the committee's request from the various states, there was a detailed report from the State of New Jersey. Mr. Sloan, of New Jersey, has developed a factor of 12.2 as representing the relation between the maximum daily and hourly travel. I have been unable to check this factor with the results we have obtained in Connecticut, but, roughly, he estimates that the maximum of travel on any road is double the average hourly travel. I would be interested if any of you can check these conclusions. In regard to foreign cars, the average of 14 traffic stations extending to all parts of the state shows a percentage of foreign cars of 20.8. He has statistics regarding draw-bridges and he draws some very interesting conclusions in regard to the value of lost time to vehicular traffic due to their opening. According to Mr. Sloan, the number of licenses will depend on growth in population, and within the next decade will reach a saturation point at about one vehicle for each four persons. By 1950 the population of the state will have increased not quite 50 per cent over that of 1920. By 1950 it is expected that the number of licenses will be 2.7 times that of the present year. It cannot be assumed, however, that highway traffic will increase in direct proportion to the number of licensed motor vehicles. It has been found that traffic has increased in New Jersey as the square root of the increase in the number of licenses. Assuming that licenses will increase 2.7 times, it is seen that highway traffic will increase slightly more than 1.5 times.

Dean A. N. Johnson: The results of the Maryland traffic census

were compiled too late to forward to Mr. Hamlin and are now presented.

The State Roads Commission of Maryland has conducted a traffic census, the results of which now cover six complete years, 1917 to 1922, inclusive. The counts were taken at approximately 200 stations throughout the state highway system. The mileage to which the traffic counts apply is approximately 1,600 miles. The counts



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FIG. A

were taken at the same stations during the six-year period, one day per month, on different days of the week. The results are best seen by reference to Figure "A."

First, attention is called to the increase in the average daily number of vehicles per mile over the state highway system—from 258 vehicles in 1917 to 579 vehicles in 1922. It is noticed, however, that the rate of increase is flattening (the diagrams being drawn to semi-logarithmic plating, the slopes of the lines indicate the true relative rate of increase). Whereas the rate of increase for the period 1918 to 1921 is approximately 25 per cent, from 1921 to 1922 it is but little over 10 per cent. It is of interest to compare this rate of increase with the rate of increase of motor vehicle registration, shown by the dotted line. It is seen that for the four years the increase in motor vehicle registration is nearly constant (about 20 per cent per

year), and that the rate of increase in total traffic has lessened somewhat in advance of what we may expect for motor vehicle registration. Both of these curves, it would be expected, ultimately would follow closely the population curve.

The traffic counts show the number of horse-drawn vehicles and the number of trucks. It is to be noted that the amount of horse-drawn traffic has varied but little in the past five years, being almost constant in amount, while the rate of increase in truck traffic has been rapid, averaging for four years, 1917 to 1920, nearly 50 per cent a year. The curve then shows a somewhat marked lessening of

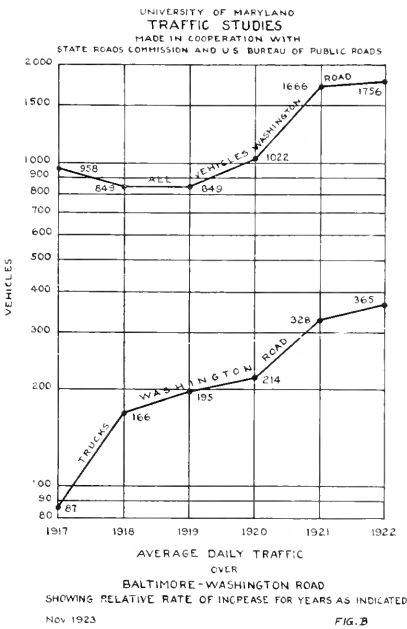


FIG. B

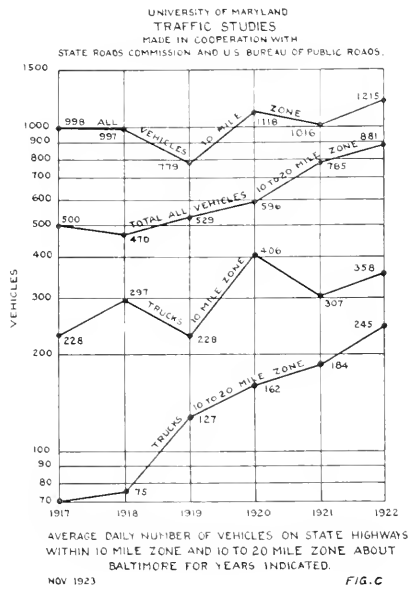


FIG. C

the rate for 1920 to 1922, inclusive, being for this period about 20 per cent, indicating that we may expect the rate of increase in truck traffic to be somewhat greater than the average for all traffic.

Attention is called to Figures B and C. Figure "B" shows the curve of increase of traffic on the Washington-Baltimore Road for the entire distance between these points, about 40 miles. The amount of traffic on this road decreased somewhat from 1917 to 1918, remaining about constant until 1919, when from this time to 1921 there is a marked increase in traffic, approximately 50 per cent per year, which has fallen off sharply in 1922, the rate of increase from 1921 to 1922 being nearly in accord with that for the average traffic over the entire state highway system.

The increase of truck traffic over the Washington-Baltimore Road is markedly different from that for the average traffic. Whereas the total traffic from 1917 to 1918 fell off over 10 per cent, the truck traffic increased about 100 per cent, and has continued to increase at a somewhat less rate throughout the entire period from 1917 to 1922, inclusive, but showing, in accord with the rate of increase for the traffic as a whole, a distinct lessening for 1922.

Figure "C" shows the rate of increase of all traffic, as well as trucks for the first ten-mile zone about Baltimore and the second ten-mile zone. The curves for the ten-mile zone for all traffic and for the truck traffic show a marked drop during the period 1918 to 1919. This probably does not reflect the true traffic conditions, owing to the fact that on certain traffic stations within this area counts were not made on all of them for the year 1919; and, while there may have been some decrease in the traffic, it is doubtful if it was as marked as has been indicated.

In general, it is to be observed that there has been a somewhat greater increase in the amount of traffic in the second ten-mile zone as compared with the first ten-mile zone.

From a study of these records, it would seem that we are now able to forecast somewhat closely the traffic, as a whole, that the state highways of Maryland will be called upon to carry for a number of years hence, as it is evident that the rate of increase must ultimately conform to the population curve, which has an increase, perhaps, of 1 or 2 per cent a year. As the present traffic increase is somewhat in excess of 10 per cent a year, for a few years hence the increase will continue somewhat more rapidly than that for the population.

The results, as here developed from the traffic census on state highways of Maryland, it is seen, coincide very closely with the results as pointed out by Mr. Hamlin from the New Jersey reports on traffic conditions, so that we may expect, in most well-settled communities, to find our traffic conditions approaching, within a very few years, more nearly the normal and fixed rates of increase, comparable with that of population.

Mr. Duchastel: I remember seeing a few weeks ago, in Quebec, at the Highway Department, the figures on the King Edward Highway, between Rosseau Point and Edward's Highway. The total number of pleasure cars was between 1,100 and 1,200. The foreign cars, and we call foreign cars the American cars, numbered over 800; so you see our proportion of foreign cars is 70 per cent, which is far more than Mr. Hamlin's count.

Chairman Johnson: Dr. J. G. McKay, of the U. S. Bureau of Public Roads, will give a talk on

ANALYSIS OF MOTOR TRANSPORT IN NEW ENGLAND

Three groups of agencies in New England are engaged in the transportation of people and commodities—steam and electric rail lines, boat lines, and highway transportation companies. The ultimate purpose of each agency is to produce the highest type of coordinated transportation service for New England producers and consumers.

The highway as an agency for the mass movement of people and commodities is a modern development of transportation. From September to December, 1922, over a million net tons of freight were transported by motor trucks over the Connecticut Highway System. Rail service during this period was below par, owing to labor difficulties, and naturally this situation increased the volume of highway transportation above the normal level. The largest portion of motor truck net tonnage movement was limited to the short-haul zone: 67.4 per cent was hauled less than 30 miles, 18.4 per cent from 30 to 69 miles, and 14.2 per cent over 70 miles.

Two factors are in general responsible for the highway transporting of commodities over 29 miles: (1) Rapid and efficient rail service for enabling shippers to obtain fast rail transportation of L. C. L. freight is lacking. (2) A limited number of commodities are especially adapted to motor-truck shipment and will probably continue to be shipped by truck for distances beyond the short-haul zone. The total ton volume of these commodities is not very significant.

Since January, 1923, the per cent of the total net tonnage transported by motor truck beyond 30 miles has decreased, indicating that, with efficient rail and boat service, the motor truck is not a major transportation factor in the middle-distance and long-haul zone in New England.

The commodities transported by motor trucks on the Connecticut highways reflect the industrial production of New England. Of the total net tonnage, 73.6 per cent are manufactured goods, 8.5 per cent products of agriculture, 7.1 per cent products of animals, 6.7 per cent products of mines and 4.1 per cent products of forests. The large per cent of manufactured goods is partly explained by the fact that more profit can be made in motor-truck transportation of goods of this character than by moving bulky goods of lower value.

Of the 240 motor trucking companies investigated in the principal cities in New England, the majority operate with a small fleet of trucks and serve a limited territory. The number of large, well-organized and efficiently-operated companies is small.

Motor-truck transportation in New England is loosely organized, keenly competitive, and operated largely on a contract basis, with rapid fluctuation in rates. A gradual growth of larger motor trucking companies is developing, which is essential to stability of service. It is entirely probable that, with the development of governmental regulation of motor-truck transportation and the resulting stabilization of the motor-truck rate structure and publication of rates, the majority of motor trucking companies operating in New England will discontinue the contract system of rate-making. Motor-truck operators, according to their own statements, will welcome regulation which will insure stability of rates and eliminate cut-throat competition.

The relatively high percentage of failure of smaller motor trucking companies indicates the narrow margin of profit in the motor-trucking business as it is now being operated in New England.

In general, New England manufacturers ship their commodities by motor trucks for two reasons: (1) prompt and reliable service; (2) trade demands.

Railroad freight congestion and rail embargoes force manufacturers to ship their products by motor trucks in both the short- and long-haul zone.

A combination of motor truck and rail, and motor truck and boat service is a modern development in highway transportation in New England territory. The combination truck and rail service has been in existence on a small scale for a number of years and is steadily growing in importance. This service has developed largely in response to the demands of shippers for a rapid pick-up and delivery service of freight. The motor trucking company assembles the commodities and loads the freight cars, which are forwarded daily, regardless of whether they are loaded to capacity or not. The cars are shipped by rail to destination and the trucking company unloads and delivers the freight. This type of service insures rapid movement of L. C. L. freight, eliminates rehandling at junction points and terminals, and reduces the amount of terminal space necessary for incoming freight. Stone's Express is typical of the companies performing this type of service and operates in connection with the New York, New Haven and Hartford Railroad in New England and the Pennsylvania Railroad in the Middle Atlantic States.

The second type of joint service is a combination motor truck and boat service, which has developed very rapidly in New England during the past few years. In most cases this service is limited to overnight delivery from New England points to New York City. This

type of service is flexible and capable of handling peak loads of traffic. The motor truck is used as a feeder from inland points to port towns and furnishes reliable and rapid service. The principal disadvantage of this type of shipment is the congestion of unloading wharves, particularly at New York City. The Starrin-New Haven line, operating between New Haven and New York City, is the best illustration of this type of service. This company maintains a sidewalk pick-up and delivery from Derby, Shelton, Ansonia, Seymour, Beacon Falls, Naugatuck, Waterbury, New Britain, Meriden, Wallingford, Middletown and Hartford, Connecticut, to New Haven, Connecticut, and ships by boat from New Haven to all points.

This modern development in the correlation of highway transportation with rail and water agencies in the movement of freight is an economic function of motor transportation and offers an extensive field of development supplementing rail and water service. It is not competitive and provides a pick-up and delivery service, allocates the short haul to motor-truck transportation and the long haul to rail and water and provides rapid transportation of freight.

Highway transportation of freight and passengers is increasing in volume each year. Its development has been so rapid and the information as to its movement so meager that it is extremely difficult to lay down any definite principles as to the economic sphere of motor trucking companies engaged in the highway transportation of freight.

The following is a tentative outline of the economic fields of motor-truck transportation as a correlated part of our transportation system.

1. *Organized urban motor-truck transportation in congested terminal areas consisting of motor-truck terminal to terminal freight transfers as well as pick-up to delivery service.*—This can be illustrated by the operation of the U. S. Trucking Company in New York City in cooperation with the Erie Railroad in the transfer of freight from the Erie-New Jersey terminal to New York City for delivery. *Carefully organized and efficiently operated motor trucking companies, assured of rail and steamship cooperation, will materially speed up terminal freight movement, decrease the volume of freight warehoused, reduce the cost of moving freight through terminals and expedite the rail delivery time of L. C. L. freight.*

2. *The organization of motor-truck freight service to supplement and extend existing rail and water transportation agencies.*—The development of motor transportation companies in areas inadequately served with rail or water transportation offers an enormous possibility for the economic extension of highway transportation. This type

of service is especially desirable in the development of new areas or localities with insufficient transportation facilities and will make available additional tonnage for movement by rail or water. This is a non-competitive service extending and supplementing existing rail and water agencies.

3. *The short-haul transportation of freight probably not to exceed 30 miles.*—The freight transported by motor trucks in the short-haul zone is largely a non-competitive assembly and distribution of commodities. The differences in the density of population in different areas, the distance between cities and areas of production and distribution, the prevailing type of production and the type of rail or water transportation available may decrease or increase the above zone of the short haul.

4. *Motor-truck transportation of a limited number of special commodities in the long-haul zone in which delivery time, the character of the goods transported or the demands of the industry or trade indicate the desirability of motor-truck transportation.*—This type of freight is but a small percentage of the total net tonnage transported over the highways.

Dean Hughes: Does Prof. McKay include the cost of carrying the commodity to the railroad and delivery from the railroad to the destination? If not, has he any figures to show what is the relative cost of delivering commodities from origin to destination by the combined system, compared to through motor trucks?

Dr. McKay: I was careful to say it was on the basis of difference between rates and not costs. Cost records are in a very unsatisfactory condition.

Dean Hughes: When you said that a lot of small truck transportation companies in New England had failed, have you found any evidence that these companies know what their services are costing them?

Dr. McKay: The smaller truck transportation companies, as a rule, do not keep cost records. The larger companies have excellent cost records. While I cannot answer your question on the basis of difference of cost of motor trucks and rail movement, I can say that one of the largest companies has an organization of about 45 trucks operating out of Boston. They informed us that their rates are about the same as rail rates to common points. They keep accurate cost records.

Dean Hughes: Is there anywhere in the country any evidence that motor-truck transportation is to be put under the same regulation as that which railroads have?

Dr. McKay: There are a number of states in which the regulation of intrastate motor transport companies' lines has been put under the Public Utilities Commissions of those states.

Chairman Johnson: Dr. Hatt reminds me that we should call attention to this report of Dr. McKay as one of the evidences of the scope of broadness of highway research in general. This report opens up practically a new field in highway research. Such studies of transportation closely touch on the development of our highway systems.

REPORT OF COMMITTEE NUMBER 7, ON MAINTENANCE

During 1923 the Maintenance Committee has made an investigation and study of seven different road-maintenance problems. In order to avoid duplication and to make responsibility more definite, each subject was assigned to an individual member of the committee, who acted as a subcommittee to study and report on that particular subject. This report has been made up from the reports of those subcommittees. The subjects and assignments were as follows:

1. Gravel Corrugations—H. K. Bishop, U. S. Bureau of Public Roads.
2. Dust Prevention and Surface Treatment of Gravel Roads, Including Sizes of Mulch Gravel—G. C. Dillman, Michigan Highway Commission.
3. Crack-fillers for Concrete Pavements—Thomas E. Stanton, California Highway Commission.
4. Snow Removal and Snow-removal Equipment—W. A. Van Duser, Pennsylvania Highway Commission.
5. Guide, Caution and Danger Signs—A. H. Hinkle, Indiana Highway Commission.
6. Maintenance Accounting—J. T. Donaghey, Wisconsin Highway Commission.
7. Maintenance Costs as Affected by the Life of the Road—W. A. McLean, Deputy Minister, Toronto, Canada.

1. *Gravel corrugations.*—Dr. George E. Ladd, Economic Geologist for the U. S. Bureau of Public Roads, has made further study of this phenomenon. Questionnaires were sent by him to all the Highway Departments in the United States; thirty-two states replied and their answers were summarized. The consensus of these replies was that corrugations form in all gravel roads when the traffic becomes excessive—probably 500 or 600 vehicles per day. The formation of corrugations is in no way dependent upon construction or maintenance methods. Corrugations are most apt to occur on flat grades. Two

general reasons were assigned for the formation of corrugations: First, acutal kick-back of material due to spin of drive wheels returning to the road surface after a bounce caused by an unevenness in the surface of the road. Second, displacement of material due to impact of the wheels, both front and rear, after the bounce. This displacement is accentuated in rainy weather by the splashing of water (carrying binder and fine material out of the corrugations).

In other words, any slight unevenness of the road which reacts on the springs of passing cars may cause a series of corrugations. When the unevenness is hit by a passing car, the springs are at first depressed; they then expand and virtually lift the weight of the car from the road. In some cases the wheels of the car actually leave the road surface; then the springs come back to normal and the weight of the car is impacted on the road surface. If the road is wet, a slight indentation is made; also, as the drive wheels are spinning, material is kicked back from the point of contact and a depression is thus started. After this depression has started it grows rapidly and other depressions are formed in a similar manner until we have a complete series. On flat grades during rains the depressions collect the water which is splashed out by passing vehicles, taking with it quantities of road binder and fine material.

The states were almost unanimously agreed as to the method of cure of corrugations—blading or dragging with heavy equipment soon after rains, while the gravel is still moist, supplemented by occasional scarifyings, seems to have produced the best results. It should be noted that this cure is not permanent, but lasts only until the next rain.

The committee does not believe that this subject should be continued as a major research problem. We feel that cause and remedy of corrugations is pretty definitely agreed upon. As it is generally conceded that corrugations form with little regard to construction or maintenance methods, it would seem, then, that their prevention is a matter of traffic restriction or regulation. We do not believe that this is feasible.

2. *Dust prevention and surface treatment of gravel roads including sizes of mulch gravel.*—Last year's maintenance report contained conclusions from the preliminary report of the joint research project of the University of Michigan and the Michigan State Highway Department. Their final report has now been published and distributed.

The Michigan Highway Department has continued this research work through the year, and they have surface-treated with refined tar approximately 45 miles of well-constructed gravel roads. These roads carry a traffic of from 800 to 1,500 vehicles a day.

The method which they have adopted this year is, briefly, as follows: The work is started early in the spring, when the frost is coming out of the ground. The road is first shaped up and the gravel allowed to consolidate. As soon as it is fairly well dried out, it is swept and an application of one-sixth of a gallon of refined tar per square yard is applied and allowed to penetrate into the surface. As soon as the surface takes on a brown appearance, approximately one-third of a gallon per square yard of the same cold material is applied and immediately given a top dressing of pea gravel or slag screenings. The Michigan Highway Department emphasizes the fact that the success of this kind of work depends largely upon the maintenance given the road, both before and after the treatment. Surface breaks are taken care of as fast as they occur. They are filled with a cold mixture of refined tar and coarse sand. These patches are struck off and smoothed with a flat-bottom shovel.

The Wisconsin Highway Commission has also treated a large mileage of gravel roads with refined tar, and they report satisfactory results. The Wisconsin method of treatment is similar to that used in Michigan. The road is first scarified and smoothed and allowed to compact. It is then swept and an application of cold tar applied from shoulder to shoulder, one-sixth of a gallon per square yard. The road is then opened to traffic for 24 hours and one-third of a gallon of cold tar per square yard applied and lightly sanded, using about 15 cubic yards of sand per mile for a 20-inch width. The travel is then allowed to use the road, and in a few days a second sand coat is applied, using about 35 cubic yards per mile for a 20-inch width.

For patching, a tar mastic is prepared and allowed to stand in piles along the side of the road. Seventeen gallons of cold tar per cubic yard of sand is used in preparing this mastic.

The Michigan Highway Department has experimented with calcium chloride and light oils for the purpose of dust prevention on their gravel roads. Their results with both have been satisfactory. They report the following points to be of great importance in calcium-chloride treatment: The chloride should be applied while there is still some moisture in the gravel and the application should be in the neighborhood of from one-half to one pound per square yard, giving a light treatment which will help avoid future trouble. The application should be uniform over the surface. The road should be left free from all lumps or piles of chloride. Ordinarily, three applications during the season is sufficient, but the second or third application should be applied before the former application of material is entirely gone. In other words, there should be a little overlap rather than a dust interval. Care should be exercised in varying the amount to be applied to the different roads or sections of roads, inas-

much as shaded portions as well as sand or clay gravel have much to do with the quantity of chloride that should be used.

Nearly every state is now maintaining most of its gravel road mileage with a mulch treatment of gravel. Various sizes and amounts are used. Little published data is available on this subject. The Michigan Department recommends the following: Replacement material should be limited to not exceeding one inch in size, preferably three-quarters inch, with around 60 to 75 per cent of the material being retained on one-eighth-inch mesh. The clay content should be held down to not over five per cent and the filler should be substantial material, which will help get away from the dust nuisance. The mulch should be applied in very light courses, not exceeding one inch in depth at any time, and should be applied preferably late in the season or during the spring months.

For future research work on this subject the committee would suggest a study of methods of maintaining tar-treated surfaces with special reference to the edges. A study should also be made to overcome as far as possible breaks that occur in the spring.

3. *Crack-fillers for concrete pavement.*—Nearly every state and numerous municipalities are experimenting more or less with various tars and asphaltic fillers for the repair of cracks in concrete pavements. A few years ago there seemed to be a demand for a light-colored filler which would harmonize with the color of concrete pavement and thus be less noticeable than the black tars or asphalts. A satisfactory light-colored filler at a reasonable price has not been developed. The committee is inclined to believe that public sentiment on this question is changing. As the mileage of concrete roads increases, the public becomes familiar with maintenance methods and does not look upon the black streaks with the horror that it did a few years ago. Furthermore, on heavily traveled pavements the oil and grease droppings from cars soon stain the pavement until the black crack-fillers are not conspicuous.

One of the most extensive tests of crack-fillers is being carried on by the Iowa Highway Commission on a concrete road immediately outside of the city of Des Moines. On this experiment three tars, nine asphalts and blown oils, one emulsified asphalt and one light-colored material were used. The experiment has just been started. One barrel of each material has been applied and is now being tried out in service. The Iowa Highway Commission will issue periodic reports on this test; the first one will be available next spring, after the road has gone through the winter.

The committee does not believe that further search for a light-colored filler is necessary. We do believe, however, that further research to determine the best specification for asphalt and tar fillers is desirable.

4. *Snow removal and snow removal equipment.*—The Bureau of Public Roads is now making a study of this subject in a number of states which are engaging in snow removal. When this investigation is completed a report will be prepared and probably made available for distribution. The committee believes that further research is necessary on this subject, particularly with the end in view of developing snow-removal equipment especially adapted to highway work.

5. *Guide, caution and danger signs.*—The rapid increase in recent years of intercounty, interstate, and even international traffic has brought a demand for standardization of guide, caution and danger signs. The idea of standardization of signs is that one can familiarize himself with the signs in his own locality, and can then proceed to travel in other parts of the state or in other parts of the United States with assurance that he need not learn a new set of signs in every county or state through which he may pass.

The most comprehensive study of this subject during 1923 was undertaken by a committee of the Mississippi Valley Association at their annual meeting in Chicago in January, 1923. Some of the outstanding features of the report are:

Highway signs are classified into three groups: (1) Route markers, including road numbers and the distinguishing symbols accompanying same; (2) Warning signs; (3) Guide and information signs.

A. Route markers. Every state should adopt a distinctive symbol for its route markers.

B. Warning signs. Should be uniform in all states and should not be used except where necessity is obvious.

- (1) Color. Warning and guide signs should be painted in black and white.
- (2) Location. Warning signs should be placed with the center 3 to 4 feet above the center of road elevation and 1 foot outside of the shoulder line. They should be placed from 300 to 500 feet in advance of the point of danger.
- (3) Shape and size. Warning signs should be 2 feet in diameter and the shape should indicate the nature of warning, as follows:

Round	Railroad crossings
Octagonal	Stop
Diamond	Slow
Square	Caution
Rectangular.	For guide and information signs

C. Guide and information signs should be rectangular. All advertising signs should be forbidden on the highway right of way.

The committee feels that the work of the Mississippi Valley Association is a step in the right direction. The next step is to make nation-wide rules, so that uniform signs may be had in all parts of the United States. We would recommend that some national organization, such as the American Association of State Highway Officials, make further study of this problem and standardize as far as possible all highway guide, caution and danger signs.

6. *Maintenance accounting.*—Last year your committee recommended that research work be undertaken to develop the most feasible uniform system of maintenance accounts, so that maintenance reports of various states might be put on a comparable basis. We are glad to report this year that both the Mississippi Valley and the American Associations of State Highway Officials have committees at work on this problem. The following report was adopted by the Mississippi Valley Association, and these states are attempting to make their accounting conform to the general classification.

“Expenditures by the states, through their maintenance organizations, shall be classified in their annual reports as follows:

1. Maintenance Administration.
2. Maintenance Proper.
3. Additions and Betterments.
4. Parks, Camping-grounds and Roadside Beautification.

“The last three classifications shall be charged to a specific section of road.

“Additions and betterments shall include expenditures for the increased permanent value of the road to accommodate traffic. This will include the cost of—

1. Increased width of surface or roadbed.
2. Increased depth of wearing surface over any previous maximum depth.
3. New guard rails.
4. New walls.
5. New drainage structures and watercourses.
6. New subdrains.
7. Improving grades, alignment and vision.”

Wisconsin has adopted the following classification:

1. Maintenance administration, covering general office overhead,

2. Maintenance supervision, covering district office overhead.
3. General maintenance, covering patrol and repair work. This cost is kept by patrol sections.
4. Reconstruction; covers replacement to restore to original condition. Cost kept by patrol sections.
5. Additions and betterments; covers expenditures which change the section of the road and produce increased capital investment.
6. Marking and signing; covers maintenance of all traffic guides on state system.

It will be noted that these classifications can be consolidated to conform to the four main divisions of the Mississippi Valley report.

When maintenance costs are kept in a uniform manner by the various states, it will be possible to make comparisons of such costs. This, however, is only the first step toward uniform maintenance reports. Maintenance reports, even though summarized from uniform records, are not of the greatest value as long as they are based on a per-mile cost. The next step is to reduce such costs to a ton-mile unit; then useful comparisons between states and between types can be undertaken. This, of course, involves traffic census data and is partly within the scope of another Advisory Board committee.

We would recommend continued efforts, in view of producing a standard basis of maintenance accounts for all state highway departments. We would then recommend that, for comparative purposes, maintenance costs on a representative number of roads in each state be reduced to cost per ton-mile of traffic on such roads.

7. *Maintenance costs as affected by the life of the road.*—Little matter is available on this subject. Constantly increasing traffic makes it almost impossible to determine accurately the effect of age on maintenance costs. We believe, however, that the subject is worthy of further consideration.

The Maintenance Committee has been handicapped in its work because funds have not been available for committee meetings. All of the work has been handled by correspondence, the committee never having held a meeting since its appointment. We believe that two committee meetings a year are necessary for satisfactory work. One committee meeting should be held soon after the annual meeting of the Advisory Board, for the purpose of outlining the year's work. The second committee meeting should be held just prior to the annual meeting of the Advisory Board, for the purpose of presenting and discussing subcommittee reports and formulating the annual report of the committee.

Mr. Root: I would like to say, in conclusion, that I concur in what Mr. MacDonald said last night. The biggest problem of a research organization is to lay out its program. I believe that if the maintenance committee can once lay out a definite program for the next year it will have gone a long way. Once the program is laid out, we shall have no trouble in securing cooperation of state highway departments. The American Association of State Highway Officials has a maintenance committee which has a subcommittee on cooperation in research. The purpose of this body is to cooperate with that committee on research problems.

Mr. H. G. Shirley, State Highway Engineer of Virginia: My observations have been that these corrugations in gravel and soil roads occur in dry weather more than in wet. In Mr. Root's report he referred to kicking back of water and mud which built up these corrugations. My experience has been that these corrugations occurred during unusually dry weather, when we were suffering from dust.

Mr. Upham: I think this report brought out some excellent ideas. I do not agree, however, that corrugations should not be continued as a research subject. As Mr. Shirley says, we have more corrugations in dry weather than in wet weather. One of the recommendations of the committee is as to scarifying the road. From a practical standpoint, a sand-clay or top-soil road will stand just so much scarifying and no more. From another point of view, scarification not followed by proper weather gives a result almost as bad after scarification as before. Just one other point in connection with these corrugations. The committee has recommended scarifying. If weather conditions are favorable, scarifying is satisfactory for the time being. In some cases we have lightly scarified the surface and added an unusually strong binding clay, and then rescarified and redisked it, and we have found by addition of the binding clay that we have increased the surface tension of that road and the corrugations do not develop so quickly after that. One cannot always get strong binding clays. During the dry spells the corrugations are quite often corrected by dry dragging.

Mr. Blair: Much complaint over the country is directed against the coarse material used in repairing corrugations. In leveling up the road, either by dragging or otherwise, what method have you used to reduce to a minimum the effect of coarse material in corrugations causing discomfort to travel and injury to tire?

Mr. Upham: If we could get a homogeneous surface we should not have trouble with corrugations, but in soil roads it is impossible to get homogeneous materials. The material varies with almost every

foot of road. We have to treat almost every section of the road differently.

We carried on a census in North Carolina in connection with the Bureau of Public Roads to determine, if possible, the limitations of the sand-clay and top-soil roads. We found that the figures were somewhere around 400 vehicles per day. This count included mostly passenger cars, a very small percentage of heavy trucks, a few light trucks and some horse-drawn vehicles. The particular road on which this investigation was made was an average sand-clay and top-soil road which satisfactorily withstood 400 vehicles. On another road, made of practically the same material, it was found that when the number of vehicles reached 500 or 600 the maintenance became somewhat high and the road corrugated badly. It seems that the limitation of sand-clay and top-soil road is somewhere around 400 vehicles per day. Of course, there are wide variations of that type of road, depending on the quality of the material in the road surface.

Mr. Mamly: I cannot see why the road should carry 400 cars per day satisfactorily and then go to pieces on 500 or 600 per day, unless there is some heating or fatigue effect.

Mr. Upham: After the corrugations once start, they develop rapidly. This may possibly be a factor if not the reason. When there is a small number of vehicles, the maintenance forces get out in time to catch corrugations in between the vehicles. When there is a large number of vehicles, there is not as intensive maintenance per vehicle. On tourist routes that pass through the state, we get as high as 800 to 1,000 vehicles per day. The particular road which is used mostly by these tourist passenger cars is corrugated very badly, and the east and west roads, made of practically the same material, that do not carry a traffic of more than half of these other roads, will be in very good shape and not corrugated and the maintenance remain quite low. These same north and south tourist lanes remain in good condition during almost the entire year, except when the tourist traffic is going north or south, and then these roads start corrugating. I do not know whether I can give you the reason why a larger number of vehicles would be harder, in proportion, on the road than the lower number of vehicles, unless it is due to the fact that they do not receive as much maintenance in relation to the number of vehicles.

Prof. Eno: Are the tourist cars heavier and driven at a more rapid rate of speed than the local cars, as a rule?

Mr. Upham: I believe not. In general, many of the touring cars are Fords. Local cars have little respect for speed laws.

Prof. Lay: We were getting ready to make some investigations on the action of the vehicle when traveling over some bumps and wanted to get a general idea of this; so we made a simple experiment with a Ford car, a rail and a pile of sand. We set the rail on a concrete road and sprinkled some sand on the road on the other side of it. We drove the Ford over this rail at various speeds. It had tires with a non-skid tread, so that we could observe any skidding or slipping of the wheels on the sand. At low speed, when the front wheels first struck the pavement they rolled along without any slipping, as we could observe the clear imprint of the non-skid tires. At higher speeds they bounded up and struck again several times. The rear wheels always wiped the sand off the spots which they struck the first time, and as we increased the speed the rear wheels jumped a little farther and perhaps would bound and strike again. When driving the car at much higher speeds the whole body was raised so high that while the springs did force the wheels and axle down, the wheels did not touch the road until at the end of the second "hop" of the rear wheels, when they struck with great force, clearing away the sand as before. This simple test throws considerable light on the corrugations formed on a dry gravel road. It shows that there can be a relation between the period of the springing system, the speed of the car and the distance between corrugations. It shows clearly how the driving wheels gain in speed while off the ground and abrade the road surface when they do come down on it.

Mr. Crandell: I should like to suggest that some one on the committee formulate a definition of gravel, because throughout the country no one seems to know just what gravel is. I have tried experiments of getting students to duplicate on a blackboard in actual size their idea of gravel. I had seventeen students at the board and got seventeen different kinds of gravel. One man thinks sand is gravel and another man thinks crushed rock or large pebbles is gravel. We should have a clear definition of what constitutes gravel.

Chairman Johnson: This was always an interesting subject for discussion. No one seems to get much further than the definition of the Massachusetts Highway Commission, that gravel is stone broken by nature.

Mr. Manly: On the matter of corrugations of gravel roads, Mr. Upham brought out the point that maintenance cost has been on a per-mile basis rather than per vehicle passing. Corrugations, therefore, have possibly formed on the basis of number of vehicles passing in any given time, but within the repair periods; so that if that is the whole answer, that is all right. On the other hand, if there is anything else in it, like the question of fatigue or the time element in

settling of the subsoil or the top-dressing, it seems that it would be rather important to determine it. It could be determined if two pieces of road as nearly alike as possible were maintained in direct comparison, the one on the present system and the other on the basis of the number of vehicles passing rather than on the mileage basis. It could be settled if this type of road is limited to so many vehicles per day, or if it were simply limited to so many vehicles per unit of maintenance expense.

Chairman Johnson: I understand the number of vehicles in each instance amounts to 400 or 500 per day.

Mr. Manly: But if it is 400 vehicles per day, and you maintain that road once a month or once in six months, it makes a difference. The question I brought up was: Are those corrugations due to passing a critical point in the expense of maintenance of that road per vehicle passing, or is there some element of the frequency of passing that is a criterion beyond which you cannot go without enormously adding to the expense?

Mr. Hubbard: It seems to me that it is not unreasonable to suppose that there is a limit to the number of vehicles that can pass over a gravel road. The suggestion has occurred to me that the resistance to displacement of surface of gravel road or top-soil road is more or less dependent upon the amount of moisture which the surface holds. During the day the moisture which is absorbed during the night gradually disappears if the weather is dry. The resistance has therefore become less as the day progresses. It is not unreasonable to suppose that if the number of vehicles is greater the punishment will be more severe and the formation of corrugations more rapid.

Mr. Bishop: I think that Mr. Upham and Mr. Shirley both disagree with conditions reported, and while I want to confess I am not an expert on this subject, I have studied with Dr. Ladd on gravel roads and I think that perhaps a part of the difference of opinion may be explained by the fact that Dr. Ladd's report covered the New England States and some of the Northwest States on gravel alone and did not extend to sand clay.

The statement made, that the corrugations occur when the number of vehicles reaches about 500 or 600, is merely a summation of statements made by state highway departments that they actually did occur between those limits. The question of maintenance, or the scarifying or dragging, is the summation of consensus of opinion of most of the state highway departments which reported on corrugations of gravel roads. His investigation did not cover the sand clay.

Mr. Older: I understand the committee recommends that main-

tenance costs be reported on the basis of ton mileage. I doubt very seriously the value of such a basis for reporting maintenance costs. For example: It might readily be conceived that a 4-inch or 5-inch concrete road might sustain 100,000 ton-miles or more of passenger car traffic without damage of any kind, and yet be practically destroyed by 1,000 or 2,000 ton-miles of freight traffic carried in units imposing wheel loads of four or five tons. To report maintenance costs on the basis of ton mileage would add enormously to the cost of keeping the records without necessarily adding to their value.

Prof. Agg: One of the things Mr. Root had in mind is suggested by the problems that are before Committee No. 1 in the determination of transportation costs. Certainly we ought to get some figure to represent transportation costs on highways, and there must be some way to correlate those costs with the volume of traffic on the highway, because we know maintenance costs increase with traffic. I would suggest that, whatever unit might be adopted, it is highly desirable that there be adopted some systematic way of reporting maintenance costs which will correlate those costs with the amount, and probably the type, of traffic that occasions those maintenance costs. Possibly a flat ton-mile is not the correct basis, but there should be some equivalent way of reporting costs. In attempting to get at the costs that have been reported, the committee has found a great deal of difficulty in interpreting the costs in such a way that those that are reported from some of the states—such, for instance, as New York State—can be compared with reports that come from Illinois, because of differences in practices in that respect. We do not use the same unit in reporting the traffic of the highway, neither do we use the same unit in reporting maintenance costs. I think that these committees should agree upon a system of units. Mr. Hamlin's committee and Mr. Root's committee might submit a unit for reporting traffic—they might work out an agreement as to a method of reporting traffic, a system of units that all would use—and likewise if the maintenance costs could be reported with some statement as to volume of traffic it would help.

Mr. Shirley: I believe that some such distribution has got to be made of highway traffic. We know that with the passenger vehicle it is the number rather than the weight, and with the freight vehicle it is the weight rather than the number.

STATEMENTS FROM REPRESENTATIVES OF CONSTITUENT ORGANIZATIONS

Mr. Prevost Hubbard, representing the American Society for Testing Materials: During the past year the American Society for Testing Materials has revised, or adopted as new, a total of forty methods of tests and specifications for highway materials, and has submitted six or more standard specifications and tests to the American Engineering Standards Committee for adoption as Tentative American Engineering Standards. Upon recommendation of Committee D-4, the Society has adopted four standard specifications for slag and stone block. It has revised three standard tests for bituminous materials and one standard specification for materials for cement mortar bed for brick and block pavements. It has revised two tentative methods for testing subgrade soils and bituminous materials, and eleven tentative specifications, one for non-bituminous, and ten for bituminous materials. In addition, it has adopted as tentative one new test for bituminous material, two new specifications for bituminous materials, and five new specifications for non-bituminous material. It is expected that at the next annual meeting of the Society a considerable number of new specifications and methods of test for highway materials will be presented, and that many existing tentative standards will be recommended for advancement to standard. It is believed that quite a number of the new tests will be of value to research workers on highway problems as a means of securing data which is necessary to the solution of such problems, even though the problems themselves are not principally concerned with materials of construction.

Mr. Ward P. Christie, Research Engineer of the Associated General Contractors of America: In undertaking the investigation of certain subjects concerned with highway development, the Associated General Contractors have proceeded on the following assumptions:

1. That problems of design and engineering will be successfully solved by the country's technical and professional minds.
2. That the development of local and state highway systems to meet the needs of agriculture, industry and pleasure will be developed by highway engineers in cooperation with representatives of these various interests and in spite of adverse political influence.
3. That it is the duty of construction companies to study the means of building these systems properly and economically.

With these assumptions in mind, therefore, the association has concentrated its investigations upon elements that affect the cost of

construction. Though these subjects may, at casual glance, appear remote from the problems of design and engineering, yet they are, in the last analysis, the controlling factors in determining whether the engineer shall be able to execute his conceptions and render his utmost service, and whether the public, which he is attempting to serve, will appreciate his efforts and receive a satisfactory mileage for its appropriation.

The field of research and investigation that may properly be assigned to construction companies is practically virgin in so far as recorded data and authentic information is concerned. Text-books and treatises have been written in great numbers, but they deal primarily with those factors that are more or less definite in character and fail to touch the less tangible problems involved in the inexact science of construction economics. It is to problems of this nature, concerned more directly with the business end of construction, but also to a great extent with the business of the designer, that the Associated General Contractors are devoting their efforts.

The principal subjects under investigation may be outlined as follows:

(1) Material supplies; (2) The field working force; (3) Construction methods; (4) Equipment development; (5) Seasonal suspension of work; (6) Preventable hazards in the industry; (7) Comparative statistical tabulations.

The following is an outline of the work which the Associated General Contractors are carrying on in their individual field:

1. *Material supplies.*—Data is being compiled from government and industrial sources to show the quantities of the principal construction materials necessary to serve the industry, so that engineers and construction companies in laying their programs may have information on production that will assist them in fitting their demand to the production capacity.

2. *Field working force.*—Efforts are being made to induce young men to join the ranks of construction labor and to train them in the use of specialized machines that are rapidly increasing in highway construction. Incident to this work is the tabulation of estimated shortages and the study of wages and cost of living.

3. *Methods.*—A study of methods is being carried on by individual companies, as the Associated General Contractors as an organization has not yet obtained the funds sufficient to carry on this work. Reports of progress and new methods are furnished, however, by individual companies to the association and to the trade magazines.

4. *Equipment development.*—In cooperation with manufacturers

of construction equipment, the improvement and development of machines is being handled through the Joint Committee on Construction Equipment, which has, to date, practically completed work in two lines, namely, wheelbarrows and concrete mixers. These items of plant have been standardized within the past year and a time limit of January 1, 1925, has been set for the elimination of non-standard types. The wheelbarrow standards have already been put into effect.

5. *Seasonal suspension of work.*—The saving of construction costs that may be produced by continuous operation in the construction industry has never been estimated, but the tendency of this continuity is well known. The Associated General Contractors for the past two years has devoted considerable effort and money in seeking to interest other elements of the industry in this question. Its policy has been that, rather than wait for quantitative estimates and exact data, it could more profitably urge adoption of the policy knowing that the energy extended would result in great economy. With this question is closely linked the problem of winter construction methods, in which the cooperation of the engineering profession in experimental work is urgently needed. How far the seasonal depression can be eliminated in the highway field is uncertain, but the consensus of opinion is that, where it can be brought about, the efforts will effect considerable saving.

6. *Removable hazards of the industry.*—As one of the important elements of cost in the construction project is the assumption of certain hazards incident to the business world and to natural causes, an effort is being made to induce the owners of public construction to assume those hazards which such owners can most economically assume rather than incorporate them into the cost of construction. Many of these hazards, occurring but once in the lifetime of a construction company, are sufficient to throw it into bankruptcy, and it must obviously protect itself by insurance or contingency charges. The infrequency of such event makes it considerably more economical for the owner to accept such hazards. Work on this subject is being continued in contingent cooperation of the American Association of State Highway Officials and various architectural and engineering organizations. The report upon the subject was issued last December by the joint committees of the first-named organization and the Associated General Contractors.

7. *Comparative statistical relations.*—In order that construction companies and others interested may keep track of the trend of various factors influencing the industry, graphical analyses comparing these factors are being carried in the magazine of the Associated

General Contractors. Among the statistical compilations carried from month to month are the construction cost index, the construction volume index, based on the quantity of material shipped, index numbers of wages, cost of living and material prices, contracts awarded, volume of transportation and other data of a similar nature.

Statistics pertaining to the construction industry have been meager in past years, but new tabulations are being started, and within the course of a few years sufficient data will be available to intelligently interpret the trend of economic factors within the industry.

The Associated General Contractors, in common with other national organizations, is restricted in its research work by lack of personnel, but the anticipation is that work of this nature will be expanded materially within the next two or three years.

One of the most important subjects upon which the construction companies of the country would like to see a definite determination made by the engineering profession is the question of hardness of aggregates and their suitability as road materials. At present, aggregates of different French coefficient are specified in particular states, apparently for highways of the same general type. Conclusive information upon this subject will doubtless make possible the utilization of many local sources of materials and result in a decrease of unit costs.

Mr. A. D. Flinn, representing the Engineering Foundation, gave assurance of the friendly support of the Engineering Foundation.

Prof. C. J. Tilden, speaking for Mr. William P. Eno, of the Eno Foundation, expressed the continued interest and cooperation of the Eno Foundation in the work of the Advisory Board on Highway Research.

Mr. Pyke Johnson, of the National Automobile Chamber of Commerce: The most interesting bit of research undertaken by the National Automobile Chamber of Commerce in recent months is an analysis of the financial aspects of the highway program in its relation to the total tax bill of the nation, by John E. Walker, former tax adviser to the United States Treasury.

Mr. Walker first determined the total national, state and county taxes, then found what percentage of these were devoted to highway work, where the funds so expended were obtained, and to what uses they were put.

As just one outstanding fact of interest, his study shows that while \$1,000,000,000 in round figures were expended for highways in 1921, and while the total taxes collected in that year were \$9,000,000,000, the actual effect on the general taxpayer was a contribution

of less than six cents of each tax dollar for highway purposes due to the many special taxes levied for highway work.

The study has only recently been completed, but will be ready for distribution within the next month.

Another survey of general interest, now nearing completion, is that of the Chamber of Commerce of the United States, which has had committees working for nearly a year on the broad question of transportation. One of these, headed by Alfred H. Swayne, Vice-President of General Motors, and including in its membership agricultural, electric and steam railway, waterway, motor and public representatives, has been engaged in studying the relation of highways and highway transport to other transportation agencies. Another committee, including A. J. Brosseau, of Mack Trucks, Inc., and Roy D. Chapin, President of the Hudson Motor Car Company, has been going into the problem of transportation taxation.

Waterways, railroad consolidations, governmental relations and the freight rate structure are other problems under review. These reports will be issued this month.

Mr. H. W. Alden, representing the Society of Automotive Engineers: The Society is continuing its work on a number of different projects. Some of these are investigations by the Bureau of Standards. Tests are to be undertaken in cooperation with the Bureau of Public Roads and the Rubber Association. This work covers impact tests, automobile brake tests and headlight specifications.

Dean Anson Marston, representing the Association of Land Grant Colleges: The members of the Association of Land Grant Colleges are the land-grant colleges of the United States, including Alaska, Hawaii, and Porto Rico. These colleges were organized in accordance with the Morrill Land Grant Act of 1862, amended by later legislation. Each of these institutions has some endowment provided by the United States Government, and in addition to the income from these endowments, the institutions also receive considerable annual sums from the central government, provided by Congress through continuing appropriations. The United States Government retains some general authority over all of these land-grant colleges, and in a general way it may be stated that they constitute the only educational institutions in the United States having any such official national relation.

In addition to the funds received from the national government, each of these institutions has state support, and in most of the institutions the state funds are several times those provided by the national government; hence each land-grant college has actual official relation to the nation and to its state. They are unique in this respect.

The United States Government appropriates very large sums of money annually to the land-grant colleges for the support of agricultural research, but as yet makes no corresponding appropriation for the support of engineering research. However, the land-grant colleges, by legislative action on the part of some states and without such action in others, have proceeded to organize engineering experiment stations in twenty-four different states. In addition, engineering research is carried on actively in many of the land-grant colleges which do not have formally organized experiment stations.

The Association of Land Grant Colleges is promoting the organization of such stations and maintains a Standing Committee on Engineering Experiment Stations. Through this committee the Association publishes quarterly the "Engineering Experiment Station Record" (in mimeographed form), which is sent to all of the land-grant colleges. Through the "Engineering Experiment Station Record" the engineering experiment stations and other engineering research organizations of the land-grant colleges in the several states are kept informed definitely of all engineering researches in progress in such institutions throughout the United States. The several institutions thus can cooperate in research and can avoid undesirable duplication. The cooperation secured to date has been of most satisfactory character.

In general, each college organizes its researches on the project basis, with definite assignment of research staff and of funds to each project. Some of these projects continue for several years, in which case progress reports are required from time to time. Eventually each project normally results in the publication of one or more bulletins.

From the forthcoming annual report of the Engineering Experiment Station Committee (which for such report collects definite statistics from every state at about this time each year), it appears that the land-grant colleges of the continental United States expended about \$589,580 in engineering research in the year 1923; that in that year their engineering research staffs included about 95 members full time, about 88 members part time paid, and more than 241 members part time with no extra pay; also, it appears that up to December 31, 1923, the colleges will have published in excess of 469 engineering research bulletins, of which approximately 53 are for the year 1923.

The magnitude of the engineering research work carried on by the land-grant colleges may be understood better by comparing it with that promoted by the Engineering Foundation. The land-grant colleges spend more annually for engineering research than the entire

endowment of Engineering Foundation. Undoubtedly the land-grant colleges together constitute the largest organized engineering research agency in the country.

The land-grant colleges are especially interested in highway research, and are especially qualified to conduct such research, and they are especially desirous of joining in a nation-wide program of highway research.

- a. They are the only nationally endowed educational and research institutions in the several states.
- b. Each of them is also a state institution, and for that reason is especially well qualified to cooperate with the state highway commission.

For these reasons the Association of Land Grant Colleges made application in 1922 for admission to the Advisory Board on Highway Research, which application was granted immediately.

The youngest member of the Advisory Board on Highway Research submits this report with its very best good wishes for the Board.

Prof. A. H. Blanchard, representing the National Highway Traffic Association, sent in the following written report:

In the 1922 Report to the Advisory Board on Highway Research, the titles of about thirty-five national committees devoted to research problems were included. Although all of these committees are actively engaged in research work, in order to avoid repetition, in this report only the following titles of those committees which will report at meetings during the current year of 1923-1924 will be mentioned.

“License Fees and Motor Vehicle Taxation.”

“Regulations Covering Speeds, Weights and Dimensions of Trailers.”

“Equitable Distribution of Cost of Construction, Interest on Bonds, Replacements and Maintenance of State Highways.”

“Development of Transportation.”

“Interrelationship and Coordination of Railway, Waterway, Airway and Highway Transportation.”

“Traffic Capacity and Widths of Highways Outside of Municipalities.”

“Widths of Roadways and Sidewalks in Municipalities.”

“Highway Transport Franchises.”

“Highway Transport Clearing Houses.”

“Uniform Highway Signs.”

“Traffic Center Lines on Roadways.”

“Safety Regulations at Railroad Grade Crossings.”

“Mechanical Devices for Highway Traffic Regulation.”

“Relative Efficiency of Different Types of Car-stop Safety Zones and Their Relation to Parking and Ranking Regulations.”

“Segregated and One-way Streets in Municipalities.”

The national committees listed in this report, as well as our other committees, are composed of from three to fifteen specialists.

Our reports are mimeographed or multigraphed and are available for distribution to those who are particularly interested, and hence are available for review and reference by any committee of the Advisory Board on Highway Research.

ELECTION OF OFFICERS

Report of Committee on Nominations:

The following nominations for officers of the Advisory Board were reported by the Committee Chairman, Mr. A. T. Goldbeck:

Chairman, Dean A. N. Johnson (renominatee).

Vice-Chairman, Mr. A. D. Flinn (renominatee).

Executive Committee:

Mr. Thos. H. MacDonald (renominatee).

Prof. T. R. Agg (renominatee).

Dr. H. C. Dickinson.

Mr. C. M. Upham.

Mr. A. J. Brosseau.

The report of the committee was accepted and the Director cast the ballot of the Board for the nominees.

Chairman Johnson: A meeting of the Executive Committee is called immediately following adjournment.

Adjourned at 10 p. m.

Publications of the National Research Council

Bulletin Series

Volume 1

- Number 1.** The national importance of scientific and industrial research. By George Ellery Hale and others. October, 1919. Pages 43. Price \$0.50.
- Number 2.** Research laboratories in industrial establishments of the United States of America. Compiled by Alfred D. Flinn. March, 1920. Pages 85. Price \$1.00. [Out of print. See Number 16.]
- Number 3.** Periodical bibliographies and abstracts for the scientific and technological journals of the world. Compiled by Ruth Cobb. June, 1920. Pages 24. Price \$0.40.
- Number 4.** North American forest research. Compiled by the Committee on American Forest Research, Society of American Foresters. August, 1920. Pages 146. Price \$2.00.
- Number 5.** The quantum theory. By Edwin Plimpton Adams. October, 1920. Pages 81. Price \$1.00. [Out of print. See Number 39.]
- Number 6.** Data relating to X-ray spectra. By William Duane. November, 1920. Pages 26. Price \$0.50.
- Number 7.** Intensity of emission of X-rays and their reflection from crystals. By Bergen Davis. Problems of X-ray emission. By David L. Webster. December, 1920. Pages 47. Price \$0.60.
- Number 8.** Intellectual and educational status of the medical profession as represented in the United States Army. By Margaret V. Cobb and Robert M. Yerkes. February, 1921. Pages 76. Price \$1.00.

Volume 2

- Number 9.** Funds available in 1920 in the United States of America for the encouragement of scientific research. Compiled by Callie Hull. March, 1921. Pages 81. Price \$1.00.
- Number 10.** Report on photo-electricity including ionizing and radiating potentials and related effects. By Arthur Llewelyn Hughes. April, 1921. Pages 87. Price \$1.00.
- Number 11.** The scale of the universe. Part I by Harlow Shapley. Part II by Heber D. Curtis. May, 1921. Pages 47. Price \$0.60.
- Number 12.** Cooperative experiments upon the protein requirements for the growth of cattle. First report of the Subcommittee on Protein Metabolism in Animal Feeding. By Henry Prentiss Armsby, Chairman. June, 1921. Pages 70. Price \$1.00.
- Number 13.** The research activities of departments of the State government of California in relation to the movement for reorganization. By James R. Douglas. June, 1921. Pages 46. Price \$0.60.
- Number 14.** A general survey of the present status of the atomic structure problem. Report of the Committee on Atomic Structure of the National Research Council. By David L. Webster and Leigh Page. July, 1921. Pages 61. Price \$0.75.
- Number 15.** A list of seismologic stations of the world. Compiled by Harry O. Wood. July, 1921. Pages 142. Price \$2.00.

Volume 3

- Number 16.** Research laboratories in industrial establishments of the United States, including consulting research laboratories. Originally compiled by Alfred D. Flinn; revised and enlarged by Ruth Cobb. December, 1921. Pages 135. Price \$2.00.

- Number 17.** Scientific papers presented before the American Geophysical Union at its second annual meeting. March, 1922. Pages 108. Price \$1.50.
- Number 18.** Theories of magnetism. By members of the Committee on Theories of Magnetism of the National Research Council. A. P. Wills, S. J. Barnett, L. R. Ingersoll, J. Kunz, S. L. Quimby, E. M. Terry, S. R. Williams. August, 1922. Pages 261. Price \$3.00.

Volume 4

- Number 19.** Celestial mechanics. Report of the Committee on Celestial Mechanics of the National Research Council. E. W. Brown, G. D. Birkoff, A. O. Leuschner, H. N. Russell. September, 1922. Pages 22. Price \$0.40.
- Number 20.** Secondary radiations produced by X-rays, and some of their applications to physical problems. Arthur H. Compton. October, 1922. Pages 56. Price \$1.00.
- Number 21.** Highway research in the United States. Results of census by Advisory Board on Highway Research, Division of Engineering, National Research Council, in cooperation with the Bureau of Public Roads, United States Department of Agriculture. William Kendrick Hatt. October, 1922. Pages 102. Price \$1.50.
- Number 22.** Mechanical aids for the classification of American investigators, with illustrations in the field of psychology. Harold C. Bingham. November, 1922. Pages 50. Price \$0.75.
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