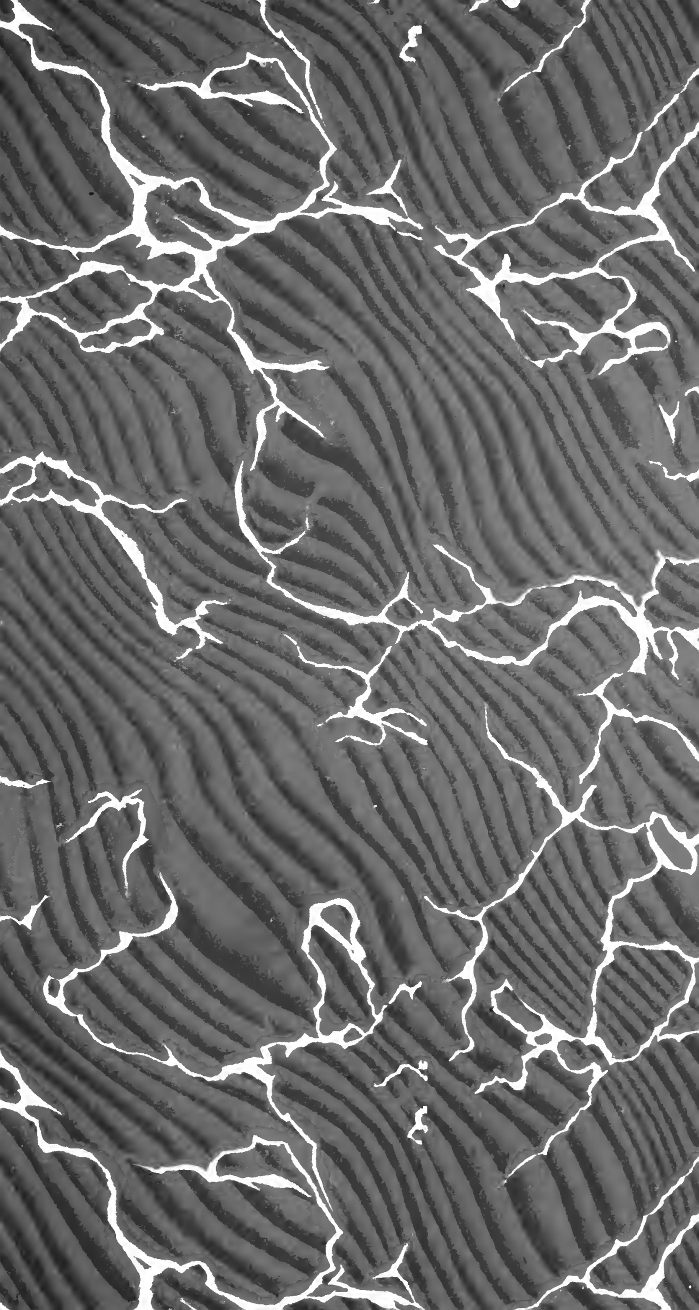

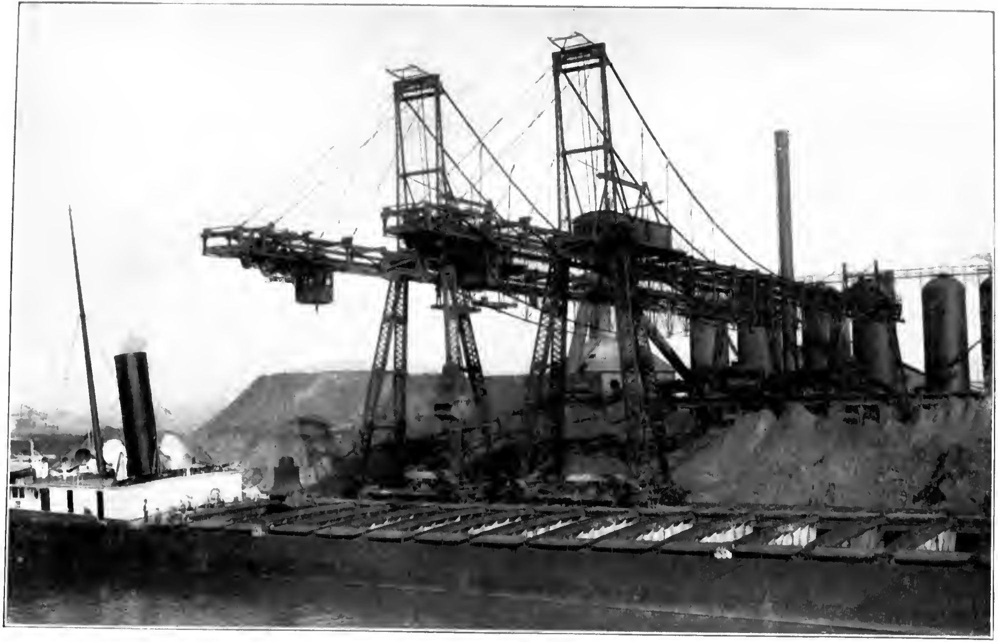

HANDLING IRON ORE BY MODERN HOISTING AND CONVEYING MACHINERY
Unloading one of the fleet of ore steamers at South Chicago steel mills.
Courtesy of Brown Hoisting Machinery Company, Cleveland, Ohio

Cyclopedia
of
Civil Engineering

A General Reference Work on

SURVEYING, HIGHWAY CONSTRUCTION, RAILROAD ENGINEERING, EARTHWORK,
STEEL CONSTRUCTION, SPECIFICATIONS, CONTRACTS, BRIDGE ENGINEERING,
MASONRY AND REINFORCED CONCRETE, MUNICIPAL ENGINEERING,
HYDRAULIC ENGINEERING, RIVER AND HARBOR IMPROVEMENT,
IRRIGATION ENGINEERING, COST ANALYSIS, ETC.

Prepared by a Corps of

CIVIL AND CONSULTING ENGINEERS AND TECHNICAL EXPERTS OF THE
HIGHEST PROFESSIONAL STANDING

Illustrated with over Two Thousand Engravings

NINE VOLUMES

CHICAGO
AMERICAN TECHNICAL SOCIETY
1916

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost Civil, Structural, Railroad, Hydraulic, and Sanitary Engineers and Manufacturers in making these volumes thoroughly representative of the very best and latest practice in every branch of the broad field of Civil Engineering.

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STEEL WORK USED AS ARCH FORM IN BUILDING TUNKHANNOCK CREEK VIADUCT ON THE LACKAWANNA RAILROAD
Courtesy of Engineering Department, Delaware, Lackawanna and Western Railroad

Foreword

OF all the works of man in the various branches of engineering, none are so wonderful, so majestic, so awe-inspiring as the works of the Civil Engineer. It is the Civil Engineer who throws a great bridge across the yawning chasm which seemingly forms an impassable obstacle to further progress. He designs and builds the skeletons of steel to dizzy heights, for the architect to cover and adorn. He burrows through a great mountain and reaches the other side within a fraction of an inch of the spot located by the original survey. He scales mountain peaks, or traverses dry river beds, surveying and plotting hitherto unknown, or at least unsurveyed, regions. He builds our Panama Canals, our Arrow Rock and Roosevelt Dams, our water-works, filtration plants, and practically all of our great public works.

¶ The importance of all of these immense engineering projects and the need for a clear, non-technical presentation of the theoretical and practical developments of the broad field of Civil Engineering has led the publishers to compile this great reference work. It has been their aim to fulfill the demands of the trained engineer for authoritative material which will solve the problems in his own and allied lines in Civil Engineering, as well as to satisfy the desires of the self-taught practical man who attempts to keep up with modern engineering developments.

¶ Books on the several divisions of Civil Engineering are many and valuable, but their information is too voluminous to be of the greatest value for ready reference. The Cyclopedia of Civil Engineering offers more condensed and less technical treatments of these same subjects from which all unnecessary duplication has been eliminated; when compiled into nine handy volumes, with comprehensive indexes to facilitate the looking up of various topics, they represent a library admirably adapted to the requirements of either the technical or the practical reader.

¶ The Cyclopedia of Civil Engineering has for years occupied an enviable place in the field of technical literature as a standard reference work and the publishers have spared no expense to make this latest edition even more comprehensive and instructive.

¶ In conclusion, grateful acknowledgment is due to the staff of authors and collaborators—engineers of wide practical experience, and teachers of well recognized ability — without whose hearty co-operation this work would have been impossible.

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* For page numbers, see foot of pages.

† For professional standing of author, see list of Authors and Collaborators at front of volume.

STEEL WORK IN THE MUNICIPAL BUILDING, NEW YORK CITY
View of roof of one of the wings taken twenty-four stories up.

ESTIMATING

ESTIMATING STRUCTURAL STEEL FOR BUILDINGS

The estimating of structural steel naturally divides into two parts, viz, computing the weights; and applying the unit prices to the weights. Each of these parts is subdivided into a number of items as discussed later.

Units. The weights of steel are expressed in pounds and the prices in cents-per-pound, or, for convenience, larger units may be used for the final results, as dollars-per-ton.

The ton here used is the short ton of 2000 pounds. As steel rails and some other steel products are sold by the long ton of 2240 pounds, it is desirable in contracts and other formal papers to state definitely that the unit of weight is the ton of 2000 pounds. The same ambiguity exists in reference to the term hundredweight (cwt.), which may mean 100 pounds ($\frac{1}{20}$ of a short ton, American) or 112 pounds ($\frac{1}{20}$ of a long ton, British). The term, one hundred pounds, is preferred as being more definite. There is not likely to be any confusion as to the meaning of these terms within the United States, but for export or import transactions the matter is important.

The unit weights of steel and the corresponding ones of cast iron are shown in Table I.

Degree of Accuracy. The accuracy of an estimate varies with the data on which it is based and the purpose for which it is used.

The data may consist only of the general dimensions, type of construction, and loading of the building, yet from these items an estimate can be made which will be correct within 10 per cent—sufficiently accurate for preliminary use. At the other extreme, the data may consist of shop detail drawings or completely detailed plans, and the estimate be exact so far as computations are concerned; subject, however, to the allowed variation of the rolled section from its theoretical weight, and to the judgment of the estimator as to unit prices.

TABLE I

Unit Weights of Steel and of Cast Iron

Units	Weights	
	Steel (lb.)	Cast Iron (lb.)
Cube, 12″×12″×12″	490.0	450. 0
Plate, 12″× 1″×12″	40.8	37.5
Bar, 1″× 1″×12″	3.4	3.125
Cube, 1″× 1″× 1″	0.283	0.261

The data usually available consists of design drawings which show the sections of all members but which are not complete as to connections and other details. From such data the weight can be computed with a difference of less than 1 per cent from scale weights of the finished material.

The fabricator's estimate of the cost of the finished material should be satisfactory to him if it is within 2 per cent of the actual cost:

Variation from Theoretical Weight. Specifications for structural steel recognize and limit the variations in weight from the computed weight due to slight inaccuracies in rolling the material. The Standard Specifications for Structural Steel for Buildings, of the American Society for Testing Materials, contain the following:

> PERMISSIBLE VARIATIONS. The cross section or weight of each piece of steel shall not vary more than 2.5 per cent from that specified; except in cases of sheared plates, which shall be covered by the following permissible variations to apply to single plates:
>
> (a) WHEN ORDERED TO WEIGHT:
>
> For plates 12½ pounds per square foot or over:
> Under 100 inches in width, 2.5 per cent above or below the specified weight;
> 100 inches in width or over, 5 per cent above or below the specified weight.
> For plates under 12½ pounds per square foot:
> Under 75 inches in width, 2.5 per cent above or below the specified weight;
> 75 to 100 inches in width, 5 per cent above or 3 per cent below the specified weight;
> 100 inches in width or over, 100 per cent above or 3 per cent below the specified weight.
>
> (b) WHEN ORDERED TO GAGE:
>
> The thickness of each plate shall not vary more than 0.01 inch under that ordered.
>
> An excess over the nominal weight corresponding to the dimensions on the order shall be allowed for each plate, if not more than that shown in Table II; 1 cubic inch of rolled steel being assumed to weigh 0.283 pound.

TABLE II

Plate Variations

Thickness Ordered (in.)	Nominal Weight (lb. per sq. ft.)	Allowable Excess (Expressed as Percentage of Nominal Weight, for Plate Widths Indicated)						
		Under 50 Inches (per cent)	50 Inches to 70 Inches (per cent)	70 Inches or Over (per cent)	Under 75 Inches (per cent)	75 Inches to 100 Inches (per cent)	100 Inches to 115 Inches (per cent)	115 Inches or Over (per cent)
$\frac{1}{8}$ to $\frac{5}{32}$	5.10 to 6.37	10	15	20				
$\frac{5}{32}$ to $\frac{3}{16}$	6.37 to 7.65	8.5	12.5	17				
$\frac{3}{16}$ to $\frac{1}{4}$	7.65 to 10.20	7	10	15				
$\frac{1}{4}$	10.20				10	14	18	
$\frac{5}{16}$	12.75				8	12	16	
$\frac{3}{8}$	15.30				7	10	13	17
$\frac{7}{16}$	17.85				6	8	10	13
$\frac{1}{2}$	20.40				5	7	9	12
$\frac{9}{16}$	22.95				4.5	6.5	8.5	11
$\frac{5}{8}$	25.50				4	6	8	10
Over $\frac{5}{8}$					3.5	5	6.5	9

The variations stipulated apply to the individual prices of steel. Some will overrun, others underrun; very few pieces will have the maximum variations. Hence it may be expected that the actual total weight of a large number of pieces will not vary much from the computed weight. This is confirmed by experience so that no allowance for the variation is made. However, the foregoing may not be true if there is a large percentage of plates, for plates are more likely to overrun than to underrun, particularly if ordered to gage or thickness. In such case an allowance for overrun may be proper. Its amount must be determined from the conditions.

Cast iron varies from the computed weight even more than steel, due to inaccuracy of patterns, shrinkage in cooling, and other causes. It is more likely to overrun than underrun and it is proper to add a percentage. Three per cent is a reasonable average allowance, although individual items may vary much more than this.

Basis of Estimates. Estimates are commonly based on the net weight of the finished structural steel, but in special cases it may be necessary to compute the gross weight of the material used in producing the fabricated steel. The difference in weight is represented by the punchings, cut corners, and other waste. The

Penthouse—Floor Framing.

Drawing S10a, dated 11-28-14.

"State-and-Adams" Building

Estimate made by N.O H.; checked by H.N.R.
Extensions made by N.O.H.; checked by H.N.R.
Estimate No. C1080.
Date 1-22-15. Page 18, of 48.

No.	Section		Weight (lb.)	Length (ft.)	Class	(b)	(d)	(r)	Fittings	Column Details	Extra-Priced Material			Totals
											Large Beams	Carnegie Light Beams	Bethlehem Girders	
	E. & W.													
1	B. G.*	24″	120	22.2	d		2,664						2,664	2,664
1	I**	24	95	17.2	d		1,634				1,634			1,634
1	I	24	105	20.5	d		2,153				2,153			2,153
1	I	24	105	22.2	d		2,331				2,331			2,331
1	I C.***	12	27.5	7.9	d		217					217		217
1	I C.	10	22	9.2	d		202					202		202
1	I C.	8	18	4.8	d		86							86
2	I C.	8	18	5.6	d		202							202
1	I C.	24	80	18.6	b	1,488					1,488			1,488
1	I C.	24	115	18.6	b	2,139					2,139			2,139
1	I C.	24	115	19.3	b	2,220					2,220			2,220
12														
	N. & S.													
1	I	24″	80	18.4	r			1,472			1,472			1,472
2	Pl.	10″x½″	17	16.0	r			544						544
2	I C.	12	27.5	11.8	d		649					649		649
2	I C.	10	22	8.0	d		352					352		352
1	I	24	105	18.5	d		1,942				1,942			1,942
1	I	20	65	19.8	d		1,287				1,287			1,287
1	I	15	42	18.4	b	773								773
3	I	15	42	19.8	d		2,495							2,495
1	I	8	18	6.8	d		122							122
1	I	8	18	4.5	d		81							81
1	I C.	24	69.5	18.4	b		1,279				1,279			1,279
16														
10	Std. beam conns.	8″ @	15		f				150		17,945	1,420	2,664	150
6	Std. beam conns.	10″ @	15		f				90					90
6	Std. beam conns.	12″ @	22		f				264					264
6	Std. beam conns.	15″ @	29		f				174					174
2	Std. beam conns.	20″ @	34		f				68					68
3	Std. beam conns.	24″ @	41		f				123					123
2	Beam conns. to cols.	15″ @	38		Col.					76				76
17	Beam conns. to cols.	24″ @	72		Col.					1,224				1,224
140	Rivets (r)		0.33					46						46
	Totals					6,620	17,696	2,062	869	1,300		Page	Total	28,547 lb.

Fig. 1. Form for Listing Material—List of Material for Floor Framing. *Bethlehem Girder; **Standard I-Beam; ***Carnegie Special I-Beam

net weight is the amount delivered by the fabricator to the purchaser; the gross weight is the amount purchased by the fabricator from the rolling mill.

The price which is paid by the purchaser to the fabricator is based on the material to be furnished and its place of delivery, and may include painting and erection. The basis must be stated definitely in all transactions. The price may be a lump sum or a price per ton.

ESTIMATING WEIGHTS

The operations involved in estimating weights consist of listing the items and of computing the weights therefrom.

The listing is usually done on forms printed for that purpose. In preparing such forms and in using them, due attention is given to the orderly arrangement of items and to the classification required for computing costs.

Forms. Fig. 1 is a form for listing and computing the detailed weights and Fig. 11 is a form used as a summary. On the latter are spaces for the general data relating to the job. These need not be repeated on the detail sheets, but each detail sheet must contain enough data in the headings to identify it and facilitate checking. Usually the name of the structure, the portion on the sheet, and the drawing number from which it is taken are sufficient. The initials of the estimator, the computer, and the checker are desirable, also the date when take-off was made. Page numbers are essential. In recording the drawing number note also the date of the drawing and the date of latest revision.

Classification. As the classification varies with different jobs it is not practicable to have the headings printed on the forms. They must be filled in as the estimate develops. As each item is listed its classification is noted in the column provided for that purpose.

Generally, the material is divided into beam work and riveted work. These may be divided into a number of classes as follows:

Beam Work. (a) Punching one size of hole in web only, or one size of hole in one or both flanges; (b) punching one size of hole in web and in one or both flanges; (c) punching two sizes of holes in web only or two sizes of holes in one or both flanges; (d) coping, ordinary beveling, riveting, or bolting connection angles, and assembling into girders with separators, including any additional punching; (r) riveting on cover plates and shelf angles; and (f) fittings, including all rivets, bolts, separators, bearing plates, anchors, and connection angles, except such as are attached to beams (r). Connection material which will be attached to columns or girders is classified as column material or girder material, respectively, although as a matter of convenience it is listed at the time the beams are taken off.

Riveted Work. Columns; plate girders without cover plates; plate girders with cover plates; lattice girders; and trusses.

The classes may be still further subdivided if required, and in addition there may be items such as cast-iron base plates, cast-iron columns, tie-rods, curved beams, etc.

In addition to the classification as to work there may be a classification as to cost of the plain material. This is discussed under Estimating Costs.

Listing Material. Listing material, or "take-off", consists of making a list on the estimate sheets of all the items of steel called for on the plans. They may be written in the form given in Fig. 1. The first column contains the number of pieces, the second the section, the third the weight per lineal foot, the fourth the length, and the fifth the classification. If the weight per lineal foot is not given on the drawings, it can be taken from the hand books. This will be required for most sections other than beams and channels. The arrangement of items given above is arbitrary and may be varied by different estimators or for different parts of the work. The material listed in Fig. 1 is taken from Fig. 2.

Usually the framing plans of a building show only the material for the main numbers. The connections are left to the detailer to develop with more or less control by provisions in the specifications. For the connections of beams to beams, standard connections are commonly used; for connections of beams to columns and in general all other connections it is required that the full strength of the member shall be developed. The estimator must supply all such details, including rivets, bolts, fillers, etc. In some cases it may be necessary for him to sketch out the details in order to determine the material required for them.

The lengths may be recorded in feet and inches, or in feet using decimals. The latter is more convenient if the computations are made by machine. The nearest inch or the nearest tenth of a foot is sufficiently accurate for most purposes. A large number of small pieces of one length may make it desirable to record the lengths more accurately.

The lengths of individual pieces are not given on the drawings but must be computed as nearly as practicable from the dimensions given. The dimensions usually given are the distances from center to center of columns, the distances from column centers to beams and the story heights. In listing lengths the estimator must allow for widths of columns, thickness of girder webs, clearance at ends of beams, position of column splices, and any other elements affecting the actual length of material required. Beams require about ¼-inch clearance at each end. Tie-rods are about 4 inches longer than the distance from center to center of beams.

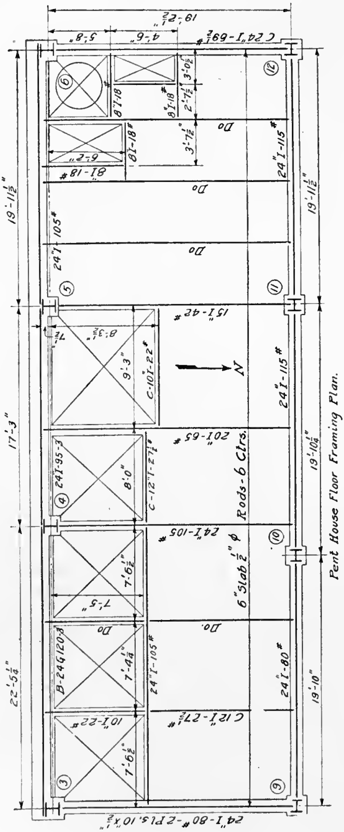


Fig. 2. Penthouse Floor Framing Plan

The estimator should establish and adhere to a definite order of procedure in taking off the quantities. A preliminary review of all the drawings will indicate the following: order in which they should be taken off, usually beginning with No. 1 and continuing in sequence; what drawings must be used together, as when the spandrel sections are shown on a certain drawing and their con-

"State-and-Adams" Building

Columns 1, 2, 3, 4 (SB.—4th).
Drawing S9, dated 11-28-14.

Estimate made by N.O.H.; checked by H.N.R.
Extensions made by N.O.H.; checked by H.N.R.
Estimate No. C1080.
Date 1-22-15. Page 25, of 48.

	No.	Section	Weight (lb. per lin. ft.)	Length (ft.)	Weight	Totals	Large Angles
		SB. to 1st					
	2	Pl. 14x ½	23.8	29.3			
(Col. 1)	4	Ls 8x6 x⅝	28.5	29.3	12,805		3,340
	2	Pl. 18x2¼	137.7	29.3			
	4	Pl. 14x ½	23.8	32.2			
(Cols. 2, 3)	8	Ls 8x6 x⅝	28.5	32.2	29,508		7,342
	2	Pl. 16x2½	136.0	32.2			
	2	Pl. 18x2⅝	160.6	32.2			
	2	Pl. 14x ½	23.8	34.3			
(Col. 4)	4	Ls 8x6 x⅝	28.5	34.3	15,517		3,910
	2	Pl. 18x2⅜	145.4	34.3			
(Bottom)	8	Ls 8x3½x¾	27.5	1.0	220		220
(Splice)	8	Pl. 16x ¾	40.8	2.5	816		
(Splice)	8	12x ½	20.4	1.5	245		
		Rivets 3½%			2,069	61,180	
		*1st to 2nd*					
	6	Pl. 14x ½	23.8	19.6			
	1	14x ⅝	29.8	19.6			
	12	Ls 6x6 x⅝	24.2	19.6	32,634		2,234
	4	8x6 x⅝	28.5	19.6			
	8	Pl. 16x2½	136.0	19.6			17,046
	8	16x ¾	40.8	2.5	816		
	8	12x ½	20.4	1.5	245		
		Rivets 3½%			1,179	34,874	
		2nd to 4th					
	4	Pl. 14x ⅝	29.8	28.2			
	16	Ls 6x6 x⅝	24.2	28.2			
	4	Pl. 16x2	108.8	28.2	40,360		
	2	16x2⅛	115.6	28.2			
	2	16x2⅜	129.2	28.2			
	8	16x ¾	40.8	2.5	816		
	8	12x ½	20.4	1.5	245		
		Rivets 3½%			1,450	42,871	
		Page Total				138,925 lb.	

Note.—Connections for floor framing are listed with beams.

Fig. 3. List of Material for Columns

nections on another; and what drawing to use when the same items are shown in two places, as when the make-up of a plate girder is given on the floor plan and a complete detail of it on another drawing.

In taking off a floor framing plan, begin at a certain point and proceed in an orderly way. It is sometimes convenient to take off all the beams in an east and west direction and then those in a north and south direction, as shown in Fig. 1. As each item is listed it is checked on the drawing. After all the beams in a floor or any convenient group have been listed, check the number by counting from the plan and comparing with the number listed. After the beams are listed, the details for a complete floor or other subdivision are taken off. These are beam connections, column connections, separators, diaphragms, tie-rods, etc. Ordinarily, connections are not delineated on the drawings but must be supplied by the estimator. Standard beam connections are used wherever they will suit. As there are no well-established standard column connections they must be sketched out unless the estimator knows from experience the material required for them.

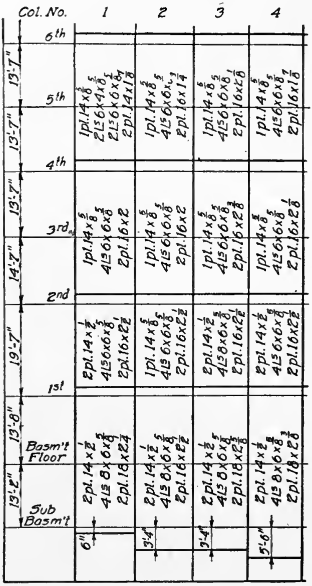


Fig. 4. Part of Column Schedule

Fig. 3 gives the list of column material taken from Fig. 4. In taking off the material from a column schedule, it usually is easier to group the items in tiers, rather than in stacks. Thus in Fig. 3, the first group is from sub-basement (SB.) to first floor, the second group from first floor to second floor, etc. The lengths in the first group will vary as indicated; also they are greater than the distance from floor to floor, including the part extending below the sub-basement floor and that from the first floor to the splice. If there is nothing on the plans to indicate the exact position of the splice, it can be assumed to be 2 feet above the floor level.

In the example given in Fig. 3 the web plates are listed, then the angles, and then the flange plates. The number of pieces can be checked easily by counting, and in case of a discrepancy the error can be located without difficulty. After the members of the column sections, the details for that tier follow. The details consist of rivet heads, splice plates, fillers, and connections for joists and girders. The rivets may be taken by an approximate count, or a percentage may be applied to cover them. Care must be taken to avoid duplicating joist and girder connections to columns. These items may be taken off with the floor framing, but if so, are classed as column material. Strict attention to the established order of procedure will prevent such duplication. In this example the beam connections have been taken with the floor framing, and the girder connections with the girders.

"State-and-Adams" Building

Cast-Iron Base Plates for Columns.
Drawing S9, dated 11-28-14.

Estimate made by J.J.L.; checked by H.N.R.
Extensions made by J.J.L.; checked by H.N.R
Estimate No. C1080.
Date 1-22-15. Page 34, of 48.

	No.	Section	Weight (lb. per lin. ft.)	Length (ft.)	Weight (lb.)	Totals
		5 Bases, for Cols. 1, 2, 7, 17, 18 (Each)				
(Bottom)	1	Pl. 52″ diam.x3″ metal			1,662	
(Hub)	1	Cyl. 19″ diam.x3″ metal		2.1	986	
(Flange)	1	Pl. 27″ diam., less 13″ diam.x2″ metal			230	
(Ribs)	8	Pl. 10¼″x2″		2.1	1,070	
(Rim)	1	Pl. 7″x2″		10.2	446	
		Fillets and overrun		7%	307	
		Total for 1 base			4,701	
		Total for 5 bases				23,505
		Steel Bearing Plates				
	5	Pl. 27′x2″	183.6	2.2	2,020	
(Deduct)	5	Corners, 7½″x2″	51.0	1.2	306	1,714
		Page Total				25,219 lb.

Fig. 5. List of Material for Cast-Iron Base Plates

Fig. 5 gives the list of material for the cast-iron base shown in Fig. 6. The ribs are listed as equivalent rectangular plates, the length being the distance between the top and bottom plates; the rim as a rectangular plate or bar, whose length is the circumference of its median line, less the thickness of ribs which intersect it; the base as a circular plate; the top as a circular plate from which the central part is deducted; the hub as a cylinder described by its wall thickness and depth, the latter being the distance between the top and bottom plates. An arbitrary percentage is added to cover the fillets and the probable overrun in weight, 7 per cent being used in this case.

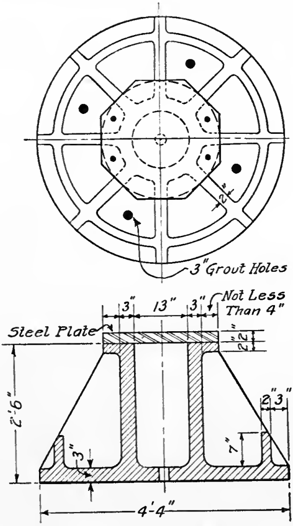


Fig. 6. Cast-Iron Base Plate

Fig. 7 is an estimate of the plate girder shown in Fig. 8. The beveled gusset plates are listed as the equivalent rectangular plates (or the extreme dimensions may be used and the beveled corners deducted). The rivet heads may be counted or a percentage used to cover them. For girders without cover plates use 3 per cent and with cover plates 5 per cent.

Standard Material. Items which have been standardized need not be listed in detail. Table III gives the standard weights used by the American Bridge Company for the connections of beams to beams, connections of beams to columns, bearing plates, and anchors. These standards are not used in all cases, and may be changed from time to time, so the estimator must determine whether they apply to the case in hand before using them.

The weights of beam connections, bearing plates, beam anchors, cast-iron separators, rivet heads, bolts, nuts, etc., are given in most of the handbooks, to which reference should be made. The

TABLE III

Standard Weights of Beam Fittings

(As used by American Bridge Company)

Size of Beam	Beam Connections	Beam Anchors	Steel Bearing Plates		Cast-Iron Bearing Plates		Steel Column Connections		Cast-Iron Column Connections Including Bolts		Size of Beam
			Size	Weight	Size	Weight	Single Beam	Double Beams Each Beam	□	○	
3" & 4"	6 #	 Government Anchors @ 3 # Strap Anchors @ 6.5 #	6"x 6"x ½"	5 #	6"x 6"x ¾"	7 #	6 #	8 #	12 #	12 #	3" & 4"
5"	7		6 x 6 x ½	5	6 x 6 x ¾	7	18	12	12	12	5"
6"	7		6 x 6 x ½	5	6 x 6 x ¾	7	18	18	12	12	6"
7"	15		8 x 8 x ⅝	11	8 x 8 x1	17	18	18	17	17	7"
8"	15		8 x 8 x ⅝	11	8 x 8 x1	17	18	18	17	17	8"
9"	15		12 x 8 x ⅝	17	12 x 8 x1	25	21	21	20	22	9"
10"	15		12 x 8 x ⅝	17	12 x 8 x1	25	21	21	20	22	10"
12"	22		12 x12 x ¾	31	12 x12 x1¼	48	30	25	25	27	12"
15"	29		16 x12 x ¾	41	16 x12 x1¼	64	38	34	33	36	15"
18"	34		16 x16 x1	73	16 x16 x1¾	119	54	48	37	40	18"
20"	34		16 x16 x1	73	16 x16 x1¾	119	60	54	42	46	20"
24"	41		16 x16 x1	73	16 x16 x2	136	72	65	53	61	24"

The 9" and 10" beams bear 8" on wall, 15" beams bear 12" on wall.

For double beam girders (**II**) bearing on wall estimate one beam anchor only. No anchors need be estimated for lintels.

In the above tables "Beam" denotes either **I** or **[**. Beam connections are the standard connections shown in the American Bridge Co.'s drawing room standards. Their weights include ¾"φ shop rivets and 75% of the ¾"φ field bolts. Weights for beam connections must be increased where beams frame into a web too thin to provide sufficient bearing for the rivets or bolts of a  standard connection. Beam connections and steel column connections must be increased for short spans of beams loaded to their full capacity.

Weights of steel and C. I. column connections and of steel and C. I. bearing plates are based on A. B. Co.'s drawing room standards.

Weights of steel column connections for beams and channels 5" and over include the following material. Seat L 6"x4"x½", 0'-6½" long (4" leg outstanding); L connecting top flange of beam to column, 4"x3"x⅜", 0'-6½" long; stiffener Ls (where necessary), 3"x3"x⅜"; ¾"φ shop rivets and four ¾"φ field bolts. In case more than two rivets or bolts are required in each flange of a beam connecting to a steel column the weight of the connection must be increased.

Weights of C. I. and Steel column connections are based on the assumption that the beams or double beam girders are concentric with, and at right angles to the faces of the columns. For those connecting to the columns eccentrically at inclined angles, or when double beam girders are widely separated, it may be necessary to modify the weights of the connections. Weights of C. I. column connections include the weights of ¾"φ bolts. When the metal in C. I. column shafts is of a less thickness than that of the stiffeners under the beam seats, the shaft should be increased to the stiffener thickness for a distance 6" above the seat and 6" below the bottom of the stiffener.

In general, where double beams (**II**) rest on masonry, estimate a standard bearing plate for each beam at each bearing. Where short spans or narrow bearing walls occur, it may be necessary to increase the weights of bearing plates. Special steel bearing plates must be designed for short beams, when loaded to their full capacity. Weights of C. I. bearing plates include 2% for overrun.

weights of connections there given should be checked to determine whether rivet heads are included.

In the estimate, Fig. 1, the weights of column connections used are those given in Table III. They are for shelf or bracket connections with angle on top. These may not apply to other cases. The connections will vary with the conditions imposed, so the estimator should determine the requirements for the case in hand. It is desirable to estimate column connections from shop details

"State-and-Adams" Building

Spandrel Girders, 4th, 5th, and 6th floors
(between col. 13–14, and col. 17–18).
Drawing S8, dated 11–28–14.

Estimate made by J.J.L.; checked by H.N.R.
Extensions made by J.J.L.; checked by H.N.R.
Estimate No. C1080.
Date 1–22–15. Page 20, of 48.

No.	Section	Weight (lb. per lin. ft.)	Length (ft.)	Weight	Totals	Large Angles
	3 Girders, betw. Col. 13 and 14 (Each)					
1	Pl. 20″x$\frac{5}{16}$″	21.2	15.2	322		
3	Ls 3$\frac{1}{2}$x3$\frac{1}{2}$x$\frac{3}{8}$	8.5	17.2	439		
1	6 x3$\frac{1}{2}$x$\frac{3}{8}$	11.7	17.2	201		
8	3 x3 x$\frac{3}{8}$	7.2	1.0	58		
1	6 x6 x$\frac{3}{4}$	28.7	3.3	95		
1	8 x6 x1	44.2	3.3	146		146
1	6 x3$\frac{1}{2}$x$\frac{5}{8}$	18.9	3.3	62		
4	Pl. 12x$\frac{5}{16}$	12.8	1.1	56		
2	6x$\frac{1}{4}$	5.1	1.1	11		
2	19x$\frac{9}{16}$	36.3	3.3	217		
	(Deduct) 12″x$\frac{9}{16}$″	22.9	1.0			
134	Rivets $\frac{3}{4}$″	.33		44		
150	Rivets $\frac{7}{8}$″	.50		75		
12	Ring fillers	.50		6		
	Total for 1 girder			1,732		
	Total for 3 girders				5,196	432
	3 Girders, betw. Col. 17 and 18 (Each)					
	(Same as 13–14, and add)			1,732		146
1	Pl. 20″x$\frac{5}{16}$″	21.2	1.2	25		
3	Ls 3$\frac{1}{2}$x3$\frac{1}{2}$x$\frac{3}{8}$	8.5	1.2	31		
1	6 x3$\frac{1}{2}$x$\frac{3}{8}$	11.7	1.2	14		
10	Rivets, $\frac{3}{4}$″			3		
	Total for 1 girder			1,802		
	Total for 3 girders				5,406	432
						864
	Page Total				10,602 lb.	

Fig. 7. List of Material for Spandrel Girders

whenever opportunity offers. In this way reliable weights can be collected covering all ordinary connections.

The rivet heads only are estimated. The shank offsets the material punched from the hole which it fills. In beam framing, rivet heads are included in the connections, but rivets in cover plates, shelf angles, and other fittings must be counted. For columns, plate girders, and trusses the rivets should be counted if the plans are in sufficient detail to permit an approximate count. Otherwise, a percentage is applied. The estimator can accumulate data as to the percentage to use by counting the number used in typical members from shop detail drawings. In the absence of more accurate data, 3 per cent may be used for columns, trusses, and plate girders without cover plates; and 5 per cent for plate girders with cover plates.

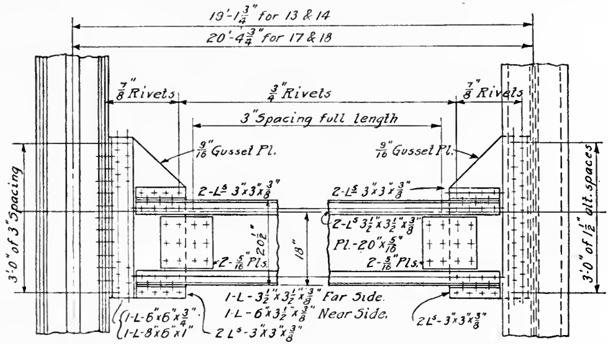


Fig. 8. Spandrel Girder 13–14, 17–18, at Fourth, Fifth, and Sixth Floors

The detail parts of riveted trusses are sometimes estimated by percentage. This is permissible if the estimator has data applicable to the particular truss under consideration. It is much better and more accurate to sketch the gusset plates and other details and list the material required.

Computing Weights. Having listed the material the computation of weights is simple arithmetic. It must be done with consistent accuracy. The length being given to the nearest inch may be inaccurate by ½ inch. The resulting discrepancy for a beam weighing 25 pounds per foot would be about 1 pound. It is the usual practice to record whole pounds disregarding decimals. On this basis the degree of accuracy of the computations will be greater than that of the take-off or that of the rolled section.

Computing machines are useful for extending the weights and adding them. The value of machine work as compared with mental and manual calculating depends largely on the ability and skill of the computer. Neither method is proof against error.

In addition to short methods of multiplication which are given in textbooks on arithmetic several short cuts are applicable to this work. For instance, the weight of an item involves three factors—number of pieces, length over all, and weight per lineal foot—and it involves two multiplications. The order in which the factors are combined may affect the amount of work in computing. Frequently one or perhaps both of the operations may be done mentally.

Examples. 1. In the case of two 18-inch I-beams 21.4 feet long and 55 pounds per lineal foot (2 Is $18''\times 55$ lb.$\times 21.4'$), the factors are (a) 2, (b) 55, (c) 21.4. (a) and (b) produce 110, and this partial product with (c) gives 2354 pounds, all being done mentally.

2. (a) 12 Ls $(3''\times 3''\times \frac{1}{4}'')\times$ (b) 4.9 lb.$\times$ (c) $8'\text{–}4''$; (a) and (c) produce 100, and this with (b) gives 490 pounds.

3. (a) 7 Cs $8''\times$ (b) $11\frac{1}{4}$ lb.$\times$ (c) $16'\text{–}0''$; (b) and (c) produce 180, and this with (a) gives 1260 pounds.

In these examples the proper order of the operations is evident at a glance.

Several items in sequence may have a common factor, as a number of pieces of different lengths of a certain size of beam or angle, or a list of column material all of one length. The partial products not containing the common factor may be added and the common factor applied to this sum, as follows:

Example. (a) (b) (c)

2 Ls $(2\frac{1}{2}''\times 2\frac{1}{2}''\times \frac{5}{16}'')\times 5$ lb.$\times 21'\text{–}0''$
3 Ls $(2\frac{1}{2}''\times 2\frac{1}{2}''\times \frac{5}{16}'')\times 5$ lb.$\times 14'\text{–}4''$
12 Ls $(2\frac{1}{2}''\times 2\frac{1}{2}''\times \frac{5}{16}'')\times 5$ lb.$\times 6'\text{–}6''$
1 Ls $(2\frac{1}{2}''\times 2\frac{1}{2}''\times \frac{5}{16}'')\times 5$ lb.$\times 17'\text{–}0''$
8 Ls $(2\frac{1}{2}''\times 2\frac{1}{2}''\times \frac{5}{16}'')\times 5$ lb.$\times 11'\text{–}3''$

Combining (a) and (c) gives

$2\times 21'\text{–}0'' = 42'\text{–}0''$
$3\times 14'\text{–}4'' = 43'$
$12\times 6'\text{–}6'' = 78'$
$1\times 17'\text{–}0'' = 17'$
$8\times 11'\text{–}3'' = 90'$
$\overline{270'\text{–}0''}$

Then multiplying by (b) 5, gives 1350 pounds.

2.

(a)	(b)	(c)
2 Pl. (14″× $\frac{5}{8}$″)	×29.75 lb.	×22′–0″
4 Ls (8″×6″x$\frac{7}{8}$″)	×39.1 lb.	×22′
4 Pl. (18″× $\frac{3}{4}$″)	×45.9 lb.	×22′

Combining (a) and (b) gives

2×29.75 = 59.5
4×39.1 = 156.4
4×45.9 = 183.6
399.5 lb.

Then multiplying by (c) 22, gives 8789 pounds.

In computing cast-iron members such as listed in Fig. 4, the weight may be computed from the weight per lineal foot of the section; or from the weight of a board foot (12″×12″×1″), 37.5 pounds; or from the weight of a cubic inch, 0.26 pound.

Checking. The most thorough check of an estimate is an independent duplication of the work, including the take-off. Less reliable, but more commonly used is a complete review of the original estimate. One large manufacturer follows an intermediate course. His estimators make a carbon copy of the lists of material, then the computations are made independently on the original and on the carbon copy.

The estimator can apply a number of checks as his work progresses. As each item is listed a check mark is placed on the drawing. When all the material on a drawing has been listed the drawing should be examined carefully and systematically to see that every piece of material is checked. A further check on the take-off is obtained by counting the items as has been suggested. The checker reviews the listing in the same manner, placing his own check mark on the drawings (using a pencil of a different color). This procedure should prevent with reasonable certainty any omission or duplication of items. Correctness of sections and lengths can be assured only by a careful review of these elements.

The larger features of the estimate need to be examined with care. A complete floor, or a tier of columns, or girders shown on a special drawing may be omitted. A general survey of the estimate and drawings will reveal such a mistake. On the other hand, there may be a duplication due to certain items being shown in two places on the drawings, as, plate girders which may be specified on a floor

EQUITABLE BUILDING, NEW YORK CITY, IN PROCESS OF CONSTRUCTION
Photo by Brown Brothers, New York City

plan and detailed on another drawing. In the final review of the take-off the large items should be counted to insure that the correct number of floors and tiers of columns have been listed; that beam and column details have been taken for all floors; that special items, such as foundation girders, sidewalk framing, and penthouses have been estimated; and that all the drawings of the set have been used.

The common sources of error in the computations are misplaced decimal points, wrong multiplications and additions, and omitting one of the factors. To check the decimal point the computer should make an approximate mental calculation by which he can locate the decimal point properly and also discover any gross error in multiplication. The addition can be checked by cross addition; thus, in Fig. 1, the weight of each item is entered in the last (total) column and in one of the classified columns; then at the bottom of the sheet are the totals for the classified columns, which, added together, must agree with the total of the last column.

The omission of one of the factors is most likely to occur when a group of items is duplicated; thus for a set of girders the material may be listed for one girder and this weight multiplied by the number of girders. The last factor may be overlooked either in the take-off or the computations.

A careful and complete review of the computations, or better still, independent computation, is essential to insure correctness in the detail figures. But even this must not be relied upon as a guard against misplaced decimal points or omitted factors. Two estimators may make the same error, especially if one is reviewing the work of the other.

The sections of members listed can be roughly checked by reading through the list while the items are fresh in mind. An omission, duplication, wrong weight of beam, wrong dimension of section, or wrong length will most likely attract attention. Errors in weights per lineal foot may occur by using the area instead of the weight. A close scrutiny will disclose this without comparing with the tables.

In many cases approximate checks may be secured by comparison of similar items or groups of items. The tiers of columns in a high building should vary in weight through the typical stories by a regular difference. Floors which have nearly the same framing

TABLE IV

Weights of Structural Steel in Certain Buildings

Class of Building as to Use	Dimensions at Grade (ft.)	Height above Grade (ft.)	No. of Stories		Live Load on Floors, per Sq. Ft. (lb.)	Contents (cu. ft.)	Total Weight of Steel (lb.)	Weight per Cu. Ft. of Building Volume (lb.)	Floor Construction	Remarks
			Below Grade	Above Grade						
Hotel	138x158	133	2	10	50	3,167,000	3,423,300	1.08	Long-span tile and concrete	
Hotel	60x150	134	1	12	100– 50	1,200,000	1,427,000	1.19	Long-span tile and concrete	
Office	68x149	218	1	17	100– 70	2,202,000	2,712,000	1.23	Tile arch	
Store and loft	89x 99	130	1	10	145	1,373,000	1,760,000	1.28	Tile arch	
Store and loft	80x172	128	1	9	125	1,963,000	2,600,000	1.32	Tile arch	
Store and loft	90x 95	125	1	10	145	1,371,000	1,820,000	1.33	Tile arch	
Hotel	100x101	200	1	17	100– 50	1,800,000	2,430,000	1.35	Long-span tile and concrete	
Loft	190x141	183	1	13	100	5,252,000	7,528,000	1.44	Tile arch	
Loft	153x100	162	1	12	100	2,840,000	4,120,000	1.45	Tile arch	
Store and loft	100x100	75	1	5	143	1,009,000	1,500,000	1.48	Tile arch	Provision for 5 additional stories
Store and loft	105x112	131	1	10	100	1,800,000	2,750,000	1.53	Tile arch	Provision for 2 additional stories
*Office and store	101x145			5	140	963,000	1,506,000	1.56	Tile arch	5-story addition
Department store	100x124		1	6	100	1,842,000	3,013,000	1.63	Reinforced concrete	4 additional stories
Printing	300x216	135	2	10	100–250 375	8,362,000	13,600,000	1.63	Reinforced concrete	
Hotel	161x182	183	3	13	100– 50	5,819,000	9,630,000	1.65	Tile arch	
Club	68x172	Irregular			100– 50	2,430,000	4,011,000	1.65	Tile arch	Framing very irregular
Bank and office	132x 94	199	1	16	150–100 75	2,346,000	4,012,000	1.71	Tile arch	
Office	111x 82	260	1	20	100– 50	3,320,000	5,840,000	1.76	Tile arch	
Office	172x 87	200	2	16	100– 50	3,203,000	5,773,000	1.80	Tile arch	
Office	66x100	208	1	17	110– 60	1,532,000	2,770,000	1.81	Tile arch	
*Office and store	101x145	260	2	18	145	4,074,000	7,414,000	1.82	Tile arch	

TABLE IV—Continued
Weights of Structural Steel in Certain Buildings

Class of Building as to Use	Dimensions at Grade (ft.)	Height above Grade (ft.)	No. of Stories		Live Load on Floors, per Sq. Ft. (lb.)	Contents (cu. ft.)	Total Weight of Steel (lb.)	Weight per Cu. Ft. of Building Volume (lb.)	Floor Construction	Remarks
			Below Grade	Above Grade						
Office	40x160	154	1	12	100	1,159,000	2,140,000	1.85	Tile arch	No interior columns
Office	110x132	221	1	18	100– 50	2,994,000	5,580,000	1.87	Tile arch	
Public	162x381	205	2	13	50	11,750,000	22,146,000	1.88	Tile arch	
Public	161x381	205	2	13	50	11,521,000	21,670,000	1.88	Tile arch	
*Office and store	101x145	200	2	13	145	3,111,000	5,908,000	1.90	Tile arch	Provision for 5 additional stories
Office and printing	121x144	165	2	13	150– 80	2,914,000	5,670,000	1.94	Tile arch	Provision for 5 additional stories
Office	66x106	187	1	15	156– 86	1,374,000	2,668,000	1.95	Tile arch	
Office	112x101	260	2	20	100– 50	4,716,000	9,250,000	1.96	Tile arch	
Printing	61x120	84	1	6	150	798,500	1,596,000	2.00	Tile arch	
Office	Irregular	210	1	17	100– 60	4,397,000	9,034,000	2.06	Tile arch	
Office and bank	48x121	196	2	15	185–160	1,403,000	2,928,000	2.08	Tile arch	
Stores and loft	100x100	79	1	7	130	995,000	2,070,000	2.08	Tile arch	
Hotel	162x179	253	2	21	80– 50	6,854,000	14,400,000	2.10	Tile arch	
Office	Irregular	261	1	20	137– 50	4,824,000	10,304,000	2.13	Tile arch	
Department store	158x326	260	3	17	150–100	17,066,000	36,400,000	2.14	Tile arch	
Office	66x100	207	1	17	110– 60	1,547,000	3,352,000	2.17	Tile arch	
Department store	151x150	247	3	16	100	8,777,000	19,728,000	2.24	Tile arch	
Office	Irregular	220	3	17	100	2,814,000	6,341,500	2.25	Tile arch	Provision for 5 additional stories
Loft	79x101	106	1	7	150	841,000	2,106,000	2.50	Tile arch	Provision for 9 additional stories
Office	190x111	201	2	16	100– 50	4,616,000	11,944,000	2.58	Tile arch	Provision for 5 additional stories
Office and loft	96x120	263	3	19	138	3,802,000	10,170,000	2.67	Tile arch	
Store	47x100	136	2	8	150	762,000	2,288,000	3.00	Tile arch	Long spans
Office and loft	72x136	104	2	6	150	1,129,000	3,422,000	3.03	Tile arch	Provision for 10 additional stories
Store	38x100	132	2	8	150	620,000	1,926,000	3.10	Tile arch	Long spans
Printing	Irregular	363	3	23		2,242,000	7,424,000	3.32	Tile arch	
Office	120x 90	40	2	3	150– 50	220,000	1,300,000	5.90	Tile arch	Provision for 19 additional stories

* All the same building.

should have approximately the same weight. Likewise similar girders can be compared by making allowance for items which occur in one and not in the other.

Approximate Estimates. It is sometimes necessary to have an approximate estimate of the tonnage of steel required for a given structure before the framework is designed. Such estimates can be made by comparing with the known quantities of steel used in structures that have been built. The basis of comparison is the cubic foot of building volume, or the square foot of floor area. The one can easily be converted to the other if the average story height is known. The data and discussion here given are on the cubic-foot basis.

The degree of accuracy of an estimate based on the cubic content of the building depends on the definiteness of the data and to some extent on the skill and experience of the estimator. The cubic content must be computed on the same basis in the example as in the data with which it is compared. The data given herein is based on the actual cubic content of the building, including penthouses, foundations, etc., and excluding all open courts.

Table IV gives the weight of steel per cubic foot of building volume for a number of buildings. The items are arranged in order of the increase of the weight of steel per cubic foot. Note that long-span concrete or tile-and-concrete floor construction requires no joists, the concrete spanning from girder to girder. The flat-tile arch requires joists spaced 5 to 6 feet apart. The weights given include cast-iron bases, and steel chimneys, as well as the structural frame of the building, all of which is the material usually included in a structural steel contract.

In Table IV all the pertinent data available is given, including special features of certain buildings. A comparison of the data discloses some of the elements which contribute to a weight greater than the minimum. Other elements, not shown in the table, which cause high weights per cubic foot are: wide column spacing; shallow girders (for flat ceilings); heavy live loads; heavy dead loads (as partitions in hotels); small area, making a large percentage of wall load; interior walls, or provision for them; high buildings; provision for future stories; foundation girders; steel in retaining walls; girders supporting columns; and low story heights.

To use this method of estimating, select from the table the item which corresponds most closely with the case in hand. If there are some elements not covered by the item selected, allowance can be made for them; thus if some special feature is required, it can be designed approximately and its weight added to that computed from the unit weight selected from the table.

Estimators and designers should make it a practice to develop data from their estimates of all classes of work for use in making approximate estimates of future similar work.

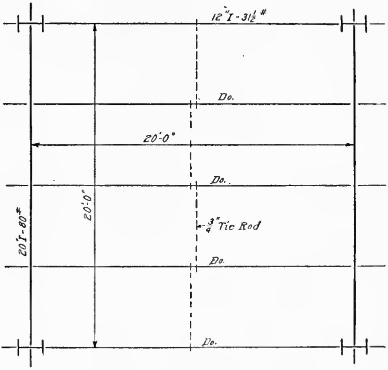


Fig. 9. Panel of Floor Framing

A comparison of the weight of steel for a structure as computed from the plans, with the approximate weight determined from Table IV will serve as a rough check of the estimate; or, assuming that the estimate from the plans is correct, the comparison will indicate in a general way, whether the design is too heavy or too light.

Another approximate method of estimating the weight is to compute it from tentative designs of typical parts.

Illustrative Example. To illustrate this method, assume the following data for a building: length 100′–0″; width 100′–0″; height—12 stories above grade and 1 basement—equals 160 feet from basement floor to roof; column spacing, approximately, 20′—0″ ×20′–0″; dead load on floors 80 lb. per sq. ft.; and live load on floors 100 lb. per sq. ft. Fig. 9 represents the floor framing for a typical panel. The weight of steel in one panel is estimated as follows:

4	Is 12″×31½ lb.×20′–0″	2520 lb.	
1	Is 20″×80 lb.×20′–0″	1600 lb.	
6	Standard beam connections, for 12″ Is @ 20 lb.	120 lb.	
2	Connections to columns, for 12″ Is @ 25 lb.	50 lb.	
2	Connections to columns, for 20″ Is @ 40 lb.	80 lb.	
4	Tie-rods ¾″×5′–4″	32 lb.	
			4402 lb.

The area of the panel is 20′×20′=400 sq. ft. The weight of steel in the floor framing per sq. ft. of floor is $\frac{4402}{400}=11$ pounds, and this multiplied by the total floor area including roof, gives the total weight of floor framing. There are 12 floors and a roof, so the total weight is

$$13\times100\times100\times11=1{,}430{,}000 \text{ lb.}$$

To determine the weight of spandrel beams, design the typical spandrel and compute its weight per lineal foot, including its connections. For this purpose only the weight of wall is used in designing the spandrel, as the material required for the support of the floor adjacent to the wall has been included in the floor framing. In the illustration let the panel length be 20 feet, the story height 12 feet, the wall 13 inches thick (disregard openings). Then the weight on the spandrel is 20×12×130=31,200 pounds, which requires a 15″ I×42 lb. Make the connections as shown in Fig. 10, using angles $6''\times4''\times\frac{5}{8}''$. Then the material for one spandrel and its connections is

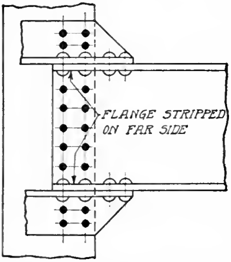


Fig. 10. Connection of I-Beam to Flange of Column for Wind Bracing

1	I 15″ ×42 lb.×20′-0″	=840 lb.
4	Ls $(6''\times4''\times\frac{5}{8}'')$×20 lb.×1′-0″	= 80 lb.
22	Rivets @ .3 lb. each	= 7 lb.
		927 lb.

The weight per lineal foot is $\frac{927}{20}=46.4$ pounds, and the total weight of spandrel metal is

$$13\times400\times46.4=241{,}280 \text{ lb.}$$

If the building will require special wind-bracing girders, as shown in Fig. 8, they must be estimated accordingly. In some instances it may be well to take several different spandrels at different elevations and to take into account different spandrel lengths.

To get the weight of the columns it is necessary to know their length and average section. The latter can be computed in a single item representing the sum of the cross sections of columns instead of computing each column. To determine the section it is first necessary to compute the loads. The assumed building is 100′–0″×100′–0″ divided into panels 20 feet square; has 36 columns, and a column length of 160 feet; dead load on floors and roof 80 lb. per sq. ft.; live loads applied to the columns as follows:

Level	Live Load
Roof	25 lb.
12th floor	85 lb.
11th floor	80 lb.
10th floor	75 lb.
9th floor	70 lb.
8th floor	65 lb.
7th floor	60 lb.
6th floor	55 lb.
5th floor	50 lb.
4th floor	50 lb.
3rd floor	50 lb.
1st floor	75 lb.
Total	740 lb. per sq. ft. of building area;

walls 13 inches thick; no deduction for openings; columns and their fireproofing taken as 500 lb. per lin. ft.

Then the total weight to be supported by columns is as follows:

		Total Load Carried
Dead load of floors and roof,	13×10,000× 80	10,400,000 lb.
Live load,	10,000×740	7,400,000 lb.
Walls,	400×160×130	8,320,000 lb.
Columns,	36×160×500	2,880,000 lb.
		29,000,000 lb.

Dividing this by 12,000 pounds unit stress, gives an area of 2417 sq. in., which corresponds to a weight per lin. ft. of 2417×3.4=8200 pounds. This is the weight at the bottom columns. Assume that the minimum or top sections weigh 50 pounds per lin. ft. each, or a total of 36×50=1800 pounds. Then the average weight of the column section is $\frac{8200+1800}{2}=5000$ pounds per lin. ft. and the total weight of steel in the columns is

$$5000\times160=800,000 \text{ lb.}$$

The total weight of steel for this building in round numbers is

Floor framing	1,430,000 lb.
Spandrels	241,000 lb.
Columns	800,000 lb.
	2,471,000 lb.

The cubic contents of this building is $100 \times 100 \times 160 = 1{,}600{,}000$ cu. ft., and the weight of steel per cu. ft. is

$$\frac{2{,}471{,}000}{1{,}600{,}000} = 1.55 \text{ lb.}$$

The foregoing illustration is a very simple case. Ordinarily, there will be light courts, penthouses, cornice or parapet framing, sidewalks, several sizes of panels—also there may be wind bracing, girders or trusses over large rooms, and chimneys to be included—all of which can be approximated in a similar manner. Such approximate estimates cannot be expected to be very accurate. With reasonable care they should be within 10 per cent of the correct figures. They are more likely to be too low than too high on account of miscellaneous details that cannot be taken into account except by making some additional allowance for them.

ESTIMATING COSTS

The cost of structural steel if analyzed to its origin would be traced from the iron mines to the docks, by cars and boats to the furnaces, through the smelters, rolling mills, and structural shops, with the intervening transportation, and finally into the structure. Each of these items could be divided into several others, so it is clear that a great many elements enter into the cost of structural steel.

The engineer who is estimating the cost of fabricated structural steel will not have occasion to go back farther than the rolling mill, beginning with the plain material after it is rolled, cut to length, and ready for shipment.

The items entering into the cost are as follows: plain material loaded on cars at the mill; transportation from rolling mill to fabricating shop; preparation of shop detail drawings; fabrication; paint and painting; transportation from fabricating shop to site of structure; erection and field painting; selling cost and miscellaneous items; and profit. The total of these items is the price which is to be paid to the contractor by the owner of the building. Each item can be analyzed into a number of elements which are discussed in the following text.

Plain Material. It has been the custom of the trade for a number of years to base the price of plain structural steel on the material delivered on cars at Pittsburgh, Pennsylvania, so that published quotations, unless otherwise stated, are understood to be f.o.b. (free on board) cars Pittsburgh. Of course quotations are made f.o.b. cars at other cities wherever the mills are located, but they are generally set at such a price that they amount to the Pittsburgh price plus the freight from Pittsburgh to the point where the quotation applies. Thus when the Pittsburgh price is 1.50 cents per pound, the Chicago price is 1.69 cents per pound. This is not always so, for there have been times when the prices in Pittsburgh and Chicago have been nearly or quite the same. Therefore, the estimator must keep informed of changes in prices from time to time so that he may know the cheapest basing point.

The price of plain material is made up of the base price and extras. The base price covers most of the steel required for a job, but extra charges are made for certain items. Thus the base price applies to the following: I-beams, 3-inch to 15-inch inclusive; angles, 3-inch to 6-inch inclusive, $\frac{1}{4}$-inch thick and over; zees, 3-inch and over; plates, $\frac{1}{4}$-inch thick and over; and rods, $\frac{3}{4}$-inch to 3-inch. The base price has varied from $1.10 per 100 pounds to $1.70 per 100 pounds, f.o.b. Pittsburgh. The proper figure to use at any time can be obtained from the trade journals, or from the dealers. It may not be the same for all the standard sections, though usually so.

Extras are required for the following items and the amounts given are those usually charged. The seller may vary these amounts from time to time.

	EXTRA (per 100 lb.)
Beams, over 15-inch	$0.10
Angles, over 6-inch	.10
Tees, 3-inch and over	.05
Cutting to exact length (within $\frac{1}{8}$ inch)	.15
Rods, $\frac{5}{8}$-inch and $\frac{11}{16}$-inch	.05
Rods, $\frac{1}{2}$-inch and $\frac{9}{16}$-inch	.10

Special shapes, rolled exclusively by one mill, are usually sold at higher than the base prices, as follows:

Special Shape	Price (per 100 lb.)
Light-weight Carnegie beams	$0.10
Bethlehem beams	.05
Bethlehem girders	.10
Bethlehem columns	.20

The cost of a bill of material f.o.b. Pittsburgh may be illustrated as follows:

Material	Weight (lb.)	Rate (per 100 lb.)	Cost
Angles and beams, base sizes	422,600	$1.40	$5,916.40
Beams, over 15-inch	77,400	1.50	1,161.00
Angles, over 6-inch	106,000	1.50	1,590.00
Bethlehem column sections	362,900	1.60	5,806.40
Rivet rods	56,200	1.40	786.80
Total	1,025,100	$1.488	$15,260.60

As the estimate of weight is intended to represent the weight of the fabricated material, some allowance must be made for waste. The waste material consists of punchings, corners cut from plates and angles, and ends milled from columns. For ordinary building work it probably does not exceed 2 per cent of the estimated weight. This, applied to the average price of material computed above, gives $0.03 per 100 pounds as the rate to apply to the total weight to cover waste. In the absence of more specific data, this can be adopted as an arbitrary rate to use.

Transportation from Mill to Shop. The price of the material at the mill includes loading on cars; the unloading at the fabricating plant is treated as a part of the fabricating cost, so that the transportation charge is for freight only. Usually the regular freight tariff includes switching charges at both ends of the route, but if not, this charge must be added. The published tariff rate multiplied by the weight gives the freight charge.

The rates are for carload shipments, and for less-than-carload shipments. Between the mill and the shop there is seldom occasion for shipping in less than carload lots, as the material for several orders can be combined if need be to make up carloads. The minimum carload is the minimum weight which is required to secure the carload rate. It is an arbitrary amount fixed as a part of the tariff by the respective railroads. It varies from 24,000 pounds to 40,000 pounds and is subject to change in the same manner as the rates.

A number of typical rates on structural steel are given in the following schedule. They serve only for illustration and must not be used in estimating without being confirmed by competent authority. Rates are given in dollars per hundred pounds, or in cents per pound. Both the carload (c.l.) rates and less-than-carload (l.c.l.) rates are listed from Pittsburgh.

Schedule of Rates on Structural Steel

Destination	Rates	
	c. l.	l. c. l.
Chicago	$0.189	$0.221
New York	0.169	0.201
Boston	0.189	0.221
Washington	0.154	0.186
Cleveland	0.105	0.137
Louisville	0.189	0.221
New Orleans	0.30	0.37
St. Louis	0.236	0.273
Kansas City	0.436	0.513
Galveston	0.571	0.77
El Paso	0.911	1.402
St. Paul	0.329	0.431
Denver	0.686	1.071
Salt Lake City	0.989	1.793
Los Angeles	0.80	1.30
San Francisco		
Seattle	0.80	2.20

Illustrative Examples. 1. 140,000 pounds of steel are to be shipped from Pittsburgh to Kansas City. The c.l. rate, as above, is $0.436 per 100 lb. and the total freight charge 140,000×0.436 = $610.40.

2. A shipment of structural steel is to be made from Pittsburgh to St. Paul. Weight 30,000 pounds. Minimum carload 36,000 pounds. The freight at the l.c.l. rate is 30,000×0.431 = $129.30. But it may be shipped as a minimum carload of 36,000, in which case the freight charge is 36,000×0.329 = $118.44. From this it is clear that the shipment should be billed as a minimum carload.

The minimum-carload weight is 36,000 pounds over most of the United States but is 40,000 pounds in the Rocky Mountain

States and the Pacific Coast States. Other amounts apply on certain local lines, especially on narrow-gage railroads.

Shop Detail Drawings. Under this heading is included the clerical work of listing and ordering material from the rolling mills, and the drafting of the detail or working drawings. In addition to the actual labor chargeable to the specific job there is also chargeable to it a portion of the general expense or overhead. This overhead expense covers supervision, supplies, rent, heat, light, blue printing, etc. It is usually expressed in terms of a percentage of the direct-labor cost. It varies and must be adjusted from time to time to suit conditions. A full force with high efficiency gives a low percentage for overhead; a small force with little work gives a high percentage.

Cost records of drawings may be in terms of the weight, or in items of the number of drawings required. If the estimate is made on the former basis, the estimator must know the weight of material involved and the character of the work, then by comparison with his records he can determine the proper figures to apply. If the estimate is based on the number of drawings, the estimator must count the number of drawings of each class of work such as column, beam, girder, and miscellaneous details, and apply the rates which his records indicate to be right for the case in hand.

Actual data for cost of detailing is not generally available, being retained as a part of the working capital of the office; furthermore the records of one office may not suit the conditions prevailing in another office. For building work the total cost of drawings may vary from \$1 to \$4 per ton of material. Probably \$1.75 or \$2 per ton represents the value of the drawings for the structural steel for an ordinary office building. Large tonnage and much duplication lead to low cost, while irregularity, little duplication, and light material lead to a high cost.

Fabrication. The cost of fabrication includes all the expense involved in converting the plain material into the finished structural members. The labor elements involved are making templets, unloading steel, marking, punching, assembling, riveting, and shipping. In addition to labor there is general expense which must cover templet lumber, oil, fitting up bolts, equipment, superintendence, insurance, taxes, upkeep and depreciation of plant, and administration. The latter group of items is usually expressed in terms of a percentage of the direct-labor cost. This percentage is a variable amount, depending upon the facilities of the shop, the volume of work, and character of the work. For a given shop the general expense is fairly constant while the labor cost may vary greatly from month to month; hence the percentage may need to be changed from month to month.

As in the case of drawings the detailed records of costs are available only to the estimators of the company to which they belong, and due to differences in equipment and other conditions, the records of one shop may not be a safe criterion of the cost of the work in another shop.

In keeping cost records and in estimating costs, the work is classified in more or less detail. The estimator generally uses the total fabricating cost of each class of material without making an analysis of the elements which have been mentioned. The extreme and average costs are approximately as tabulated:

	Fabrication Costs (per 100 pounds)		
	Min.	Max.	Avg.
Beams	$0.10	$0.50	$0.25
Columns	.40	1.50	.60
Girders	.30	.75	.50

In each class the low price applies to large tonnage of simple workmanship with much duplication; and the high price to small tonnage, complicated workmanship, and little duplication.

Paint and Painting. The cost of paint and painting at the shop may be considered as a part of the fabrication, but usually is treated as a separate item.

The paints used on steel are graphites, carbons, iron oxides, red lead, and various combinations of them.

The spreading capacity may be as high as 1200 square feet per gallon for the light carbon and graphite paints and as low as 400 square feet for heavy red-lead paint. For second-coat and third-coat work, most paints will cover about 20 per cent more surface than for the first coat. But if the second and third coats are applied after erection the waste will probably offset the added covering power. The actual spread realized for a paint will depend on the smoothness of surface, the temperature, and the amount of labor expended in applying it. For estimating purposes the spreading capacity per gallon of heavy red lead may be taken as 500 square feet, medium-weight red lead, 600 square feet, iron oxide 600 square feet, graphite and carbon 800 square feet.

The surface to be painted per ton of steel depends on the thickness of metal. Metal 1-inch thick has 100 square feet of surface per ton; $\frac{1}{4}$-inch thick has 400 square feet. A lot of I-beams, ranging from 10-inch to 20-inch as required for ordinary floor framing, have about 200 square feet of surface per ton. Plate girders for building framework will vary from 100 to 300 square feet per ton, and columns from 50 to 200 square feet. From a set of drawings an accurate estimate can be made if desired. Generally, it suffices to use an approximate figure. For the ordinary framework for office buildings 200 square feet of paint surface per ton weight of steel is a fair value.

The prices of paints range from \$1 to \$2 per gallon. Actual prices must be secured from dealers for the particular paint specified.

Illustrative Examples. 1. Assume a carbon paint at \$1 per gallon, covering capacity 800 square feet, surface of steel 200 square feet per ton. Then the quantity of paint required per ton of steel is $\frac{1}{4}$ gallon, and its cost is 25 cents.

2. Assume a red-lead paint at \$1.85 per gallon, covering capacity 500 square feet, surface of steel 200 square feet per ton. Then the quantity of paint required per ton of steel is $\frac{2}{5}$ gallon, and its value 74 cents.

The cost of painting includes the direct-labor cost, superintendence, and such supplies as brushes and pails. The estimate should be based on the actual cost records at the place where the work is to be done. For the carbon and graphite paint which are easily applied, this cost may be taken at 25 cents per ton. For red-lead paint which is harder to apply use 50 cents per ton, in the absence of more accurate data.

Transportation from Fabricating Shop to Building Site. The freight rates on fabricated structural steel are the same as for the plain material, so that the same discussion regarding transportation from mill to shop applies also from shop to site. However, there are some additional points to consider.

It is easy to make shipments in carloads of minimum weight when the material is straight, such as beams and columns, but if there are bulky items, such as trusses or chimneys, it may be impossible to load up to the minimum weight, in which case there will be excess freight to pay.

In most cases the material must be hauled by wagon from the railroad cars to the site. In the charge for this hauling is included the cost of unloading from cars to wagon and from the wagons at the site. Also there may be included the cost of sorting and of storing, if the material does not arrive on the cars in the order in which it is needed at the building. With good derricks at railroad and site, and a short haul, the cost of handling may be as low as 50 cents per ton. From this it may range upward to $2 per ton.

The best means of estimating the cost of hauling is by securing sub-bids from teaming contractors.

Erection. The erection cost is chiefly labor cost. However, in addition to the labor cost there must be estimated wear and tear on equipment, fuel, power, and insurance. The labor cost may be divided into hoisting and assembling, scaffolding and false work, and riveting. For the class of buildings under consideration false work is seldom required. If required in considerable quantity it is estimated separately. The conditions which make cheap erection are heavy members, large tonnage, small number of field rivets per ton of steel. The opposite conditions of course cause high cost.

The value of erection varies from $6 to $12 per ton. For the ordinary office building it is about $8. In the absence of accurate data as the basis for estimating a given job it should be submitted to a sub-contractor for a bid.

The foregoing discussion and prices do not include field paint and painting. If this is required, it is estimated in the same manner as the shop painting. In general the paint for the field coat may be figured at the same cost per ton as the shop paint, although the quantity required is somewhat less if there is little waste. The labor cost of field painting is from 25 per cent to 100 per cent more than for shop painting.

Selling Costs. Under this heading are covered all expenses incidental to the estimating and selling of the structural steel. It

ESTIMATE FOR General Contractors
Name and Location United Drug Building, Chicago, Ill.
Description Steel-Frame Building, 40 ft. x 100 ft.
15 stories, 2 basements
Drawing No. S1 to S8 inclusive, dated 11-28-14
Plans Smith and Smith, Archts.
Specifications Smith & Smith, Archts.
Material Standard A. S. T. T.
Workmanship Ordinary, part of columns reamed
Erection by Ourselves
Haul 2 miles
Condition of Site Restricted, co-operate with other trades
Facilities for Storage None. Haul as needed
Bid $93,000 erected, Chicago

Date 1-25-15
Inquiry No. C1080
Sheet No. 1 **of** 1

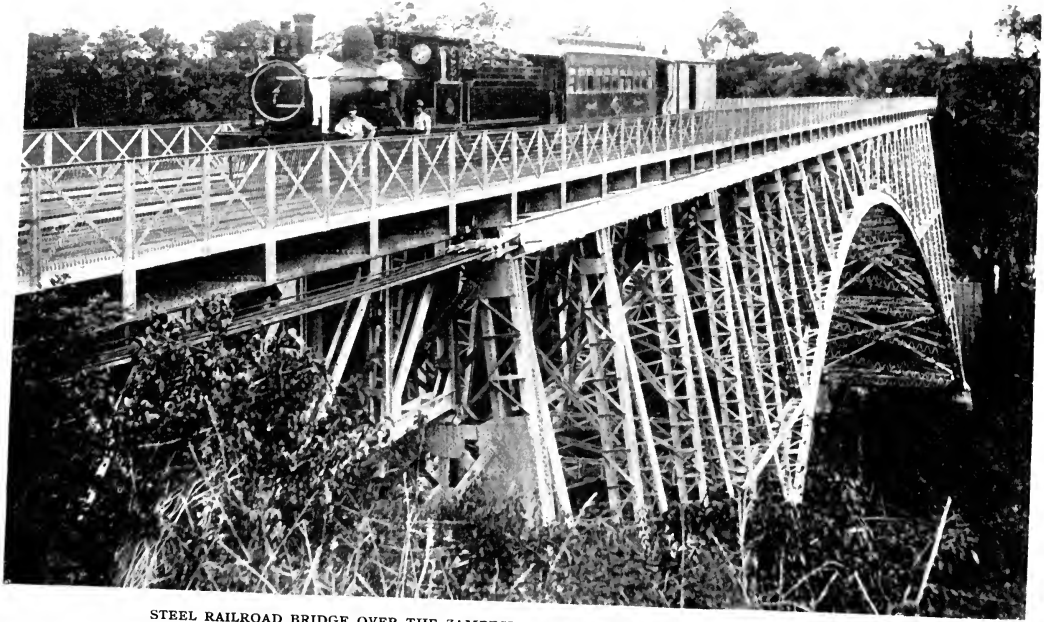
Anchor Bolts furnished by None
Field Connections Riveted Except as noted
Shop Painting One coat red lead, 25c per gallon
Field Painting Same, on spandrels only
Due-Erected 4 months
Penalty or Bonus None
Inspection Mill and shop. Paid by owner
Transportation Ourselves

COST IN CENTS PER LB.	1	2	3	4	5	6	7	8
Material	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Shop Work	.05	.10	.20	.35	1.00	.50	.70	.60
Waste	.03	.03	.03	.03	.03	.03	.03	.03
Fr't to Chicago	.19	.19	.19	.19	.19	.19	.19	.19
Total	1.57	1.62	1.72	1.87	2.52	2.02	2.22	2.12

Material	Price
Large Is	1.40
Ord. Is & s	1.30
Large Ls	1.40
Ord. Ls	1.30
Beth. G.	1.50
Bars	
U. M. Pl.	1.30
Sh. Pl.	1.30
Pin. R'ds	
Rivets	
Nuts	
Bolts	

SUB-CONTRACTS	MAIN CONTRACT	QUANTITY	RATE	AMOUNT
	1 Beams a	44,000	1.57	691
	2 Beams b	77,800	1.62	1,260
Cast-Iron Base Plates 96,000 @ 1.85 $1,776	3 Beams d	1,317,500	1.72	22,661
	4 Beams r	282,600	1.87	5,285
	5 Fittings	46,700	2.52	1,177
	6 Columns	1,088,600	2.02	21,990
	7 Spandrel girders	240,100	2.22	5,330
	8 Chimney	60,900	2.12	1,291
		3,158,200		
	Drawings		.08	2,527
	Paint, shop		.04	1,263
	Painting, shop		.025	790
	Paint, field	320,000	.04	128
	Extra for material			
	Large Beams and Angles	418,000	.10	418
	Beth. Girders	111,000	.20	222
	Cast-Iron Bases	96,000	1.85	1,776
	Material Delivered	3,254,200	2.05	66,809
	Erection and Ptg.		.42	13,668
	Hauling		.05	1,627
Net Cost Sub-Contracts	Net Cost, Erected	3,254,200	2.52	82,104
	Selling Cost @ 5%			4,106
				86,210
	Profit, about 8%			6,790
	Bid	3,254,200	2.86	93,000

Fig. 11. Form for Estimate Summary



STEEL RAILROAD BRIDGE OVER THE ZAMBESI RIVER ON THE CAPE TO

STATICS.

This subject, called Statics, is a branch of Mechanics. It deals with principles relating especially to forces which act upon bodies at rest, and with their useful applications.

There are two quite different methods of carrying on the discussions and computations. In one, the quantities under consideration are represented by lines and the discussion is wholly by means of geometrical figures, and computations are carried out by means of figures drawn to scale; this is called the *graphical method.* In the other, the quantities under consideration are represented by symbols as in ordinary Algebra and Arithmetic, and the discussions and computations are carried on by the methods of those branches and Trigonometry; this is called the *algebraic method.* In this paper, both methods are employed, and generally, in a given case, the more suitable of the two.

I. PRELIMINARY.

1. Force. The student, no doubt, has a reasonably clear idea as to what is meant by force, yet it may be well to repeat here a few definitions relative to it. By force is meant simply a *push* or *pull.* Every force has **magnitude,** and to express the magnitude of a given force we state how many times greater it is than some standard force. Convenient standards are those of weight and these are almost always used in this connection. Thus when we speak of a force of 100 pounds we mean a force equal to the weight of 100 pounds.

We say that a force has **direction,** and we mean by this the direction in which the force would move the body upon which it acts if it acted alone. Thus, Fig. 1 represents a body being pulled to the right by means of a cord; the direction of the force exerted upon the body is horizontal and to the right. The direction may be indicated by any line drawn in the figure parallel to the cord with an arrow on it pointing to the right.

We say also that a force has a **place of application,** and we mean by that the part or place on the body to which the force is applied. When the place of application is small so that it may be regarded as a point, it is called the "point of application." Thus the place of application of the pressure (push or force) which a locomotive wheel exerts on the rail is the part of the surface of the rail in contact with the wheel. For practically all purposes this pressure may be considered as applied at a point (the center of the surface of contact), and it is called the point of application of the force exerted by the wheel on the rail.

A force which has a point of application is said to have a **line of action,** and by this term is meant the line through the point of application of the force parallel to its direction. Thus, in the Fig. 1, the line of action of the force exerted on the body is the line representing the string. Notice clearly the distinction between the direction and line of action of the force; the direction of the force in the illustration could be represented by any horizontal line in the figure with an arrowhead upon it pointing toward the right, but the line of action can be represented only by the line representing the string, indefinite as to length, but definite in position.

Fig. 1.

That part of the direction of a force which is indicated by means of the arrowhead on a line is called the **sense** of the force. Thus the sense of the force of the preceding illustration is toward the right and not toward the left.

2. Specification and Graphic Representation of a Force. For the purposes of statics, a force is completely specified or described if its

(1) magnitude, (2) line of action, and (3) sense are known or given.

These three elements of a force can be represented graphically, that is by a drawing. Thus, as already explained, the straight line (Fig. 1) represents the line of action of the force exerted upon the body; an arrowhead placed on the line pointing toward the right gives the sense of the force; and a definite length marked off on the line represents to some scale the magnitude of the force. For example, if the magnitude is 50 pounds, then to a scale of 100 pounds to the inch, one-half of an inch represents the magnitude of the force.

It is often convenient, especially when many forces are concerned in a single problem, to use two lines instead of one to represent a force—one to represent the magnitude and one the line of action, the arrowhead being placed on either. Thus Fig. 2 also represents the force of the preceding example, AB (one-half inch long) representing the magnitude of the force and *ab* its line of action. The line AB might have been drawn anywhere in the figure, but its length is definite, being fixed by the scale.

The part of a drawing in which the body upon which forces act is represented, and in which the lines of action of the forces are drawn, is called the **space diagram** (Fig. 2*a*). If the body were drawn to scale, the scale would be a certain number of inches or feet to the inch. The part of a drawing in which the force magnitudes are laid off (Fig. 2*b*) is called by various names; let us call it the **force diagram.** The scale of a force diagram is always a certain number of pounds or tons to the inch.

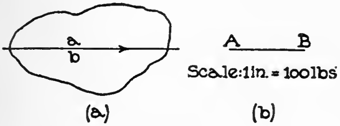


Fig. 2.

3. Notation. When forces are represented in two separate diagrams, it is convenient to use a special notation, namely: a capital letter at each end of the line representing the magnitude of the force, and the same small letters on opposite sides of the line representing the action line of the force (see Fig. 2). When we wish to refer to a force, we shall state the capital letters used in the notation of that force; thus "force AB" means the force whose magnitude, action line, and sense are represented by the lines AB and *ab*.

In the algebraic work we shall usually denote a force by the letter F.

4. Scales. In this subject, scales will always be expressed in feet or pounds to an inch, or thus, 1 inch = 10 feet, 1 inch = 100 pounds, etc. The number of feet or pounds represented by one inch on the drawing is called the *scale number.*

To find the length of the line to represent a certain distance or force, divide the distance or force by the scale number; the quotient is the length to be laid off in the drawing. To find the *magnitude of a distance or a force represented by a certain line in a drawing, multiply the length of the line by the scale number; the product is the magnitude of the distance or force, as the case may be.*

The scale to be used in making drawings depends, of course, upon how large the drawing is to be, and upon the size of the quantities which must be represented. In any case, it is convenient to select the scale number so that the quotients obtained by dividing the quantities to be represented may be easily laid off by means of the divided scale which is at hand.

Examples. 1. If one has a scale divided into 32nds, what is the convenient scale for representing 40 pounds, 32 pounds, 56 pounds, and 70 pounds?

According to the scale, 1 inch = 32 pounds, the lengths representing the forces are respectively:

$$\frac{40}{32} = 1\tfrac{1}{4};\ \frac{32}{32} = 1;\ \frac{56}{32} = 1\tfrac{3}{4};\ \frac{70}{32} = 2\tfrac{3}{16}\text{ inches.}$$

Since all of these distances can be easily laid off by means of the "sixteenths scale," 1 inch = 32 pounds is convenient.

2. What are the forces represented by three lines, 1.20, 2.11, and 0.75 inches long, the scale being 1 inch = 200 pounds?

According to the rule given in the foregoing, we multiply each of the lengths by 200, thus:

$$\begin{aligned} 1.20 \times 200 &= 240 \text{ pounds.} \\ 2.11 \times 200 &= 422 \text{ pounds.} \\ 0.75 \times 200 &= 150 \text{ pounds.} \end{aligned}$$

EXAMPLES FOR PRACTICE.

1. To a scale of 1 inch = 500 pounds, how long are the lines to represent forces of 1,250, 675, and 900 pounds?

Ans. 2.5, 1.35, and 1.8 inches

2. To a scale of 1 inch = 80 pounds, how large are the forces represented by $1\frac{1}{4}$ and 1.6 inches?

Ans. 100 and 128 pounds.

5. Concurrent and Non-concurrent Forces. If the lines of action of several forces intersect in a point they are called concurrent forces, or a concurrent system, and the point of intersection is called the *point of concurrence* of the forces. If the lines of action of several forces do not intersect in the same point, they are called non-concurrent, or a non-concurrent system.

We shall deal only with forces whose lines of action lie in the same plane. It is true that one meets with problems in which there are forces whose lines of action do not lie in a plane, but such problems can usually be solved by means of the principles herein explained.

6. Equilibrium and Equilibrant. When a number of forces act upon a body which is at rest, each tends to move it; but the effects of all the forces acting upon that body may counteract or neutralize one another, and the forces are said to be *balanced* or *in equilibrium*. Any one of the forces of a system in equilibrium balances all the others. A single force which balances a number of forces is called the *equilibrant* of those forces.

7. Resultant and Composition. Any force which would produce the same effect (so far as balancing other forces is concerned) as that of any system, is called the *resultant* of that system. Evidently the resultant and the equilibrant of a system of forces must be equal in magnitude, opposite in sense, and act along the same line.

The process of determining the resultant of a system of forces is called composition.

8. Components and Resolution. Any number of forces whose combined effect is the same as that of a single force are called *components* of that force. The process of determining the components of a force is called *resolution.* The most important case of this is the resolution of a force into two components.

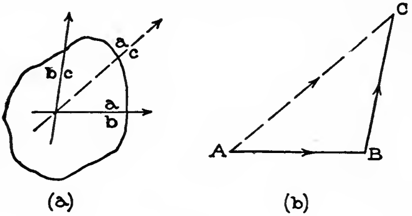
II. CONCURRENT FORCES; COMPOSITION AND RESOLUTION.

9. Graphical Composition of Two Concurrent Forces. *If two forces are represented in magnitude and direction by AB and BC (Fig. 3), the magnitude and direction of their resultant is represented by AC.* This is known as the "triangle law."

The line of action of the resultant is parallel to AC and passes through the point of concurrence of the two given forces; thus the line of action of the resultant is *ac*.

The law can be proved experimentally by means of two spring balances, a drawing board, and a few cords arranged as shown in

Fig. 4. The drawing board (not shown) is set up vertically, then from two nails in it the spring balances are hung, and these in turn support by means of two cords a small ring A from which a heavy body (not shown) is suspended. The ring A is in equilibrium under the action of three forces, a downward force equal to the weight of the suspended body, and two forces exerted by the upper cords whose values or magnitudes can be read from the spring balances. The first force is the equilibrant of the other two. Knowing the weight of the suspended body and the readings of the balances, lay off AB equal to the pull of the right-hand upper string according to some convenient scale, and BC parallel to the left-hand upper string and equal to the force exerted by it. It will then be found that the line joining A and C is vertical, and equals (by scale) the weight of the suspended body. Hence AC, with arrowhead pointing down, represents the equilibrant of the two upward pulls on the ring; and with arrowhead pointing up, it represents the resultant of those two forces.



(a) (b)

Fig. 3.

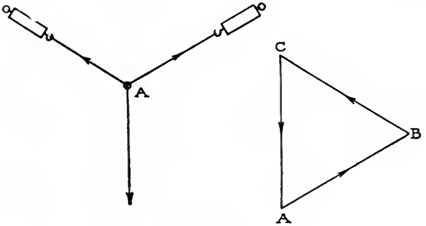


Fig. 4.

Notice especially how the arrowheads are related in the triangle (Fig. 3), and be certain that you understand this law before proceeding far, as it is the basis of most of this subject.

Examples. Fig. 5 represents a board 3 feet square to which forces are applied as shown. It is required to compound or find the resultant of the 100- and 80-pound forces.

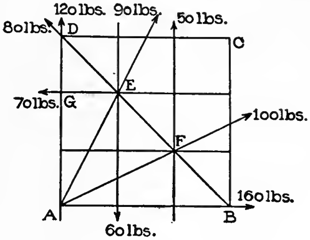
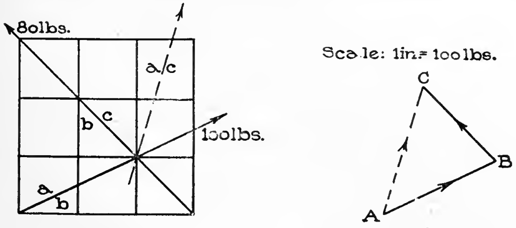


Fig. 5.

First we make a drawing of the board and mark upon it the lines of action of the two forces whose resultant is to be found, as in Fig. 6. Then by some convenient scale, as 100 pounds to the inch, lay off from any convenient point A, a line AB in the direction of the 100-pound force, and make AB one inch long, representing 100 pounds by the scale. Then from B lay off a line BC in the direction of the second force and make BC, 0.8 of an inch long, representing 80 pounds by the scale. Then the line AC, with the arrow pointing *from A to C*, represents the magnitude and direction of the resultant. Since AC equals 1.06 inch, the resultant equals



(a.) (b)

Fig. 6.

$$1.06 \times 100 = 106 \text{ pounds.}$$

The line of action of the resultant is *ac*, parallel to AC and passing through the intersection of the lines of action (the point of concurrence) of the given forces. To complete the notation, we mark these lines of action *ab* and *bc* as in the figure.

EXAMPLES FOR PRACTICE.*

1. Determine the resultant of the 100- and the 120-pound forces represented in Fig. 5.

Ans. The magnitude is 188 pounds; the force acts upward through A and a point 1.62 feet to the right of D.

2. Determine the resultant of the 120- and the 160-pound forces represented in Fig. 5.

Ans. The magnitude is 200 pounds; the force acts upward through A and a point 9 inches below C.

10. Algebraic Composition of Two Concurrent Forces. If the angle between the lines of action of the two forces is not 90 degrees, the algebraic method is not simple, and the graphical is usually preferable. If the angle is 90 degrees, the algebraic method is usually the shorter, and this is the only case herein explained.

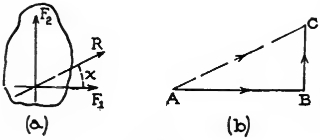


Fig. 7.

Let F_1 and F_2 be two forces acting through some point of a body as represented in Fig. 7*a*. AB and BC represent the magnitudes and direction of F_1 and F_2 respectively; then, according to the triangle law (Art. 9), AC represents the magnitude and direction of the resultant of F_1 and F_2, and the line marked R (parallel to AC) is the line of action of that resultant. Since ABC is a right triangle,

$$(AC)^2 = (AB)^2 + (BC)^2$$

and,

$$\tan CAB = \frac{BC}{AB}.$$

---

* Use sheets of paper not smaller than large letter size, and devote a full sheet to each example. In reading the answers to these examples, remember that the board on which the forces act was stated to be 3 feet square.

Now let R denote the resultant. Since AC, AB, and BC represent R, F_1, and F_2 respectively, and angle CAB $= x$,

$$R^2 = F_1^2 + F_2^2; \text{ or } R = \sqrt{F_1^2 + F_2^2};$$

and,
$$\tan x = F_2 \div F_1.$$

By the help of these two equations we compute the magnitude of the resultant and inclination of its line of action to the force F_1.

Example. It is required to determine the resultant of the 120- and the 160-pound forces represented in Fig. 5.

Let us call the 160-pound force F_1; then,

$$R = \sqrt{160^2 + 120^2} = \sqrt{25{,}600 + 14{,}400}$$
$$= \sqrt{40{,}000} = 200 \text{ pounds};$$

and,
$$\tan x = \frac{120}{160} = \tfrac{3}{4}; \text{ hence } x = 36^\circ\ 52'.$$

The resultant therefore is 200 pounds in magnitude, acts through A (Fig. 5) upward and to the right, making an angle of 36° 52′ with the horizontal.

EXAMPLES FOR PRACTICE.

1. Determine the resultant of the 50- and 70-pound forces represented in Fig. 5.

Ans. $\begin{cases} R = 86 \text{ pounds}; \\ \text{angle between R and 70-pound force} = 35^\circ\ 32'. \end{cases}$

2. Determine the resultant of the 60- and 70-pound forces represented in Fig 5.

Ans. $\begin{cases} R = 92.2 \text{ pounds}; \\ \text{angle between R and 70-pound force} = 40^\circ\ 36'. \end{cases}$

11. Force Polygon. If lines representing the magnitudes and directions of any number of forces be drawn continuous and so that the arrowheads on the lines point the same way around on the series of lines, the figure so formed is called the *force polygon* for the forces. Thus ABCD (Fig. 8) is a force polygon for the 80-, 90-, and 100-pound forces of Fig. 5, for AB, BC, and CD represent the magnitudes and directions of those forces respectively, and the arrowheads point in the same way around, from A to D.

A number of force polygons can be drawn for any system of forces, no two alike. Thus A_1 B_1 C_1 D_1 and A_2 B_2 C_2 D_2 are other force polygons for the same three forces, 80, 90, and 100 pounds. Notice that A_3 B_3 C_3 D_3 is not a force polygon for the three forces although the lines represent the three forces in magnitude and direction. The reason why it is not a force polygon is that the arrowheads do not all point the same way around.

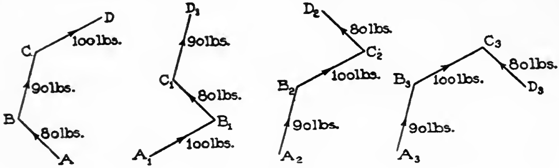


Fig. 8.

A force polygon is not necessarily a closed figure. If a force polygon closes for a system of concurrent forces, then evidently the resultant equals zero.

EXAMPLE FOR PRACTICE.

Draw to the same scale as many different force polygons as you can for the 100-, 120- and 160-pound forces of Fig. 5. Bear in mind that the arrowheads on a force polygon point the same way around.

12. Composition of More Than Two Concurrent Forces. The graphical is much the simpler method; therefore the algebraic one will not be explained. The following is a rule for performing the composition graphically:

(1). Draw a force polygon for the given forces.

(2). Join the two ends of the polygon and place an arrowhead on the joining line pointing from the beginning to the end of the polygon. That line then represents the magnitude and direction of the resultant.

(3). Draw a line through the point of concurrence of the given forces parallel to the line drawn as directed in (2). This line represents the action line of the resultant.

Example. It is required to determine the resultant of the four forces acting through the point E (Fig. 5).

First, make a drawing of the board and indicate the lines of action of the forces as shown in Fig. 9, but without lettering. Then to construct a force polygon, draw from any convenient point A, a line in the direction of one of the forces (the 70-pound force), and make AB equal to 70 pounds according to the scale (70 ÷ 100 = 0.7 inch). Then from B draw a line in the direction of the next force (80-pound), and make BC equal to 0.8 inch, representing 80 pounds. Next draw a line from C in the direction of the third force (90-pound), and make CD equal to 0.9 inch, representing 90 pounds. Finally draw a line from D in the direction of the last force, and make DE equal to 0.6 inch, representing 60 pounds. The force polygon is ABCDE, beginning at A and ending at E.

The second step is to connect A and E and place an arrowhead on the line pointing from A to E. This represents the magnitude and direction of the resultant. Since AE = 1.16 inches, the resultant is a force of

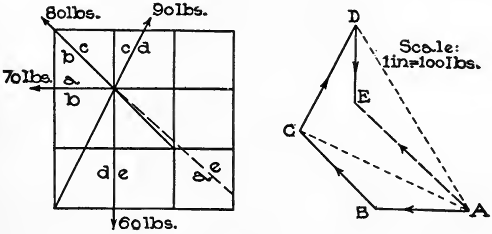


Fig. 9.

$$1.16 \times 100 = 116 \text{ pounds.}$$

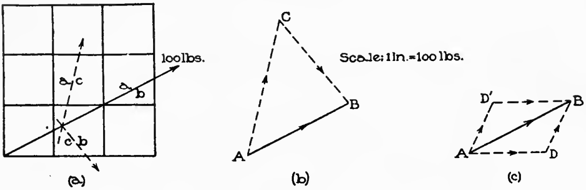
The third step is to draw a line *ae* through the point of concurrence and parallel to AE. This is the line of action of the resultant. (To complete the notation the lines of action of the 70-, 80-, 90- and 60-pound forces should be marked *ab*, *bc*, *cd*, and *de* respectively.)

That the rule for composition is correct can easily be proved. According to the triangle law, AC (Fig. 9), with arrowhead pointing from A to C, represents the magnitude and direction of the resultant of the 70- and 80-pound forces. According to the law, AD, with arrowhead pointing from A to D, represents the magnitude and direction of the resultant of AC and the 90-pound force, hence also of the 70-, 80-, and 90-pound forces. According to the law, AE with arrowhead pointing from A to E, represents the magnitude and direction of the resultant of AD and the 60-pound force. Thus we see that the foregoing rule and the triangle law lead to the same result, but the application of the rule is shorter as in it we do not need the lines AC and AD.

EXAMPLES FOR PRACTICE.

1. Determine the resultant of the four forces acting through the point A (Fig. 5).

Ans. { 380 pounds acting upward through A and a point 0.45 feet below C.



(a) (b) (c)

Fig. 10.

2. Determine the resultant of the three forces acting at the point F (Fig. 5).

Ans. { 155 pounds acting upward through F and a point 0.57 feet to left of C.

13. Graphical Resolution of Force into Two Concurrent Components. This is performed by applying the triangle law inversely. Thus, if it is required to resolve the 100-pound force of Fig. 5 into two components, we draw first Fig. 10 (a) to show the line of action of the force, and then AB, Fig. 10 (b), to represent the magnitude and direction. Then draw from A and B any two lines which intersect, mark their intersection C, and place arrowheads on AC and CB, pointing from A to C and from C to B. Also draw two lines in the space diagram parallel to AC and CB and so that they intersect on the line of action of the 100-pound force, *ab*.

The test of the correctness of a solution like this is to take the two components as found, and find their resultant; if the resultant thus found agrees in magnitude, direction, and sense with the given force (originally resolved), the solution is correct.

Notice that the solution above given is not definite, for the lines drawn from A and B were drawn at random. A force may therefore be resolved into two components in many ways. If, however, the components have to satisfy conditions, there may be but one solution. In the most important case of resolution, the lines of action of the components are given; this case is definite, there being but one solution, as is shown in the following example.

Example. It is required to resolve the 100-pound force (Fig. 5) into two components acting in the lines AE and AB.

Using the space diagram of Fig. 10, draw a line AB in Fig. 10 (c) to represent the magnitude and direction of the 100-pound force, and then a line from A parallel to the line of action of either of the components, and a line from B parallel to the other, thus locating D (or D′). Then AD and DB (or AD′ and D′B) represent the magnitudes and directions of the required components.

EXAMPLES FOR PRACTICE.

1. Resolve the 160-pound force of Fig. 5 into components which act in AF and AE.

Ans. The first component equals 238½ pounds, and its sense is from A to F; the second component equals 119½ pounds, and its sense is from E to A.

2. Resolve the 50-pound force of Fig. 5 into two components, acting in FA and FB.

Ans. The first component equals 37.3 pounds, and its sense is from A to F; the second component equals 47.0 pounds, and its sense is from B to F.

14. Algebraic Resolution of a Force Into Two Components. If the angle between the lines of action of the two components is not 90 degrees, the algebraic method is not simple and the graphical method is usually preferable. When the angle is 90 degrees, the algebraic method is usually the shorter, and this is the only case herein explained.

Let F (Fig. 11) be the force to be resolved into two components acting in the lines OX and OY. If AB is drawn to represent the magnitude and direction of F, and lines be drawn from A and B parallel to OX and OY, thus locating C, then AC and BC with arrowheads as shown represent the magnitudes and directions of the required components.

Now if F′ and F″ represent the components acting in OX and OY, and x and y denote the angles between F and F′, and F and F″ respectively, then AC and BC represent F′ and F″, and the angles BAC and ABC equal x and y respectively. From the right triangle ABC it follows that

$$F' = F \cos x, \quad \text{and } F'' = F \cos y.$$

If a force is resolved into two components whose lines of action are at right angles to each other, each is called a *rectangular component* of that force. Thus F′ and F″ are rectangular components of F.

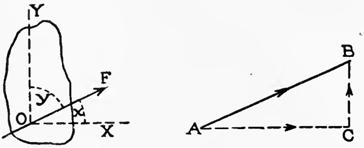


Fig. 11.

The foregoing equations show that *the rectangular component of a force along any line equals the product of the force and the cosine of the angle between the force and the line.* They show also that *the rectangular component of a force along its own line of action equals the force, and its rectangular component at right angles to the line of action equals zero.*

Examples. 1. A force of 120 pounds makes an angle of 22 degrees with the horizontal. What is the value of its component along the horizontal?*

Since cos $22° = 0.927$, the value of the component equals $120 \times 0.927 = 111.24$ pounds.

2. What is the value of the component of the 90-pound force of Fig. 5 along the vertical?

First we must find the value of the angle which the 90-pound force of Fig. 5 makes with the vertical.

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* When nothing is stated herein as to whether a component is rectangular or not, then rectangular component is meant.

LIDGERWOOD-CRAWFORD SCRAPER BUCKET EXCAVATOR
Courtesy of Lidgerwood Manufacturing Company, New York City

Since $\tan \text{EAG} = \frac{\text{EG}}{\text{AG}} = \frac{1}{2}$, angle $\text{EAG} = 26° \, 34'$.

Hence the value of the desired component equals

$$90 \times \cos 26° \, 34' = 90 \times 0.8944 = 80.50 \text{ pounds.}$$

EXAMPLES FOR PRACTICE.

1. Compute the horizontal and vertical components of a force of 80 pounds whose angle with the horizontal is 60 degrees

Ans. { 40 pounds.
69.28 pounds.

2. Compute the horizontal and vertical components of the 100-pound force in Fig. 5. What are their senses?

Ans. { 89.44 pounds to the right.
44.72 pounds upwards.

3. Compute the component of the 70-pound force in Fig. 5 along the line EA. What is the sense of the component?

Ans. 31. 29 pounds ; E to A.

III. CONCURRENT FORCES IN EQUILIBRIUM.

15. Condition of Equilibrium Defined. By condition of equilibrium of a system of forces is meant a relation which they must fulfill in order that they may be in equilibrium or a relation which they fulfill when they are in equilibrium.

In order that any system may be in equilibrium, or be balanced, their equilibrant, and hence their resultant, must be zero, and this is a condition of equilibrium. If a system is known to be in equilibrium, then, since the forces balance among themselves, their equilibrant and hence their resultant also equals zero. This (the necessity of a zero resultant) is known as the general condition of equilibrium for it pertains to all kinds of force systems. For special kinds of systems there are special conditions, some of which are explained in the following.

16. Graphical Condition of Equilibrium. *The "graphical condition of equilibrium" for a system of concurrent forces is that the polygon for the forces must close.* For if the polygon closes, then the resultant equals zero as was pointed out in Art 11.

By means of this condition we can solve problems relating to concurrent forces which are known to be in equilibrium. The most common and practically important of these is the following:

The forces of a concurrent system in equilibrium are all known except two, but the lines of action of these two are known; it is required to determine their magnitudes and directions. This problem arises again and again in the "analysis of trusses" (Arts. 23 to 26) but will be illustrated first in simpler cases.

Example. 1. Fig. 12 represents a body resting on an inclined plane being prevented from slipping down by a rope fastened to it as shown. It is required to determine the pull or tension on the rope and the pressure of the plane if the body weighs 120 pounds and the surface of the plane is perfectly smooth.*

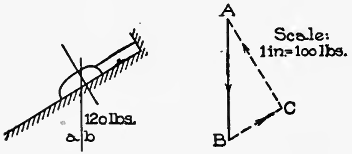

Fig. 12.

There are three forces acting upon the body, namely, its weight directly downwards, the pull of the rope and the reaction or pressure of the plane which, as explained in the footnote, is perpendicular to the plane. We now draw the polygon for these forces making it close; thus draw AB (1.2 inches long) to represent the magnitude and direction of the weight, 120 pounds, then from A a line parallel to either one of the other forces, from B a line parallel to the third, and mark the intersection of these two lines C; then ABCA is the polygon. Since the arrowhead on AB must point down and since the arrowheads in any force polygon must point the same way around, those on BC and CA must point as shown.

Hence BC (0.6 inch, or 60 pounds) represents the magnitude and direction of the pull of the rope and CA (1.04 inches, or 104

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* By "a perfectly smooth" surface is meant one which offers no resistance to the sliding of a body upon it. Strictly, there are no such surfaces, as all real surfaces exert more or less frictional resistance. But there are surfaces which are practically perfectly smooth. We use perfectly smooth surfaces in some of our illustrations and examples for the sake of simplicity, for we thus avoid the force of friction, and the reaction or force exerted by such a surface on a body resting upon it is perpendicular to the surface.

pounds) represents the magnitude and direction of the pressure of the plane on the body.

2. A body weighing 200 pounds is suspended from a small ring which is supported by means of two ropes as shown in Fig. 13. It is required to determine the pulls on the two ropes.

There are three forces acting on the ring, namely the downward force equal to the weight of the body and the pulls of the two ropes. Since the ring is at rest, the three forces balance or are in equilibrium, and hence their force polygon must close. We proceed to draw the polygon and in making it close, we shall determine the values of the unknown pulls. Thus, first draw AB (1 inch long) to represent the magnitude and direction of the known force, 200 pounds; the arrowhead on it must point down. Then from A a line parallel to one of the ropes and from B a line parallel to the other and mark their intersection C. ABCA is the polygon for the three forces, and since in any force polygon the arrows point the same way around, we place arrowheads on BC and CA as shown. Then BC and CA represent the magnitudes and directions of the pulls exerted on the ring by the right- and left-hand ropes respectively.

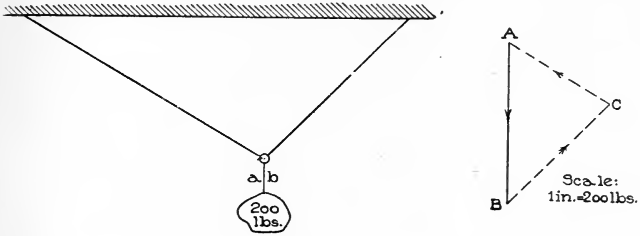

Fig. 13.

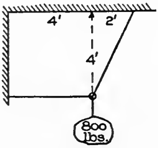

Fig. 14.

BC = 0.895 inches and represents 179 pounds.
CA = 0.725 inches and represents 145 pounds.

The directions of the pulls are evident in this case and the arrowheads are superfluous, but they are mentioned to show how to place them and what they mean so that they may be used when necessary. To complete the notation, the rope at the right should be marked *bc* and the other *ca*.

EXAMPLES FOR PRACTICE.

1. Fig. 14 represents a body weighing 800 pounds suspended from a ring which is supported by two ropes as shown. Compute the pulls on the ropes.

Ans. { Pull in the horizontal rope = 400 pounds.
Pull in the inclined rope = 894 pounds.

2. Suppose that in Fig. 12 the rope supporting the body on the plane is so fastened that it is horizontal. Determine the pull on the rope and the pressure on the plane if the inclination of the plane to the horizontal is 30 degrees and the body weighs 120 pounds.

Ans. { Pull = 68.7 pounds.
Pressure = 138 pounds.

3. A sphere weighing 400 pounds rests in a V-shaped trough, the sides of which are inclined at 60 degrees with the horizontal. Compute the pressures on the sphere.

Ans. 400 pounds.

17. Algebraic Conditions of Equilibrium. Imagine each one of the forces of a concurrent system in equilibrium replaced by its components along two lines at right angles to each other, horizontal and vertical for example, through the point of concurrence. Evidently the system of components would also be in equilibrium. Now since the components act along one of two lines (horizontal or vertical), all the components along each line must balance among themselves for if either set of components were not balanced, the body would be moved along that line. Hence we state that the conditions of equilibrium of a system of concurrent forces are that the resultants of the two sets of components of the forces along any two lines at right angles to each other must equal zero.

If the components acting in the same direction along either of the two lines be given the plus sign and those acting in the other direction, the negative sign, then it follows from the foregoing that the condition of equilibrium for a concurrent system is that *the algebraic sums of the components of the forces along each of two lines at right angles to each other must equal zero.*

Examples. 1. It is required to determine the pull on the rope and the pressure on the plane in Example 1, Art. 16 (Fig. 12), it being given that the inclination of the plane to the horizontal is 30 degrees.

Let us denote the pull of the rope by F_1 and the pressure of the plane by F_2. The angles which these forces make with the horizontal are 30° and 60°, respectively; hence

the horizontal component of $F_1 = F_1 \times \cos 30° = 0.8660\ F_1$,
and " " " " $F_2 = F_2 \times \cos 60° = 0.5000\ F_2$;
also " " " " the weight $= 0$.

The angles which F_1 and F_2 make with the vertical are 60° and 30° respectively, hence

the vertical component of $F_1 = F_1 \times \cos 60° = 0.5000\ F_1$,
and the vertical component of $F_2 = F_2 \times \cos 30° = 0.8660\ F_2$;
also the vertical component of the weight $= 120$.

Since the three forces are in equilibrium, the horizontal and the vertical components are balanced, and hence

$$0.866\ F_1 = 0.5\ F_2$$

and

$$0.5\ F_1 + 0.866\ F_2 = 120.$$

From these two equations F_1 and F_2 may be determined; thus from the first,

$$F_2 = \frac{0.866}{0.5}\ F_1 = 1.732\ F_1.$$

Substituting this value of F_2 in the second equation we have

$$0.5\ F_1 + 0.866 \times 1.732\ F_1 = 120,$$

or

$$2\ F_1 = 120;$$

hence,

$$F_1 = \frac{120}{2} = 60 \text{ pounds},$$

and

$$F_2 = 1.732 \times 60 = 103.92 \text{ pounds}.$$

2. It is required to determine the pulls in the ropes of Fig. 13 by the algebraic method, it being given that the angles which the left- and right-hand ropes make with the ceiling are 30 and 70 degrees respectively and the body weighs 100 pounds.

Let us denote the pulls in the right- and left-hand ropes by F_1 and F_2 respectively. Then

the horizontal component of $F_1 = F_1 \times \cos 70° = 0.342\ F_1$,
the horizontal component of $F_2 = F_2 \times \cos 30° = 0.866\ F_2$,
the horizontal component of the weight $= 0$,
the vertical component of $F_1 = F_1 \times \cos 20° = 0.9397\ F_1$,
the vertical component of $F_2 = F_2 \times \cos 60° = 0.500\ F_2$,
and the vertical component of the weight $= 100$.

Now since these three forces are in equilibrium, the horizontal and the vertical components balance; hence

$$0.342\ F_1 = 0.866\ F_2$$

and

$$0.9397\ F_1 + 0.5\ F_2 = 100.$$

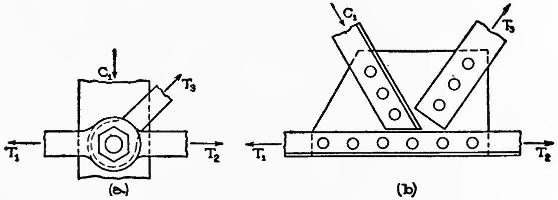

Fig. 15.

These equations may be solved for the unknown forces; thus from the first,

$$F_1 = \frac{0.866}{0.342} F_2 = 2.532\ F_2.$$

Substituting this value of F_1 in the second equation, we get

$$0.9397 \times 2.532\ F_2 + 0.5\ F_2 = 100,$$

or,

$$2.88\ F_2 = 100;$$

hence

$$F_2 = \frac{100}{2.88} = 34.72 \text{ pounds},$$

and

$$F_1 = 2.532 \times 34.72 = 87.91 \text{ pounds}.$$

EXAMPLES FOR PRACTICE.

1. Solve Ex. 1, Art. 16 algebraically. (First determine the angle which the inclined rope makes with the horizontal; you should find it to be 63° 26′.)

2. Solve Ex. 2, Art. 16 algebraically.
3. Solve Ex. 3, Art. 16 algebraically.

IV. ANALYSIS OF TRUSSES; "METHOD OF JOINTS."

18. **Trusses.** A truss is a frame work used principally to support loads as in roofs and bridges. Fig. 16, 25, 26 and 27 represent several forms of trusses. The separate bars or rods, $\overline{12}$, $\overline{23}$, etc. (Fig. 16) are called *members* of the truss and all the parts immediately concerned with the connection of a number of members at one place constitute a *joint*. A "pin joint" is shown in Fig. 15 (a) and a "riveted joint" in 15 (b).

19. **Truss Loads.** The loads which trusses sustain may be classified into fixed, or dead, and moving or live loads. A fixed, or dead load, is one whose place of application is fixed with reference to the truss, while a moving or live load is one whose place of application moves about on the truss.

Roof truss loads are usually fixed, and consist of the weight of the truss, roof covering, the snow, and the wind pressure, if any. Bridge truss loads are fixed and moving, the first consisting of the weights of the truss, the floor or track, the snow, and the wind pressure, and the second of the weight of the passing trains or wagons.

In this paper we shall deal only with trusses sustaining fixed loads, trusses sustaining moving loads being discussed later.

Weight of Roof Trusses. Before we can design a truss, it is necessary to make an estimate of its own weight; the actual weight can be determined only after the truss is designed. There are a number of formulas for computing the probable weight of a truss, all derived from the actual weights of existing trusses. If W denotes the weight of the truss, l the span or distance between supports in feet and a the distance between adjacent trusses in feet, then for steel trusses

$$W = al\left(\frac{l}{25} + 1\right);$$

and the weight of a wooden truss is somewhat less.

Roof Covering. The beams extending between adjacent trusses to support the roof are called *purlins*. On these there are sometimes placed lighter beams called *rafters* which in turn support *roof boards* or "*sheathing*" and the other covering. Sometimes the purlins are spaced closely, no rafters being used.

The following are weights of roof materials in *pounds per square foot* of roof surface:

Sheathing: Boards, 3 to 5.
Shingling: Tin, 1; wood shingles, 2 to 3; iron, 1 to 3; slate, 10; tiles, 12 to 25.
Rafters: 1.5 to 3.
Purlins: Wood, 1 to 3; iron, 2 to 4.

Snow Loads. The weight of the snow load that may have to be borne depends, of course, on location. It is usually taken from 10 to 30 pounds per square foot of area covered by the roof.

Wind Pressure. Wind pressure per square foot depends on the velocity of the wind and the inclination of the surface on which it blows to the direction of the wind. A horizontal wind blowing at 90 miles per hour *produces a pressure of about 40 pounds per square foot on a surface perpendicular to the wind, while on surfaces inclined, the pressures are as follows:

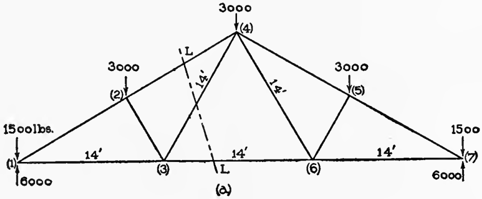

Fig. 16.

10° to horizontal, 15 lb. per sq. ft.
20° to horizontal, 24 lb. per sq. ft.
30° to horizontal, 32 lb. per sq. ft.
40° to horizontal, 36 lb. per sq. ft.
50°-90° to horizontal, 40 lb. per sq. ft.

The wind pressure on an inclined surface is practically perpendicular to the surface.

20. **Computation of "Apex Loads."** The weight of the roof covering including rafters and purlins comes upon the trusses at the points where they support the purlins; likewise the

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* For pressure per sq. ft. using other values than 90 miles, use formula $P = .004\, V^2$, where P = pressure per sq. ft. in lb. and V = velocity of wind in miles per hr.

pressure due to wind and snow. Sometimes all the purlins are supported at joints; in such cases the loads mentioned act upon the truss at its joints. However, the roof, snow, and wind loads are always assumed to be applied to the truss at the upper joints of the trusses. This assumption is equivalent to neglecting the bending effect due to the pressure of those purlins which are not supported at joints. This bending effect can be computed separately.

The weight of the truss itself is assumed to come upon the truss at its upper joints; this, of course, is not exactly correct. Most of the weight does come upon the upper joints for the upper members are much heavier than the lower and the assumption is in most cases sufficiently correct.

Examples. 1. It is required to compute the apex loads for the truss represented in Fig. 16, it being of steel, the roof such that it weighs 15 pounds per square foot, and the distance between adjacent trusses 14 feet.

The span being 42 feet, the formula for weight of truss (Art. 19) becomes

$$14 \times 42 \left(\frac{42}{25} + 1\right) = 1{,}575.84 \text{ pounds.}$$

The length $\overline{14}$ scales about $24\frac{1}{4}$ feet, hence the area of roofing sustained by one truss equals

$$48\tfrac{1}{2} \times 14 = 679 \text{ square feet,}$$

and the weight of the roofing equals

$$679 \times 15 = 10{,}185 \text{ pounds.}$$

The total load equals

$$1{,}575.84 + 10{,}185 = 11{,}760.84 \text{ pounds.}$$

Now this load is to be proportioned among the five upper joints, but joints numbered (1) and (7) sustain only one-half as much load as the others. Hence for joints (1) and (7) the loads equal

$$\frac{1}{8} \text{ of } 11{,}760 = 1{,}470,$$

and for (2), (4) and (5) they equal

$$\frac{1}{4} \text{ of } 11{,}760 = 2{,}940 \text{ pounds.}$$

As the weight of the truss is only estimated, the apex loads would be taken as 1,500 and 3,000 pounds for convenience.

2. It is required to compute the apex loads due to a snow load on the roof represented in Fig. 16, the distance between trusses being 14 feet.

The horizontal area covered by the roof which is sustained by one truss equals

$$42 \times 14 = 588 \text{ square feet.}$$

If we assume the snow load equal to 10 pounds per horizontal square foot, than the total snow load borne by one truss equals

$$588 \times 10 = 5{,}880 \text{ pounds.}$$

This load divided between the upper joints makes

$$\frac{1}{8} \times 5{,}880 = 735 \text{ pounds}$$

at joints (1) and (7); and

$$\frac{1}{4} \times 5{,}880 = 1{,}470 \text{ pounds}$$

at the joints (2), (4), and (5).

3. It is required to compute the apex loads due to wind pressure on the truss represented in Fig. 16, the distance between trusses being 14 ft.

The inclination of the roof to the horizontal can be found by measuring the angle from a scale drawing with a protractor or by computing as follows: The triangle $\overline{346}$ is equilateral, and hence its angles equal 60 degrees and the altitude of the triangle equals

$$14 \times \sin 60 = 12.12 \text{ feet.}$$

The tangent of the angle $\overline{413}$ equals

$$\frac{12.12}{21} = 0.577,$$

and hence the angle equals 30 degrees.

According to Art. 19, 32 pounds per square foot is the proper value of the wind pressure. Since the wind blows only on one side of the roof at a given time, the pressure sustained by one truss is the wind pressure on one half of the area of the roof sustained by one truss, that is

$$14 \times 24\tfrac{1}{4} \times 32 = 10{,}864 \text{ pounds.}$$

One half of this pressure comes upon the truss at joint (2) and one fourth at joints (1) and (4).

EXAMPLES FOR PRACTICE.

1. Compute the apex loads due to weight for the truss represented in Fig. 27 if the roofing weighs 12 pounds per square foot and the trusses (steel) are 12 feet apart.

Ans. As shown in Fig. 27.

2. Compute the apex loads due to a snow load of 20 pounds per square foot on the truss of Fig. 25, the distance between trusses being 15 feet.

Ans.
For joints (4) and (7), 1,200 pounds.
For joints (1) and (3), 3,600 pounds.
For joint (2) , 4,800 pounds.

3. Compute the apex loads due to wind for the truss of Fig. 26, the distance between trusses being 15 feet.

Ans. Pressure equals practically 29 pounds per square foot. Load at joint (2) is 4,860 and at joints (1) and (3) 2,430 pounds.

21. **Stress in a Member.** If a truss is loaded only at its joints, its members are under either tension or compression, but the weight of a member tends to bend it also, unless it is vertical. If purlins rest upon members between the joints, then they also bend these members. We have therefore tension members, compression members, and members subjected to bending stress combined with tension or compression. Calling simple tension or compression *direct stress* as in "Strength of Materials," then the process of determining the direct stress in the members is called "analyzing the truss."

22. **Forces at a Joint.** By "forces at a joint" is meant all the loads, weights, and reactions which are applied there and the forces which the members exert upon it. These latter are pushes for compression members and pulls for tension members, in each case acting along the axis of the member. Thus, if the horizontal

and inclined members in Fig. 15 are in tension, they exert pulls on the joint, and if the vertical is a compression member, it exerts a push on the joint as indicated. *The forces acting at a joint are therefore concurrent and their lines of action are always known.*

23. **General Method of Procedure.** The forces acting at a joint constitute a system in equilibrium, and since the forces are concurrent and their lines of action are all known, we can determine the magnitude of two of the forces if the others are all known; for this is the important problem mentioned in Art. 16 which was illustrated there and in Art. 17.

Accordingly, after the loads and reactions on a truss, which is to be analyzed, have been ascertained*, we look for a joint at which only two members are connected (the end joints are usually such). Then we consider the forces at that joint and determine the two unknown forces which the two members exert upon it by methods explained in Arts. 16 or 17. The forces so ascertained are the direct stresses, or stresses, as we shall call them for short, and *they are the values of the pushes or pulls which those same members exert upon the joints at their other ends.*

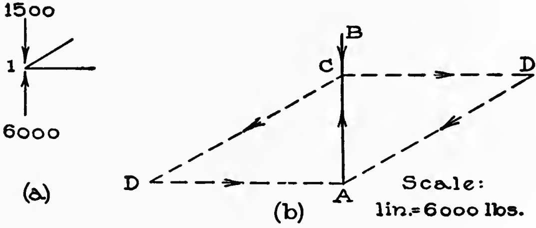

Fig. 17.

Next we look for another joint at which but two unknown forces act, then determine these forces, and continue this process until the stress in each member has been ascertained. We explain further by means of

Examples. 1. It is desired to determine the stresses in the

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* How to ascertain the values of the reactions is explained in Art. 37. For the present their values in any given case are merely stated.

members of the steel truss, represented in Fig. 16, due to its own weight and that of the roofing assumed to weigh 12 pounds per square foot. The distance between trusses is 14 feet.

The apex loads for this case were computed in Example 1, Art. 20, and are marked in Fig. 16. Without computation it is plain that each reaction equals one-half the total load, that is, $\frac{1}{2}$ of 12,000, or 6,000 pounds.

The forces at joint (1) are four in number, namely, the left reaction (6,000 pounds), the load applied there (1,500 pounds), and the forces exerted by members $\overline{12}$ and $\overline{13}$. For clearness, we represent these forces so far as known in Fig. 17 (*a*); we can determine the two unknown forces by merely constructing a closed force polygon for all of them. To construct the polygon, we first represent the known forces; thus AB (1 inch long with arrowhead pointing up) represents the reaction and BC ($\frac{1}{4}$ inch long with arrowhead pointing down) represents the load. Then from A and C we draw lines parallel to the two unknown forces and mark their intersection D (or D′). Then the polygon is ABCDA, and CD (1.5 inches = 9,000 pounds) represents the force exerted by the member $\overline{12}$ on the joint and DA (1.3 inches = 7,800 pounds) represents the force exerted by the member $\overline{13}$ on the joint. The arrowheads on BC and CD must point as shown, in order that all may point the same way around, and hence the force exerted by member $\overline{12}$ acts toward the joint and is a push, and that exerted by $\overline{13}$ acts away from the joint and is a pull. It follows that $\overline{12}$ is in compression and $\overline{13}$ in tension.

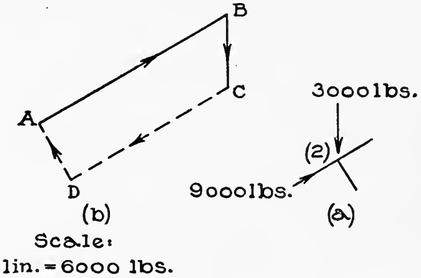

Fig. 18.

If D′ be used, the same results are reached, for the polygon is ABCD′A with arrowheads as shown, and it is plain that CD′ and DA also D′A and CD are equal and have the same sense. But one of these force polygons is preferable for reasons explained later.

Since $\overline{12}$ is in compression, it exerts a push (9,000 pounds) on joint (2) as represented in Fig. 18 (*a*), and since $\overline{13}$ is in tension it exerts a pull (7,800 pounds) on joint (3) as represented in Fig. 19 (*a*).

The forces at joint (2) are four in number, the load (3,000 pounds), the force 9,000 pounds, and the force exerted upon it by the members $\overline{24}$ and $\overline{23}$; they are represented as far as known in Fig. 18 (*a*). We determine the unknown forces by constructing a closed polygon for all of them. Representing the known forces first, draw AB (1.5 inches long with arrowhead pointing up) to represent the 9,000 pound force and BC ($\frac{1}{2}$ inch long with arrowhead pointing down) to represent the load of 3,000 pounds. Next from A and C draw lines parallel to the two unknown forces and mark their intersection D; then the force polygon is ABCDA and the arrowheads on CD and DA must point as shown. CD (1.25 inches = 7,500 pounds) represents the force exerted on joint (2) by $\overline{24}$; since it acts toward the joint the force is a push and member $\overline{24}$ is in compression. DA (0.43 inches = 2,580 pounds) represents the force exerted on the joint by member $\overline{23}$; since the force acts toward the joint it is a push and the member is in compression. Member 23 therefore exerts a push on joint (3) as shown in Fig. 19 (*a*).

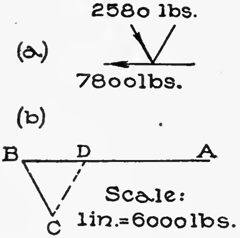

Fig. 19.

At joint (3) there are four forces, 7,800 pounds, 2,580 pounds, and the forces exerted on the joint by members $\overline{34}$ and $\overline{36}$. To determine these, construct the polygon for the four forces. Thus, AB (1.3 inches long with arrowhead pointing to the left) represents the 7,800-pound force and BC (0.43 inches long with arrowheads pointing down) represents the 2,580-pound force. Next draw from A and C two lines parallel to the unknown forces and mark their intersection D; then the force polygon is ABCDA and the arrowhead on CD and DA must point upward and to the right respectively. CD (0.43 inches = 2,580 pounds) represents the force exerted on the joint by member $\overline{34}$; since the force acts away from the joint it is a pull and the member is in tension. DA (0.87 inches = 5,220 pounds) represents the force exerted upon the joint by the member $\overline{36}$; since the force acts away from the joint, it is a pull and the member is in tension.

We have now determined the amount and kind of stress in members $\overline{12}$, $\overline{13}$, $\overline{23}$, $\overline{24}$, $\overline{34}$ and $\overline{36}$. It is evident that the stress in each of the members on the right-hand side is the same as the stress in the corresponding one on the left-hand side; hence further analysis is unnecessary.

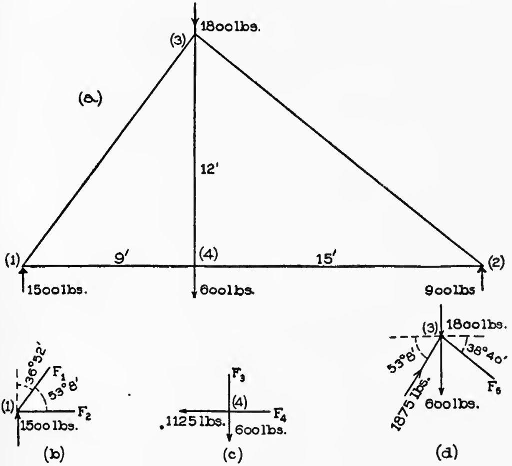

Fig. 20.

2. It is required to analyze the truss represented in Fig. 20 (*a*), the truss being supported at the ends and sustaining two loads, 1,800 and 600 pounds, as shown. (For simplicity we assumed values of the load; the lower one might be a load due to a suspended body. We shall solve algebraically.)

The right and left reactions equal 900 and 1,500 pounds as is shown in Example 1, Page 56. At joint (1) there are three forces, namely, the reaction 1,500 pounds and the forces exerted by members $\overline{13}$ and $\overline{14}$, which we will denote by F_1 and F_2 respect

ively. The three forces are represented in Fig. 20 (*b*) as far as they are known. These three forces being in equilibrium, their horizontal and their vertical components balance. Since there are but two horizontal components and two vertical components it follows that (for balance of the components) F_1 must act downward and F_2 toward the right. Hence member $\overline{13}$ pushes on the joint and is under compression while member $\overline{14}$ pulls on the joint and is under tension. From the figure it is plain that
the horizontal component of $F_1 = F_1 \cos 53° \, 8' = 0.6\,F_1$*,
the horizontal component of $F_2 = F_2$,
the vertical component of $F_1 = F_1 \cos 36° \, 52' = 0.8\,F_1$,
and the vertical component of the reaction $= 1{,}500$.

Hence $$0.6\,F_1 = F_2, \text{ and } 0.8\,F_1 = 1{,}500;$$

or, $$F_1 = \frac{1{,}500}{0.8} = 1{,}875 \text{ pounds},$$

and $$F_2 = 0.6 \times 1{,}875 = 1{,}125 \text{ pounds.}$$

Since members $\overline{14}$ and $\overline{13}$ are in tension and compression respectively, $\overline{14}$ pulls on joint (4) as shown in Fig. 20 (*c*) and $\overline{13}$ pushes on joint (3) as shown in Fig. 20 (*d*).

The forces acting at joint (4) are the load 600 pounds, the pull 1,125 pounds, and the forces exerted by members $\overline{34}$ and $\overline{24}$; the last two we will call F_3 and F_4 respectively. The four forces being horizontal or vertical, it is plain without computation that for balance F_4 must be a pull of 1,125 pounds and F_3 one of 600 pounds. Since members $\overline{42}$ and $\overline{43}$ pull on the joint they are both in tension.

Member $\overline{43}$, being in tension, pulls down on joint (3) as shown in Fig. 20 (*d*). The other forces acting on that joint are the load 1,800 pounds, the push 1,875 pounds, the pull 600 pounds, and the force exerted by member $\overline{32}$ which we will call F_5. The only one of these forces having horizontal components are 1,875 and F_5; hence in order that these two components may balance, F_5 must act toward the left. F_5 is therefore a push and the member $\overline{32}$ is under compression.

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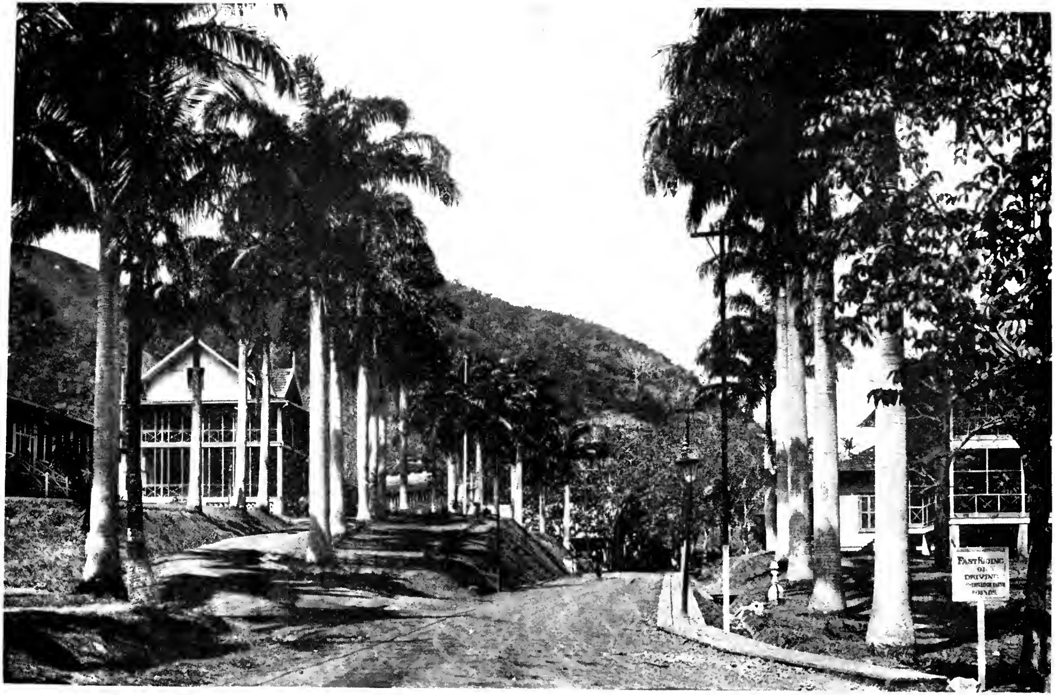
* The angles can be computed from the dimensions of the truss: often they can be ascertained easiest by scaling them with a protractor from a large size drawing of the truss.



VIEW OF HOSPITAL GROUNDS FROM ENTRANCE ANCON

Courtesy of Panama Canal Commission, United States Government, Washington, D. C.

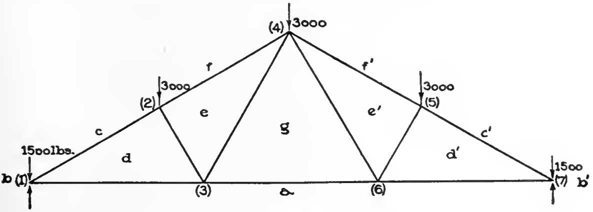
The horizontal component of 1,875 = 1,875 × cos 53° 8′ = 1,125; and the horizontal component of $F_5 = F_5 \times \cos 38° 40' = 0.7808\ F_5$.

Hence $$0.7808\ F_5 = 1{,}125,$$

or, $$F_5 = \frac{1{,}125}{.7808} = 1{,}440 \text{ pounds.}$$

(This same truss is analyzed graphically later.)

24. **Notation for Graphical Analysis of Trusses.** The notation described in Art. 3 can be advantageously systematized in this connection as follows: Each triangular space in the diagram of the truss and the spaces between consecutive lines of action of the loads and reactions should be marked by a small letter (see Fig. 21 *a*). Then the two letters on opposite sides of any line serve to denote that line and the same large letters are used to denote the force acting in that line. Thus *cd* (Fig. 21 *a*) refers to the member $\overline{12}$ and CD should be used to stand for the force or stress in that member.



(a)

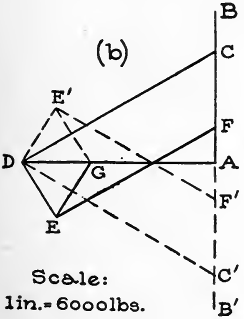
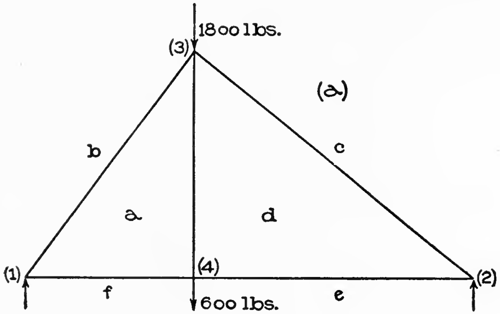


Fig. 21.

25. **Polygon for a Joint.** In drawing the polygon for all the forces at a joint, it is advantageous to represent the forces in the order in which they occur about the joint. Evidently there are always two possible orders thus (see Fig. 20 *d*) F_5, 600, 1,875, and 1,800 is one order around, and F_5, 1,800, 1,875, and 600 is another. The first is called a clockwise order and the second counter-clockwise.

A force polygon for the forces at a joint in which the forces are represented in either order in which they occur about the joint is called *a polygon for the joint*, and it will be called a clockwise or counter-clockwise polygon according as the order followed is clockwise or counter-clockwise. Thus in Fig. 17 (*b*), ABCDA is a clockwise polygon for joint (1). ABCD′A is a polygon for the *forces* at the joint; it is not a polygon for the *joint* because the order in which the forces are represented in that polygon is not the same as either order in which they occur about the joint.



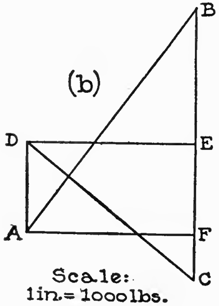


Fig. 22.

(Draw the counter-clockwise polygon for the joint and compare it with ABCDA and ABCD′A.)

26. **Stress Diagrams.** If the polygons for all the joints of a truss are drawn separately as in Example 1, Art. 23, the stress in each member will have been represented twice. It is possible to combine the polygons so that it will be unnecessary to represent the stress in any one member more than once, thus reducing the number of lines to be drawn. Such a combination of force polygons is called a stress diagram.

Fig 21 (*b*) is a stress diagram for the truss of Fig. 21 (*a*) same as the truss of Fig. 16. It will be seen that the part of the stress diagram consisting of solid lines is a combination of separate polygons previously drawn for the joints on the left half of the truss (Figs. 17, 18 and 19.) It will also be seen that the polygons are all clockwise, but counter-clockwise polygons could be combined into a stress diagram.

To Construct a Stress Diagram for a Truss Under Given Loads.

1. Determine the reactions*.

2. Letter the truss diagram as explained in Art. 24.

3. Construct a force polygon for all the forces applied to the truss (loads and reactions) representing them in the order in which they occur around the truss, clockwise or counter-clockwise. (The part of this polygon representing the loads is called a load line.)

4. On the sides of that polygon, construct the polygons for all the joints. They must be clockwise or counter-clockwise according as the polygon for the loads and reactions is clockwise or counter-clockwise. (The first polygon for a joint must be drawn for one at which but two members are connected—the joints at the supports are usually such. Then one can draw in succession the polygons for joints at which there are not more than two unknown forces until the stress diagram is completed.)

Example. It is desired to construct a stress diagram for the truss represented in Fig. 22 (a), it being supported at its ends and sustaining two loads of 1,800 and 600 pounds as shown.

The right and left reactions are 900 and 1,500 pounds as is shown in Example 1, Art. 37. Following the foregoing directions we first letter the truss, as shown. Then, where convenient, draw the polygon for all the loads and reactions, beginning with any force, but representing them in order as previously directed. Thus, beginning with the 1,800-pound load and following the clockwise order for example, lay off a line 1.8 inch in length representing 1,800 pounds (scale 1,000 pounds to an inch); since the line of action of the force is bc, the line is to be marked BC and B should be placed at the upper end of the line for a reason which

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* As already stated, methods for determining reactions are explained in Art. 37; for the present the values of the reactions in any example will be given.

will presently appear. The next force to be represented is the right reaction, 900 pounds; hence from C draw a line upward and 0.90 inch long. The line of action of this force being *ce*, the line just drawn should be marked CE and since C is already at the lower end, we mark the upper end E. (The reason for placing B at the upper end of the first line is now apparent.) The next force to be represented is the 600-pound load; therefore we draw from E a line downward and 0.6 inch long, and since the line of action of that force is *ef*, mark the lower end of the line F. The next force to be represented is the left reaction, 1,500 pounds, hence we draw a line 1.5 inches long and upward from F. If the lines have been carefully laid off, the end of the last line should fall at B, that is, the polygon should close.

We are now ready to draw polygons for the joints; we may begin at the right or left end as we please but we should bear in mind that the polygons must be clockwise because the polygon for the loads and reactions (BCEFB) is such an one. Beginning at the right end for example, notice that there are three forces there, the right reaction, *de* and *dc*. The right reaction is represented by CE, hence from E draw a line parallel to *de* and from C one parallel to *dc* and mark their intersection D. Then CEDC is the clockwise polygon for the right-hand joint, and since CE acts up, the arrows on ED and DC would point to the left and down respectively. It is better to place the arrows near the joint to which they refer than in the stress diagram; this is left to the student. The force exerted by member *ed* on joint (2) being a pull, *ed* is under tension, and since ED measures 1.12 inches, the value of that tension is 1,120 pounds. The force exerted by member *dc* on joint (2) being a push, *dc* is under compression, and since DC measures 1.44 inches, the value of that compression is 1,440 pounds.

The member *dc* being in compression, exerts a push on the joint (3) and the member *de* being in tension, exerts a pull on the joint (4). Next indicate this push and pull by arrows.

We might now draw the polygon for any one of the remaining joints, for there are at each but two unknown forces. We choose to draw the polygon for the joint (3). There are four forces acting there, namely, the 1,800-pound load, the push (1,440 pounds) exerted by *cd*, and the forces exerted by members *ad* and *ab*, unknown in amount and sense. Now the first two of these forces are already represented in the stress diagram by BC and CD, therefore we draw from D a line parallel to *da* and from B a line parallel to *ba* and mark their intersection A. Then BCDAB is the polygon for the joint, and since the arrowhead on BC and CD would point down and up respectively, DA acts down and AB up; hence place arrowheads in those directions on *da* and *ab* near the joint being considered. These arrows signify that member *da* pulls on the joint and *ba* pushes; hence *da* is in tension and *ba* in compression. Since DA and AB measure 0.6 and 1.88 inches respectively, the values of the tension and compression are 600 and 1,880 pounds.

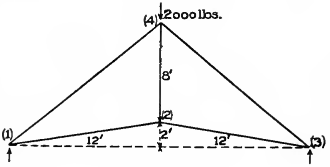


Fig. 23.

Next place arrowheads on *ab* and *ad* at joints (1) and (4) to represent a push and a pull respectively. There remains now but one stress undetermined, that in *af*. It can be ascertained by drawing the polygon for joint 1 or 4; let us draw the latter. There are four forces acting at that joint, namely, the 600-pound load, and the forces exerted by members *ed*, *da*, and *af*. The first three forces are already represented in the drawing by EF, DE and DA, and the polygon for those three forces (not closed) is ADEF. The fourth force must close the polygon, that is, a line from F parallel to *af* must pass through A, and if the drawing has been accurately done, it will pass through A. The polygon for the four forces then is ADEFA, and an arrowhead placed on FA ought to point to the left, but as before, place it in the truss diagram on *af* near joint (4). The force exerted by member *af* on joint (4) being a pull, *af* is under tension, and since AF measures 1.12 inches, the value of the tension is 1,120 pounds.

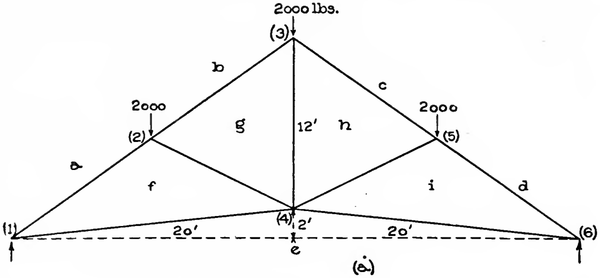
Since *af* is in tension it pulls on joint (1), hence we place an arrowhead on *af* near joint (1) to indicate that pull.

EXAMPLES FOR PRACTICE.

1. Construct a stress diagram for the truss of the preceding Example (Fig. 22*a*) making all the polygons counter-clockwise, and compare with the stress diagram in Fig. 22.

2. Determine the stresses in the members of the truss represented in Fig. 23 due to a single load of 2,000 pounds at the peak.

Ans. $\begin{cases} \text{Stresses in } \overline{12} \text{ and } \overline{23} = 1{,}510 \text{ pounds,} \\ \text{Stresses in } \overline{14} \text{ and } \overline{43} = 1{,}930 \text{ pounds,} \\ \text{Stress in } \overline{24} = 490 \text{ pounds.} \end{cases}$



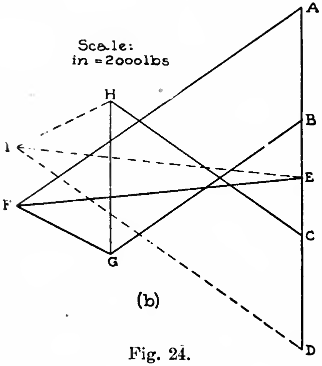


Fig. 24.

27. **Stress Records.** When making a record of the values of the stresses as determined in an analysis of a truss, it is convenient to distinguish between tension and compression by means of the signs plus and minus. Custom differs as to use of the signs for this purpose, but we shall use *plus for tension and minus for compression*. Thus + 4,560 means a tensile stress of 4,560 pounds, and – 7,500 means a compressive stress of 7,500 pounds.

The record of the stresses as obtained in an analysis can be conveniently made in the form of a table, as in Example 1 following, or in the truss diagram itself, as in Example 2 (Fig. 25).

As previously explained, the stress in a member is tensile or compressive according as the member pulls or pushes on the joints between which it extends. If the arrowheads are placed on the lines representing the members as was explained in Example 1 of Art. 26 (Fig. 22), the two arrowheads on any member

> point toward each other on tension members,
> and from each other on compression members.

If the system of lettering explained in Art. 24 is followed in the analysis of a truss, and if the first polygon (for the loads and reactions) is drawn according to directions (Art. 26), then the system of lettering will guide one in drawing the polygons for the joints as shown in the following illustrations. It must be remembered always that any two parallel lines, one in the truss and one in the stress diagram, must be designated by the same two letters, the first by small letters on opposite sides of it, and the second by the same capitals at its ends.

Examples. 1. It is required to construct a stress diagram for the truss represented in Fig. 24 supported at its ends and sustaining three loads of 2,000 pounds as shown. Evidently the reactions equal 3,000 pounds.

Following the directions of Art. 26, we letter the truss diagram, then draw the polygon for the loads and reactions. Thus, to the scale indicated in Fig. 24 (*b*), AB, BC, and CD represent the loads at joints (2), (3) and (5) respectively and DE and EA represent the right and the left reactions respectively. Notice that the polygon (ABCDEA) is a clockwise one.

At joint (1)there are three forces, the left reaction and the forces exerted by the members *af* and *fe*. Since the forces exerted by these two members must be marked AF and EF we draw from A a line parallel to *af* and from E one parallel to *ef* and mark their intersection F. Then EAFE is the polygon for joint (1), and since EA acts up (see the polygon), AF acts down and FE to the right. We, therefore, place the proper arrowheads on *af* and *fe* near (1), and record (see adjoining table) that the stresses in those members are compressive and tensile respectively. Measuring, we find that AF and FE equal 6,150 and 5,100 pounds respectively.

Member....	af	fe	bg	fg	gh
Stress......	− 6,150	+5,100	− 4,100	− 1,875	+2,720

We may next draw the polygon for joint (6) or (2) since there are but two unknown forces at each. At joint (2) for instance, the unknown forces are those exerted by *fg* and *bg*, and the known are the load *ab* (2,000 pounds) and the force exerted by *af*. Since the unknown forces must be marked FG and GB, draw from F a line parallel to *fg*, from B a line parallel to *bg*, and mark their intersection G. Then the polygon for the joint is FABGF, and since AB acts down (see the polygon) BG and GF act down and up respectively. Therefore, place the proper arrowheads on *bg* and *gf* near (2), and record that the stresses in those members are both compressive. Measuring, we find that BG and GF scale 4,100 and 1,875 pounds respectively.

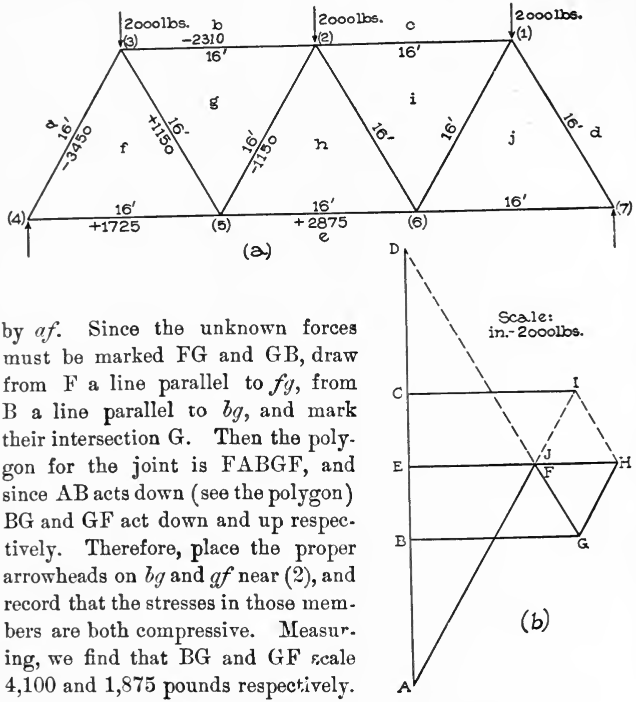


Fig. 25.

Now draw a polygon for joint (3) or (6) since there are but two unknown forces at each joint. At (3) for instance, the unknown forces are those exerted by *ch* and *gh*, the known forces being the load (2,000 pounds) and the force 4,100 pounds, exerted by *bg*. Since the unknown forces must be marked CH and GH, draw from C a line parallel to *ch*, from G one parallel to *gh*, and mark their intersection H. Then

GBCHG is the polygon for the joint, and since BC acts down (see the polygon) CH acts up and HG down. Therefore, place the proper arrowheads on *ch* and *hg* near (3), and record that the stresses in those members are compressive and tensile respectively. Measuring, we find that CH and HG scale 4,100 and 2,720 pounds respectively.

It is plain that the stress in any member on the right-hand side is the same as that in the corresponding member on the left, hence it is not necessary to construct the complete stress diagram.

2. It is required to analyze the truss of Fig. 25 which rests on end supports and sustains three loads each of 2,000 pounds as shown. Each member is 16 feet long.

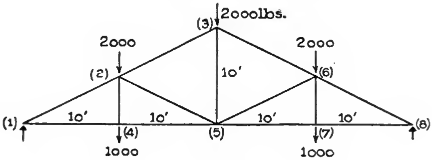


Fig. 26.

Evidently, reactions are each 3,000 pounds. Following directions of Art. 26, first letter the truss diagram and then

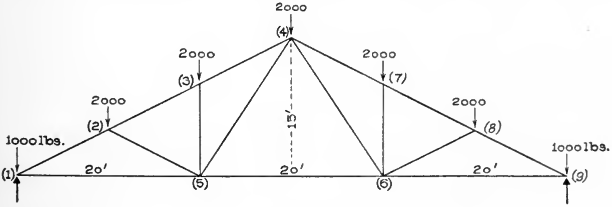


Fig. 27.

draw a polygon for the loads and reactions representing them in either order in which they occur about the truss. DCBAED is a counter-clockwise polygon, DC, CB, and BA representing the loads at joints (1), (2) and (3), AE the left reaction, ED the right reaction.

The construction of the polygons is carried out as in the preceding illustration, and little explanation is necessary. The polygon for joint (4) is AEFA, EF (1,725 pounds tension) representing the stress in *ef* and FA (3,450 pounds compression) that in *af*. The polygon for joint (3) is BAFGB, FG (1,150 pounds tension) representing the stress in *fg* and GB (2,300 pounds compression) that in *gb*. The polygon for joint (5) is GFEHG, EH (2,875 pounds tension) representing the stress in *eh* and HG (1,150 pounds compression) that in *hg*.

Evidently the stress in any member on the right side of the truss is like that in the corresponding member on the left, therefore it is not necessary to construct the remainder of the stress diagram.

EXAMPLES FOR PRACTICE.

1. Analyze the truss represented in Fig. 26, it being supported at its ends and sustaining three loads of 2,000 and two of 1,000 pounds as represented.

STRESS RECORD.

Member.......	$\overline{12}$	$\overline{23}$	$\overline{14}$	$\overline{45}$	$\overline{24}$	$\overline{25}$	$\overline{35}$
Stress.........	–8,950	–5,600	+8,000	+8,000	+1,000	–3,350	+3,000

2. Analyze the truss represented in Fig. 27, it being supported at its ends and sustaining five 2,000-pound loads and two of 1,000 as shown.

STRESS RECORD.

Member .	$\overline{12}$	$\overline{23}$	$\overline{34}$	$\overline{51}$	$\overline{52}$	$\overline{53}$	$\overline{54}$	$\overline{56}$
Stress . . .	– 11,200	– 8,900	– 8.900	+ 10.000	– 2.200	– 2,000	+3.600	+6,000

28. Analysis for Snow Loads. In some cases the apex snow loads are a definite fractional part of the apex loads due to the weights of roof and truss. For instance, in Examples 1 and 2, Pages 25 and 26, it is shown that the apex loads are 1,500 and 3,000 pounds due to weight of roof and truss, and 735 and 1,470 due to snow; hence the snow loads are practically equal to one-half of the permanent dead loads. It follows that the stress in any member due to snow load equals practically one-half of the stress in that member due to the permanent dead load. The snow load stresses in this case can therefore be obtained from the permanent load stresses and no stress diagram for snow load need be drawn.

In some cases, however, the apex loads due to snow at the various joints are not the *same* fractional part of the permanent load. This is the case if the roof is not all of the same slope, as for instance in Fig. 25 where a part of the roof is flat. In such a case the stresses due to the snow load cannot be determined from a stress diagram for the permanent dead load but a separate stress diagram for the snow load must be drawn. Such diagrams are drawn like those for permanent dead load.

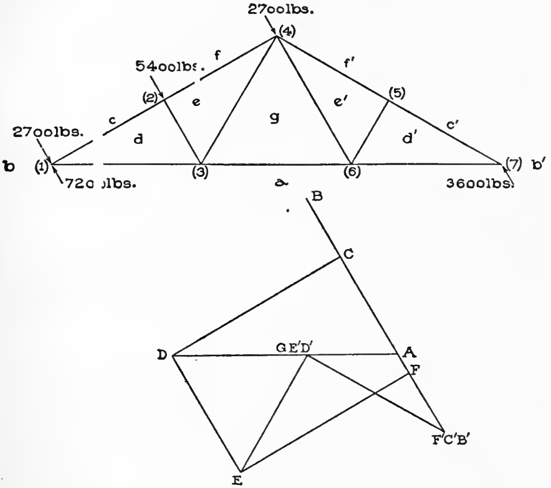


Fig. 28.

29. **Analysis for Wind Loads.** Stresses due to wind pressure cannot be computed from permanent load stresses; they can be most easily determined by means of a stress diagram. Since wind pressure exists only on one side of a truss at a time, the stresses in corresponding members on the right and left sides of a truss are unequal and the whole stress diagram must be drawn in analysis for "wind stresses." Moreover, where one end of the

truss rests on rollers, two stress diagrams must be drawn for a complete analysis, one for wind blowing on the right and one for wind blowing on the left (see Example 2 following).

Examples. 1. It is required to analyze the truss of Fig. 16 for wind pressure, the distance between trusses being 14 feet.

The apex loads for this case are computed in Example 3, Page 26, to be as represented in Fig. 28. Supposing both ends of the truss to be fastened to the supports, then the reactions (due to the wind alone) are parallel to the wind pressure and the right and left reactions equal 3,600 and 7,200 pounds as explained in Example 2, Page 57.

To draw a clockwise polygon for the loads and reactions, we lay off BC, CF, and FF′ to represent the loads at joints (1), (2), and (4) respectively; then since there are no loads at joints (5) and (7) we mark the point F′ by C′ and B′ also; then lay off B′A to represent the reaction at the right end. If the lengths are laid off carefully, AB will represent the reaction at the left end and the polygon is BCFF′C′B′AB.

At joint (1) there are four forces, the reaction, the load, and the two stresses. AB and BC represent the first two forces, hence from C draw a line parallel to *cd* and from A a line parallel to *ad* and mark their intersection D. Then ABCDA is the polygon for the joint and CD and DA represent the two stresses. The former is 7,750 pounds compression and the latter 9,000 pounds tension.

At joint (2) there are four forces, the stress in *cd* (7,750 pounds compression), the load, and the stresses in *fe* and *ed*. As DC and CF represent the stress 7,750 and the load, from F draw a line parallel to *fe* and from D a line parallel to *de*, and mark their intersection E. Then DCFED is the polygon for the joint and FE and ED represent the stresses in *fe* and *ed* respectively. The former is 7,750 pounds and the latter 5,400, both compressive.

At joint (3) there are four forces, the stresses in *ad* (9,000 pounds), *de* (5,400 pounds), *eg* and *ga*. AD and DE represent the first two stresses; hence from E draw a line parallel to *eg* and from A a line parallel to *ag* and mark their intersection G. Then ADEGA is the polygon for the joint and EG and GA represent the stresses in *eg* and *ga* respectively The former is 5,400 and the latter 3,600 pounds, both tensile.

At joint (4) there are five forces, the stresses in *eg* (5,400 pounds) and *ef* (7,750 pounds), the load, and the stresses in *f′e′* and *e′g*. GE, EF and FF′ represent the first three forces; hence draw from F′ a line parallel to *f′e′* and from G a line parallel to *e′g* and mark their intersection E′. (The first line passes through G, hence E′ falls at G). Then the polygon for the joint is GEFF′E′G, and

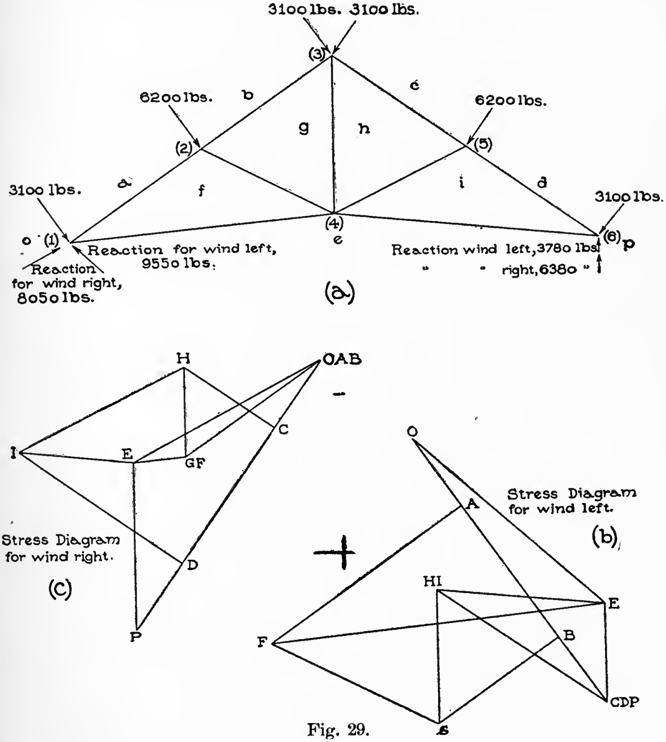


Fig. 29.

F′E′ (6,250 pounds compression) represents the stress in *f′e′*. Since E′G = 0, the wind produces no stress in member *ge′*.

At joint (5) three members are connected together and there is no load. The sides of the polygon for the joint must be parallel to the members joined there. Since two of those members are in the same straight line, two sides of the polygon will be parallel and it follows as a consequence that the third side must be zero. Hence the stress in the member *e'd'* equals zero and the stresses in *f'e'* and *d'c'* are equal. This result may be explained slightly differently: Of the stresses in ***e'f'***, ***e'd'***, and ***d'c'*** we know the first (6,250) and it is represented by E'F'. Hence we draw from F' a line parallel to *c'd'* and one from E' parallel to *d'e* and mark their intersection D'. Then the polygon for the joint is E'F'C'D'E; C'D' (6,250 pounds compression) representing the stress in *c'd'*. Since E' and D' refer to the same point, E'D' scales zero and there is no stress in *e'd'*.

The stress in *ad'* can be determined in various ways. Since at joint (6) there are but two forces (the stresses in *ge'* and *e'd'* being zero), the two forces must be equal and opposite to balance. Hence the stress in *d'a* is a tension and its value is 3,600 pounds.

2. It is required to analyze the truss represented in Fig. 24 for wind pressure, the distance between trusses being 15 feet.

The length $\overline{13}$ equals $\sqrt{20^2 + 14^2}$ or

$$\sqrt{400 + 196} = 24.4 \text{ feet.}$$

Hence the area sustaining the wind pressure to be borne by one truss equals $24.4 \times 15 = 366$ square feet.

The tangent of the angle which the roof makes with the horizontal equals $14 \div 20 = 0.7$; hence the angle is practically 35 degrees. According to Art. 19, the wind pressures for slopes of 30 and 40 degrees are 32 and 36 pounds per square foot; hence for 35 degrees it is 34 pounds per square foot. The total wind pressure equals, therefore, $366 \times 34 = 12{,}444$, or practically 12,400 pounds.

The apex load for

joint (2) is ½ of 12,400, or 6,200 pounds,
and for joints (1) and (3), ¼ of 12,400, or 3,100 pounds (see Fig. 29).

When the wind blows from the right the

load for joint (5) is 6,200 pounds, and
for joints (3) and (6) 3,100 pounds.

If the left end of the truss is fastened to its support and the right rests on rollers*, when the wind blows on the left side the right and left reactions equal 3,780 and 9,550 pounds respectively and act as shown. When the wind blows on the right side, the right and left reactions equal 6,380 and 8,050 pounds and act as shown. The computation of these reactions is shown in Example 1, Page 58.

For the wind on the left side, OA, AB, and BC (Fig. 29*b*) represent the apex loads at joints (1), (2) and (3) respectively and CE and EO represent the right and left reactions; then the polygon (clockwise) for the loads and reactions is OABCDPEO. The point C is also marked D and P because there are no loads at joints (5) and (6).

The polygon for joint (1) is EOAFE, AF and FE representing the stresses in *af* and *fe* respectively. The values are recorded in the adjoining table. The polygon for joint (2) is FABGF, BG and GF representing the stresses in *bg* and *fg*. The polygon for joint (3) is GBCHG, CH and HG representing the stresses in *ch* and *hg* respectively. At joint (5) there is no load and two of the members connected there are in the same line; hence there is no wind stress in the third member and the stresses in the other two members are equal. The point H is therefore also marked I to make HI equal to zero. The polygon for joint (5) is HCDIH.

STRESS RECORD.

Member.	Stress, Wind Left.	Stress, Wind Right.
af	− 8,850	− 6,300
fe	+12,700	− 2,000
bg	− 5,600	− 6,300
fg	− 7,000	0
hg	+ 5,100	+3,400
hi	0	− 7,000
ch	− 7,700	−4,100
ie	+ 6,400	+4,400
di	− 7,700	− 7,500

At joint (4) there are four forces, all known except the one in *ie*. EF, FG, and GH represent the first three; hence the line

---

* Rollers to allow for free expansion and contraction of the truss would not be required for one as short as this. They are not used generally unless the truss is 55 feet or more in length.

joining I and E must represent the stress in *ie*. This line, if the drawing has been correctly and accurately made, is parallel to *ie*.

For wind on right side, BC, CD, and DP Fig. 29(*c*) represent the loads at joints (3), (5) and (6) respectively and PE and EB the right and left reactions; then BCDPEB is the polygon for the loads and reactions. The point B is also marked A and O because there are no loads at joints (2) and (1).

The polygon for joint (6) is DPEID, EI and ID representing the stresses in *ei* and *id* respectively. The polygon for joint (5) is CDIHC, IH, and HC representing the stresses in *ih* and *hc* respectively. The polygon for joint (3) is BCHGB, HG, and GB representing the stresses in *hg* and *gb* respectively. The polygon for joint (2) is BGFAB, FA representing the stress in *fa*, and since GF equals zero there is no stress in *gf*.

At joint (1) there are three forces, the left reaction, AF and the stress in *fe*. This third force must close the polygon, so we join F and E and this line represents the stress in *fe*. If the work has been accurately done, FE will be parallel to *fe*.

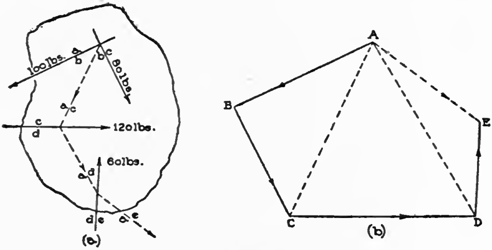


Fig 30.

EXAMPLE FOR PRACTICE.

Analyze the truss represented in Fig. 26 for wind pressure, the distance between trusses being 15 feet. (See Ex. 3, Page 27, for apex loads.) Assuming both ends of the truss fastened to the supports, the reactions are both parallel to the wind pressure and the reaction on the windward side equals 6,707 pounds and the other equals 3,053 pounds.

Ans. Stress Record for Wind Left.

Member.	Stress.
12	−8,500
14	+8,600
45	+8,600
24	0
23	− 5,000
25	− 6,080
35	+2,800
36	− 6,080
56	0
57	+4,200
68	− 6,200
67	0
78	+4,200

V. COMPOSITION OF NON-CONCURRENT FORCES.

30. **Graphical Composition.** As in composition of concurrent systems, we first compound any two of the forces by means of the Triangle Law (Art. 9), then compound the resultant of these two forces with the third, then compound the resultant of the first three with the fourth and so on until the resultant of all has been found. It will be seen in the illustration that the actual constructions are not quite so simple as for concurrent forces.

Example. It is required to determine the resultant of the four forces (100, 80, 120, and 60 pounds) represented in Fig. 30 (*a*).

If we take the 100- and 80-pound forces first, and from any convenient point A lay off AB and BC to represent the magnitudes and directions of those forces, then according to the triangle law AC represents the magnitude and direction of their resultant and its line of action is parallel to AC and passes through the point of concurrence of the two forces. This line of action should be marked *ac* and those of the 100- and 80-pound forces, *ab* and *bc* respectively.

If we take the 120-pound force as third, lay off CD to represent the magnitude and direction of that force; then AD represents the magnitude and direction of the resultant of AC and the third force, while the line of action of that resultant is parallel to AD and passes through the point of concurrence of the forces AC and CD. That line of action should be marked *ad* and that of the third force *cd*.

It remains to compound AD and the remaining one of the given forces, hence we lay off DE to represent the magnitude and direction of the fourth force; then AE represents the magnitude and direction of the resultant of AD and the fourth force (also of the four given forces). The line of action of the resultant is parallel to AE and passes through the point of concurrence of the forces AD and DE. That line should be marked *ae* and the line of action of the fourth face *de*.

It is now plain that the magnitude and direction of the resultant is found exactly as in the case of concurrent forces, but finding the line of action requires an extra construction.

31. **When the Forces Are Parallel or Nearly So,** the method of composition explained must be modified slightly because there is no intersection from which to draw the line of action of the resultant of the first two forces.

To make such an intersection available, resolve any one of the given forces into two components and imagine that force replaced by them; then find the resultant of those components and the other given forces by the methods explained in the preceding article. Evidently this resultant is the resultant of the given forces.

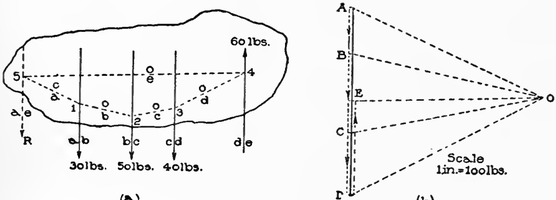
Example. It is required to find the resultant of the four parallel forces (50, 30, 40, and 60 pounds) represented in Fig. 31 (*a*).

Choosing the 30-pound force as the one to resolve, lay off AB to represent the magnitude and direction of that force and mark its line of action *ab*. Next draw lines from A and B intersecting at any convenient point O; then as explained in Art. 13, AO and OB (direction from A to O and O to B) represent the magnitudes and directions of two components of the 30-pound force, and the lines of action of those components are parallel to AO and OB and must intersect on the line of action of that force, as at 1. Draw next two such lines and mark them *ao* and *ob* respectively. Now imagine the 30-pound force replaced by its two components and then compound them with the 50-, 40- and 60-pound forces.

In the composition, the second component should be taken as the first force and the first component as the last. Choosing the 50-pound force as the second, lay off BC to represent the magnitude and direction of that force and mark the line of action *bc*. Then OC (direction O to C) represents the magnitude and direction of the resultant of OB and BC, and *oc* (parallel to OC and passing through the point of concurrence of the forces OB and BC) is the line of action.

Choosing the 40-pound force next, lay off CD to represent the magnitude and direction of that force and mark its line of action *cd*. Then OD (direction O to D) represents the magnitude and direction of the resultant of OC and CD, and *od* (parallel to OD and passing through the point of concurrence of the forces OC and CD) is the line of action of it.

Next lay off a line DE representing the magnitude and direction of the 60-pound force and mark the line of action *de*. Then OE (direction O to E) represents the magnitude and direction of the resultant of OD and DE, and *oe* (parallel to OE and passing through the point of concurrence of the forces OD and DE) is the line of action of it.



(a) (b)

Fig. 31.

It remains now to compound the last resultant (OE) and the first component (AO). AE represents the magnitude and direction of their resultant, and *ae* (parallel to AE and passing through the point of concurrence of the forces OE and AO) is the line of action.

32. **Definitions and Rule for Composition.** The point O (Fig. 31) is called a *pole*, and the lines drawn to it are called *rays*. The lines *oa*, *ob*, *oc*, etc., are called *strings* and *collectively* they are called a *string polygon*. The string parallel to the ray drawn to the beginning of the force polygon (A) is called the first string, and the one parallel to the ray drawn to the end of the force polygon is called the last string.

The method of construction may now be described as follows:

1. Draw a force polygon for the given forces. The line drawn from the beginning to the end of the polygon represents the magnitude and direction of the resultant.

2. Select a pole, draw the rays and then the string polygon. The line through the intersection of the first and last strings parallel to the direction of the resultant is the line of action of the resultant. (In constructing the string polygon, observe carefully that the two strings intersecting on the line of action of any one of the given forces are parallel to the two rays which are drawn to the ends of the line representing that force in the force polygon.)

EXAMPLES FOR PRACTICE.

1. Determine the resultant of the 50-, 70-, 80- and 120-pound forces of Fig. 5.

Ans. { 260 pounds acting upwards 1.8 and 0.1 feet to the right of A and D respectively.

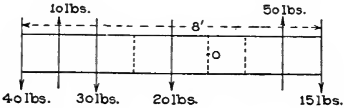


Fig. 32.

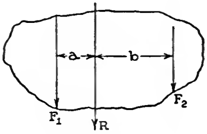


Fig. 33.

2. Determine the resultant of the 40-, 10-, 30- and 20-pound forces of Fig. 32.

Ans. { 80 pounds acting down $1\frac{5}{8}$ feet from left end.

33. **Algebraic Composition.** The algebraic method of composition is best adapted to parallel forces and is herein explained only for that case.

If the plus sign is given to the forces acting in one direction, and the minus sign to those acting in the opposite direction, the magnitude and sense of the resultant is given by the algebraic sum of the forces; the magnitude of the resultant equals the value of the algebraic sum; the direction of the resultant is given by the sign of the sum, thus the resultant acts in the direction which has been called plus or minus according as the sign of the sum is plus or minus.

If, for example, we call up plus and down minus, the algebraic sum of the forces represented in Fig. 32 is

$$-40 + 10 - 30 - 20 + 50 - 15 = -45;$$

hence the resultant equals 45 pounds and acts downward.

The line of action of the resultant is found by means of the principle of moments which is (as explained in "Strength of Materials") that *the moment of the resultant of any number of forces about any origin equals the algebraic sum of the moments of the forces.* It follows from the principle that the arm of the resultant with respect to any origin equals the quotient of the algebraic sum of the moments of the forces divided by the resultant; also the line of action of the resultant is on such a side of the origin that the sign of the moment of the resultant is the same as that of the algebraic sum of the moments of the given forces.

For example, choosing O as origin of moments in Fig. 32, the moments of the forces taking them in their order from left to right are

$$-40\times5 = -200,\ +10\times4 = +40,\ -30\times3 = -90,$$
$$-20\times1 = -20,\ -50\times2 = -100,\ +15\times3 = +45.^{*}$$

Hence the algebraic sum equals

$$-200 + 40 - 90 - 20 - 100 + 45 = -325 \text{ foot-pounds.}$$

The sign of the sum being negative, the moment of the resultant about O must also be negative, and since the resultant acts down, its line of action must be on the left side of O. Its actual distance from O equals

$$\frac{325}{45} = 7.22 \text{ feet.}$$

EXAMPLES FOR PRACTICE.

1. Make a sketch representing five parallel forces, 200, 150 100, 225, and 75 pounds, all acting in the same direction and 2 feet apart. Determine their resultant.

---

* The student is reminded that when a force tends to turn the body on which it acts in the clockwise direction, about the selected origin, its moment is a given a plus sign, and when counter-clockwise, a minus sign.

Ans. { Resultant = 750 pounds, and acts in the same direction as the given forces and 4.47 feet to the left of the 75-pound force.

2. Solve the preceding example, supposing that the first three forces act in one direction and the last two in the opposite direction.

Ans. { Resultant = 150 pounds, and acts in the same direction with the first three forces and 16.3 feet to the left of the 75-pound force.

Two parallel forces acting in the same direction can be compounded by the methods explained in the foregoing, but it is sometimes convenient to remember that the resultant equals the sum of the forces, acts in the same direction as that of the two forces and between them so that the line of action of the resultant divides the distance between the forces inversely as their magnitudes. For example, let F_1 and F_2 (Fig. 33) be two parallel forces. Then if R denotes the resultant and a and b its distances to F_1 and F_2 as shown in the figure,

$$R = F_1 + F_2,$$

and

$$a : b :: F_2 : F_1.$$

34. Couples. Two parallel forces which are equal and act in opposite directions are called a couple. The forces of a couple cannot be compounded, that is, no single force can produce the same effect as a couple. The perpendicular distance between the lines of action of the two forces is called the *arm*, and the product of one of the forces and the arm is called the *moment of the couple.*

A plus or minus sign is given to the moment of a couple according as the couple turns or tends to turn the body on which it acts in the clockwise or counter-clockwise direction.

VI. EQUILIBRIUM OF NON-CONCURRENT FORCES.

35. Conditions of Equilibrium of Non-Concurrent Forces Not Parallel may be stated in various ways; let us consider four. First:

1. The algebraic sums of the components of the forces along each of two lines at right angles to each other equal zero.

2. The algebraic sum of the moments of the forces about any origin equals zero.

Second:

1. The sum of the components of the forces along any line equals zero.
2. The sums of the moments of the forces with respect to each of two origins equal zero.

Third:

The sums of the moments of the forces with respect to each of three origins equals zero.

Fourth:

1. The algebraic sum of the moments of the forces with respect to some origin equals zero.
2. The force polygon for the forces closes.

It can be shown that if any one of the foregoing sets of conditions are fulfilled by a system, its resultant equals zero. Hence each is called a set of conditions of equilibrium for a non-concurrent system of forces which are not parallel.

The first three sets are "algebraic" and the last is "mixed," (1) of the fourth, being algebraic and (2) graphical. There is a set of graphical conditions also, but some one of those here given is usually preferable to a set of wholly graphical conditions.

Like the conditions of equilibrium for concurrent forces, they are used to answer questions arising in connection with concurrent systems known to be in equilibrium. Examples may be found in Art. 37.

36. Conditions of Equilibrium for Parallel Non-Concurrent Forces. Usually the most convenient set of conditions to use is one of the following:

First:

1. The algebraic sum of the forces equals zero, and
2. The algebraic sum of the moments of the forces about some origin equals zero.

Second:

The algebraic sums of the moments of the forces with respect to each of two origins equal zero.

37. Determination of Reactions. The weight of a truss, its loads and the supporting forces or reactions are balanced and constitute a system in equilibrium. After the loads and weight are ascertained, the reactions can be determined by means of conditions of equilibrium stated in Arts. 35 and 36.

The only cases which can be taken up here are the following common ones: (1) The truss is fastened to two supports and (2) The truss is fastened to one support and simply rests on rollers at the other.

Case (1) Truss Fastened to Both Its Supports. If the loads are all vertical, the reactions also are vertical. If the loads are not vertical, we assume that the reactions are parallel to the resultant of the loads.

The algebraic is usually the simplest method for determining the reactions in this case, and two moment equations should be used. Just as when finding reactions on beams we first take moments about the right support to find the left reaction and then about the left support to find the right reaction. As a check we add the reactions to see if their sum equals the resultant load as it should.

Examples. 1. It is required to determine the reactions on the truss represented in Fig. 20, it being supported at its ends and sustaining two vertical loads of 1,800 and 600 pounds as shown.

The two reactions are vertical; hence the system in equilibrium consists of parallel forces. Since the algebraic sum of the moments of all the forces about any point equals zero, to find the left reaction we take moments about the right end, and to find the right reaction we take moments about the left end. Thus, if R_1 and R_2 denote the left- and right-reactions respectively, then taking moments about the right end,

$$(R_1 \times 24) - (1800 \times 15) - (600 \times 15) = 0,$$

or
$$24R_1 = 27{,}000 + 9{,}000 = 36{,}000;$$

hence
$$R_1 = \frac{36{,}000}{24} = 1{,}500 \text{ pounds.}$$

Taking moment about the left end,

$$-R_2 \times 24 + 1{,}800 \times 9 + 600 \times 9 = 0.$$

or
$$24R_2 = 16{,}200 + 5{,}400 = 21{,}600;$$

hence
$$R_2 = 900 \text{ pounds.}$$

As a check, add the reactions to see if the sum equals that of the loads as should be the case. (It will be noticed that reactions on trusses and beams under vertical loads are determined in the same manner.)

2. It is required to determine the reactions on the truss represented in Fig. 28 due to the wind pressures shown (2,700, 5,400 and 2,700 pounds), the truss being fastened to both its supports.

The resultant of the three loads is evidently a single force of 10,800 pounds, acting as shown in Fig. 34. The reactions are parallel to this resultant; let R_1 and R_2 denote the left and right reactions respectively.

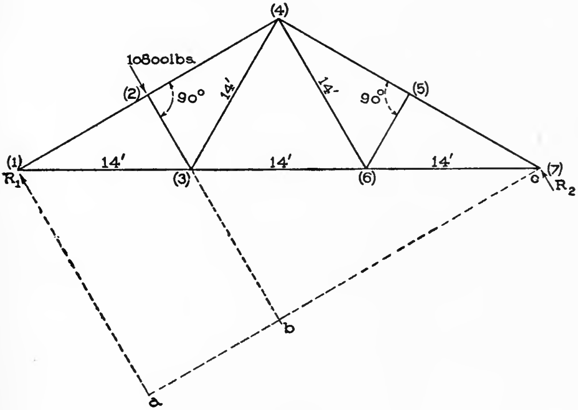


Fig. 34.

The line abc is drawn through the point 7 and perpendicular to the direction of the wind pressure; hence with respect to the right support the arms of R_1 and resultant wind pressure are ac and bc, and with respect to the left support, the arms of R_2 and the resultant wind pressure are ac and ab. These different arms can be measured from a scale drawing of the truss or be computed as follows: The angle $\overline{17a}$ equals the angle $\overline{417}$, and $\overline{417}$ was shown to be 30 degrees in Example 3, Page 26. Hence

$$ab = 14 \cos 30^\circ,\ bc = 28 \cos 30^\circ,\ ac = 42 \cos 30^\circ.$$

Since the algebraic sums of the moments of all the forces acting on the truss about the right and left supports equal zero,

$$R_1 \times 42 \cos 30^\circ = 10{,}800 \times 28 \cos 30^\circ,$$

and

$$R_2 \times 42 \cos 30^\circ = 10{,}800 \times 14 \cos 30^\circ.$$

From the first equation,

$$R_1 = \frac{10{,}800 \times 28}{42} = 7{,}200 \text{ pounds,}$$

and from the second,

$$R_2 = \frac{10{,}800 \times 14}{42} = 3{,}600 \text{ pounds.}$$

Adding the two reactions we find that their sum equals the load as it should.

Case (2) One end of the truss rests on rollers and the other is fixed to its support. The reaction at the roller end is always vertical, but the direction of the other is not known at the outset unless the loads are all vertical, in which case both reactions are vertical.

When the loads are not all vertical, the loads and the reactions constitute a non-concurrent non-parallel system and any one of the sets of conditions of equilibrium stated in Art. 35 may be used for determining the reactions. In general the fourth set is probably the simplest. In the first illustration we apply the four different sets for comparison.

Examples. 1. It is required to compute the reactions on the truss represented in Fig. 29 due to the wind pressures shown on the left side (3,100, 6,200 and 3,100 pounds), the truss resting on rollers at the right end and being fastened to its support at the left.

(*a*) Let R_1 and R_2 denote the left and right reactions. The direction of R_2 (at the roller end) is vertical, but the direction of R_1 is unknown. Imagine R_1 resolved into and replaced by its horizontal and vertical components and call them R_1' and R_1'' respectively (see Fig. 35.) The six forces, R_1', R_1'', R_2 and the three wind pressures are in equilibrium, and we may apply any one of the sets of statements of equilibrium for this kind of a system (see Art. 35) to determine the reactions. If we choose to use the first set we find, resolving forces along a horizontal line,

$$-R_1' + 3{,}100 \cos 55° + 6{,}200 \cos 55° + 3{,}100 \cos 55° = 0;$$

resolving forces along a vertical line,

$$+R_1'' + R_2 - 3{,}100 \cos 35° - 6{,}200 \cos 35° - 3{,}100 \cos 35° = 0;$$

taking moments about the left end,

$$+ 6{,}200 \times 12.2 + 3{,}100 \times 24.4 - R_2 \times 40 = 0.$$

From the first equation,

$$R_1' = 3{,}100 \cos 55° + 6{,}200 \cos 55° + 3{,}100 \cos 55° = 7{,}113 \text{ pounds},$$

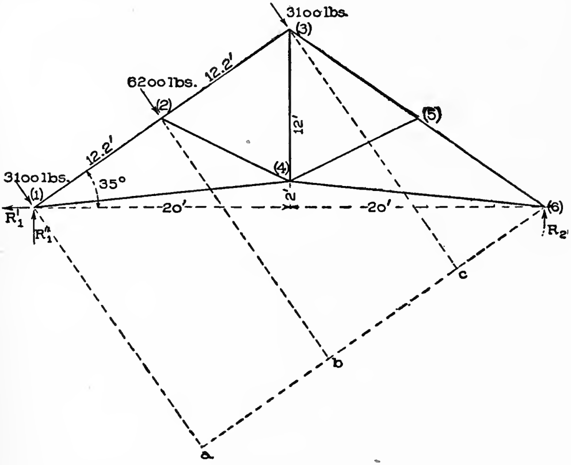


Fig. 35.

and from the third,

$$R_2 = \frac{6{,}200 \times 12.2 + 3{,}100 \times 24.4}{40} = 3{,}782 \text{ pounds}.$$

Substituting this value of R_2 in the second equation we find that

$$R_1'' = 3{,}100 \cos 35° + 6{,}200 \cos 35° + 3{,}100 \cos 35° - 3{,}782$$
$$= 10{,}156 - 3{,}782 = 6{,}374 \text{ pounds}.$$

If desired, the reaction R_1 can now be found by compounding its two components R_1' and R_1''.

(*b*) Using the second set of conditions of equilibrium stated in Art. 35 we obtain the following three "equilibrium equations":
As in (1), resolving forces along the horizontal gives

$$-R_1' + 3{,}100 \cos 55° + 6{,}200 \cos 55° + 3{,}100 \cos 55° = 0,$$

and taking moments about the left end,

$$6{,}200 \times 12.2 + 3{,}100 \times 24.4 - R_2 \times 40 = 0.$$

Taking moments about the right end gives

$$R_1'' \times 40 - 3{,}100 \times \overline{a6} - 6{,}200 \times \overline{b6} - 3{,}100 \times \overline{c6} = 0$$

Just as in (*a*), we find from the first and second equations the values of R_1' and R_2. To find R_1'' we need values of the arms $\overline{a6}$, $\overline{b6}$, and $\overline{c6}$. By measurement from a drawing we find that

$$\overline{a6} = 32.7,\ \overline{b6} = 20.5,\ \text{and}\ \overline{c6} = 8.3 \text{ feet.}$$

Substituting these values in the third equation and solving for R_1'' we find that

$$R_1'' = \frac{3{,}100 \times 32.7 + 6{,}200 \times 20.5 + 3{,}100 \times 8.3}{40} = 6{,}355 \text{ pounds.}$$

(*c*) Using the third set of conditions of equilibrium stated in Art. 35 we obtain the following three equilibrium equations:
As in (*b*), taking moments about the right and left ends we get

$$R_1'' \times 40 - 3{,}100 \times 32.7 - 6{,}200 \times 20.5 - 3{,}100 \times 8.3 = 0,$$

and $$-R_2 \times 40 + 6{,}200 \times 12.2 + 3{,}100 \times 24.4 = 0.$$

Choosing the peak of the truss as the origin of moments for the third equation we find that

$$R_1' \times 14 + R_1'' \times 20 - 3{,}100 \times 24.4 - 6{,}200 \times 12.2 - R_2 \times 20 = 0.$$

As in (*b*) we find from the first two equations the values of R_1'' and R_2. These values substituted in the third equation change it to

$$R_1' \times 14 + 6{,}373 \times 20 - 3{,}100 \times 24.4 - 6{,}200 \times 12.2 - 3{,}782 \times 20 = 0$$

or

$$R_1' = \frac{-6{,}373 \times 20 + 3{,}100 \times 24.4 + 6{,}200 \times 12.2 + 3{,}782 \times 20}{14}$$

$= 7{,}104.$*

(*d*) When using the fourth set of conditions we always determine the reaction at the roller end from the moment equation. Then, knowing the value of this reaction, draw the force polygon for all the loads and reactions and thus determine the magnitude and direction of the other reaction.

Taking moments about the left end, we find as in (*a*), (*b*), and

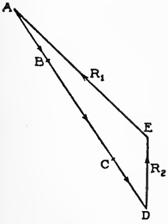


Fig. 36.

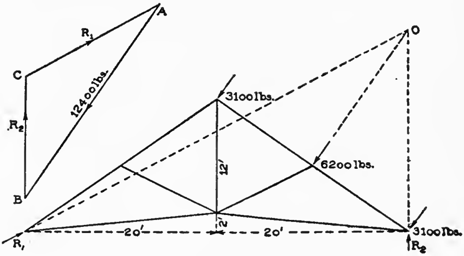


Fig. 37.

(*c*) that $R_2 = 3{,}782$. Then draw AB, BC and CD (Fig. 36) to represent the wind loads, and DE to represent R_2. Since the force polygon for all the forces must close, EA represents the magnitude and direction of the left reaction; it scales 9,550 pounds.

2. It is required to determine the reactions on the truss of the preceding illustration when the wind blows from the right.

The methods employed in the preceding illustration might be used here, but we explain another which is very simple. The truss and its loads are represented in Fig. 37. Evidently the resultant of the three wind loads equals 12,400 pounds and acts in the same line with the 6,200-pound load. If we imagine this resultant to replace the three loads we may regard the truss acted upon by three forces, the 12,400-pound force and the reactions, and these three forces as in equilibrium. Now when three forces

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* The slight differences in the answers obtained from the different sets of equilibrium equations are due to inaccuracies in the measured arms of some of the forces.

are in equilibrium they must be concurrent or parallel, and since the resultant load (12,400 pounds) and R_2 intersect at O, the line of action of R_1 must also pass through O. Hence the left reaction acts through the left support and O as shown. We are now ready to determine the values of R_1 and R_2. Lay off AB to represent the resultant load, then from A and B draw lines parallel to R_1 and R_2, and mark their intersection C. Then BC and CA represent the magnitude and directions of R_2 and R_1 respectively; they scale 6,380 and 8,050 pounds.

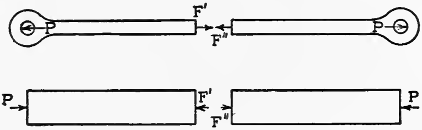

Fig. 38.

EXAMPLE FOR PRACTICE.

1. Determine the reactions on the truss represented in Fig. 26 due to wind pressure, the distance between trusses being 15 feet, supposing that both ends of the truss are fastened to the supports.

Ans. { Reaction at windward end is 6,682½ pounds.
Reaction at leeward end is 3,037½ pounds.

VII. ANALYSIS OF TRUSSES (CONTINUED); METHOD OF SECTIONS.

38. Forces in Tension and Compression Members. As explained in "Strength of Materials" if a member is subjected to forces, any two adjacent parts of it exert forces upon each other which hold the parts together. Figs. 38 (*a*) and 38 (*b*) show how these forces act in a tension and in a compression member. F' is the force exerted on the left part by the right, and F'' that exerted on the right part by the left. The two forces F' and F'' are equal, and in a tension member are pulls while in a compression member they are pushes.

39. Method of Sections. To determine the stress in a member of a truss by the method explained in the foregoing (the "method of joints"), we begin at one end of the truss and draw polygons for joints from that end until we reach one of the joints to which that member is connected. If the member is near the middle of a long truss, such a method of determining the stress in it requires the construction of several polygons. It is sometimes desirable to determine the stress in a member as directly as possible without having first determined stresses in other members. A method for doing this will now be explained ; it is called the method of sections.

Fig. 39 (*a*) is a partial copy of Fig. 16. The line LL is intended to indicate a "section" of the truss "cutting" members $\overline{24}$, $\overline{34}$ and $\overline{36}$. Fig. 39 (*b*) and (*c*) represents the parts of the truss to the left and right of the section. By "part of a truss" we mean either of the two portions into which a section separates it when it cuts it completely.

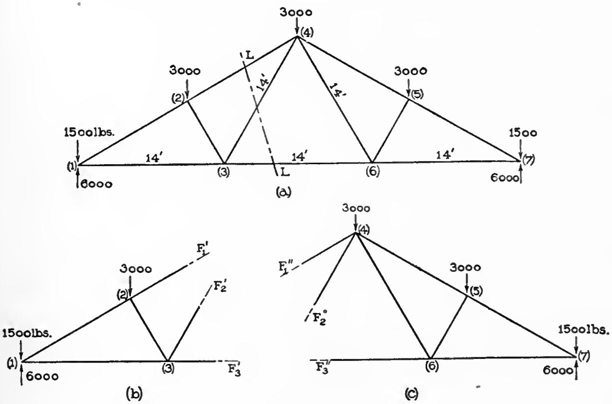

Fig. 39.

Since each part of the truss is at rest, all the forces acting on each part are balanced, or in equilibrium. The forces acting on each part consist of the loads and reactions applied to that part together with the forces exerted upon it by the other part. Thus the forces which hold the part in Fig. 39 (*b*) at rest are the 1,500- and 3,000-pound loads, the reaction 6,000 and the forces which the right part of the cut members exert upon the left parts. These latter forces are marked F_1', F_2' and F_3'; their senses are unknown.

but each acts along the axis of the corresponding member. The forces which hold the part in Fig. 39 (*c*) at rest are the two 3,000-pound loads, the 1,500-pound load, the right reaction 6,000 pounds and the forces which the left parts of the cut members exert upon the right parts. These are marked F_1'', F_2'' and F_3''; their senses are also unknown but each acts along the axis of the corresponding member. The forces F_1' and F_1'', F_2' and F_2'', and F_3' and F_3'' are equal and opposite; they are designated differently only for convenience.

If, in the system of forces acting on either part of the truss, there are not more than three unknown forces, then those three can be computed by "applying" one of the sets of the conditions of equilibrium stated in Art. 35.* In writing the equations of equilibrium for the system it is practially necessary to assume a sense for one or more of the unknown forces. *We shall always assume that such forces are pulls that is, act away from the part of the truss upon which they are exerted. Then if the computed value of a force is plus, the force is really a pull and the member is in tension and if the value is minus, then the force is really a push and the member is in compression.*

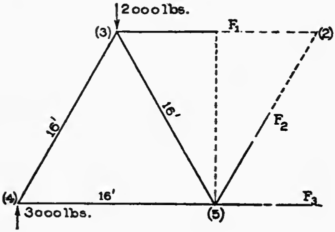

Fig. 40.

To determine the stress in any particular member of a truss in accordance with the foregoing, "pass a section" through the truss cutting the member under consideration, and then apply as many conditions of equilibrium to all the forces acting on either part of the truss as may be necessary to determine the desired force. In passing the section, care should be taken to cut as few members as possible, and never should a section be passed so as to cut more than three, the stresses in which are unknown; neither should the three be such that they intersect in a point.

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*If, however, the lines of action of the three forces intersect in a point then the statement is not true.

Examples. 1. It is required to determine the amount and kind of stress in the member $\overline{24}$ of the truss represented in Fig. 39 (*a*) when loaded as shown.

Having determined the reactions (6,000 pounds each) we pass a section through the entire truss and cutting $\overline{24}$; LL is such a section. Considering the part of the truss to the left of the section, the forces acting upon that part are the two loads, the left reaction and the forces on the cut ends of members $\overline{24}$, $\overline{34}$ and $\overline{36}$ (F_1', F_2', and F_3'). F_1' can be determined most simply by writing a moment equation using (3) as the origin, for with respect to that origin the moments of F_2' and F_3' are zero, and hence those forces will not appear in the equation. Measuring from a large scale drawing, we find that the arm of F_1' is 7 feet and that of the 3,000-pound load is 3.5 feet. Hence

$$(F_1' \times 7)+(6{,}000 \times 14)-(1{,}500 \times 14)-(3{,}000 \times 3.5)= 0$$

$$\text{or } F_1' = \frac{-(6{,}000 \times 14) + (1{,}500 \times 14) + (3{,}000 \times 3.5)}{7} = -7{,}500$$

The minus sign means that F_1' is a push and not a pull, hence the member $\overline{24}$ is under 7,500 pounds compression.

The stress in the member 24 may be computed from the part of the truss to the right of the section. Fig. 39 (*c*) represents that part and all the forces applied to it. To determine F_1'' we take moments about the intersection of F_2'' and F_3''. Measuring from a drawing we find that the arm of F_1'' is 7 feet,

that of the load at joint (4) is 7 feet,
that of the load at joint (5) is 17.5 feet,
that of the load at joint (7) is 28 feet,
and that of the reaction is 28 feet.

Hence, assuming F_1'' to be a pull,

$$-(F_1'' \times 7)+(3{,}000 \times 7)+(3{,}000 \times 17.5)+(1{,}500 \times 28)-(6{,}000 \times 28) = 0,$$

$$\text{or } F_1'' = \frac{(3{,}000 \times 7)+(3{,}000 \times 17.5)+(1{,}500 \times 28) - (6{,}000 \times 28)}{7}$$

$$= -7{,}500$$

The minus sign means that F_1'' is a push, hence the member $\overline{24}$ is under compression of 7,500 pounds, a result agreeing with that previously found.

2. It is required to find the stress in the member *gh* of the truss represented in Fig. 25, due to the loads shown.

If we pass a section cutting *bg*, *gh* and *he*, and consider the left part, we get Fig. 40, the forces on that part being the 2,000-pound load, the left reaction, and the forces F_1, F_2 and F_3 exerted by the right part on the left. To compute F_2 it is simplest to use the condition that the algebraic sum of all the vertical components equals zero. Thus, assuming that F_2 is a pull, and since its angle with the vertical is 30°,

$$F_2 \cos 30° - 2{,}000 + 3{,}000 = 0; \text{ or,}$$

$$F_2 = \frac{2{,}000 - 3{,}000}{\cos 30°} = \frac{-1{,}000}{0.866} = -1{,}154.$$

The minus sign means that F_2 is a push, hence the member is under a compression of 1,154 pounds.

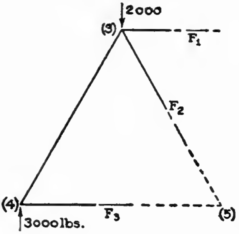

Fig. 41.

3. It is required to determine the stress in the member *bg* of the truss represented in Fig. 25, due to the loads shown.

If we pass a section cutting *bg* as in the preceding illustration, and consider the left part, we get Fig. 40. To compute F_1 it is simplest to write the moment equation for all the forces using joint 5 as origin. From a large scale drawing, we measure the arm of F_1 to be 13.86 feet hence, assuming F_1 to be a pull,

$$F_1 \times 13.86 - 2{,}000 \times 8 + 3{,}000 \times 16 = 0;$$

or,

$$F_1 = \frac{2{,}000 \times 8 - 3{,}000 \times 16}{13.86} = \frac{-32{,}000}{13.86} = -2{,}310.$$

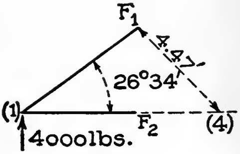

Fig. 42.

The minus sign means that F_1 is a push; hence the member is under a compression of 2,308 pounds.

The section might have been passed so as to cut members *bg*, *fg*, and *fe*, giving Fig. 41 as the left part, and the desired force might be obtained from the system of forces acting on that part (3,000, 2,000, F_1, F_2, and F_3.) To compute F_1 we take moments about the intersection of F_2 and F_3, thus

$$F_1 \times 13.86 - 2{,}000 \times 8 + 3{,}000 \times 16 = 0.$$

This is the same equation as was obtained in the first solution, and hence leads to the same result.

4. It is required to determine the stress in the member $\overline{12}$ of the truss represented in Fig. 26, due to the loads shown.

Passing a section cutting members $\overline{12}$ and $\overline{14}$, and considering the left part, we get Fig. 42. To determine F_1 we may write a moment equation preferably with origin at joint 4, thus:

$$F_1 \times 4.47 + 4{,}000 \times 10 = 0^*;$$

or,
$$F_1 = \frac{-4{,}000 \times 10}{4.47} = -8{,}948 \text{ pounds},$$

the minus sign meaning that the stress is compressive.

F_1 might be determined also by writing the algebraic sum of the vertical components of all the forces on the left part equal to zero, thus:

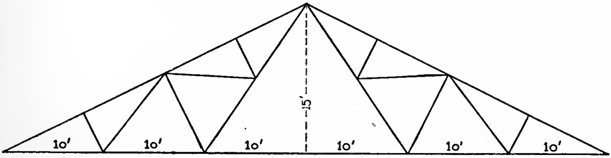

Fig. 43.

$$F_1 \sin 26° 34' + 4{,}000 = 0;$$

or,
$$F_1 = \frac{-4{,}000}{\sin 26° 34'} = \frac{-4{,}000}{0.447} = -8{,}948,$$

agreeing with the first result.

EXAMPLES FOR PRACTICE.

1. Determine by the method of sections the stresses in members $\overline{23}$, $\overline{25}$, and $\overline{45}$ of the truss represented in Fig. 26, due to the loads shown.

$$\text{Ans.} \begin{cases} \text{Stress in } \overline{23} = -\ 5{,}600 \text{ pounds,} \\ \text{Stress in } \overline{25} = -\ 3{,}350 \text{ pounds.} \\ \text{Stress in } \overline{45} = +\ 8{,}000 \text{ pounds} \end{cases}$$

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* The arm of F_1 with respect to (4) is 4.47 feet.

2. Determine the stresses in the members $\overline{12}$, $\overline{15}$, $\overline{34}$, and $\overline{56}$ of the truss represented in Fig. 27, due to the loads shown.

Ans. Stress in $\overline{12} = -11{,}170$ pounds,
Stress in $\overline{15} = +10{,}000$ pounds,
Stress in $\overline{34} = -8{,}940$ pounds,
Stress in $\overline{56} = +6{,}000$ pounds.

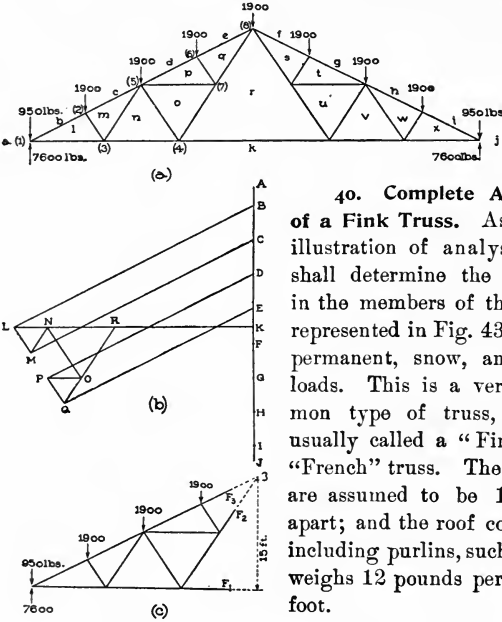


Fig. 44.

40. Complete Analysis of a Fink Truss. As a final illustration of analysis, we shall determine the stresses in the members of the truss represented in Fig. 43, due to permanent, snow, and wind loads. This is a very common type of truss, and is usually called a "Fink" or "French" truss. The trusses are assumed to be 15 feet apart; and the roof covering, including purlins, such that it weighs 12 pounds per square foot.

The length from one end to the peak of the truss equals

$$\sqrt{15^2 + 30^2} = \sqrt{1{,}125} = 33.54 \text{ feet},$$

hence the area of the roofing sustained by one truss equals

$$(33.54 \times 15)\,2 = 1{,}006.2 \text{ square feet},$$

and the weight of that portion of the roof equals

$$1{,}006.2 \times 12 = 12{,}074 \text{ pounds}.$$

The probable weight of the truss (steel), according to the formula of Art. 19, is

$$15 \times 60 \left(\frac{60}{25} + 1\right) = 3{,}060 \text{ pounds.}$$

The total permanent load, therefore, equals

$$12{,}074 + 3{,}060 = 15{,}134 \text{ pounds;}$$

the end loads equal $\frac{1}{16}$ of the total, or 950 pounds, and the other apex loads equal $\frac{1}{8}$ of the total, or 1,900 pounds.

Dead Load Stress. To determine the dead load stresses, construct a stress diagram. Evidently each reaction equals one-half the total load, that is 7,600 pounds; therefore ABCDEFGHIJKA (Fig. 44*b*) is a polygon for all the loads and reactions. First, we draw the polygon for joint 1; it is KABLK, BL and LK representing the stress in *bl* and *lk* (see record Page 72 for values). Next draw the polygon for joint 2; it is LBCML, CM and ML representing the stresses in *cm* and *ml*. Next draw the polygon for joint 3; it is KLMNK, MN and NK representing the stresses in *mn* and *nk*.

At each of the next joints (4 and 5), there are three unknown forces, and the polygon for neither joint can be drawn. We might draw the polygons for the joints on the right side corresponding to 1, 2, and 3, but no more until the stress in one of certain members is first determined otherwise. If, for instance, we determine by other methods the stress in *rk*, then we may construct the polygon for joint 4; then for 5, etc., without further difficulty.

To determine the stress in *rk*, we pass a section cutting *rk*, *qr*, and *eq*, and consider the left part (see Fig. 44*c*). The arms of the loads with respect to joint 8 are 7.5, 15, 22.5, and 30 feet; and hence, assuming F_1 to be a pull,

$$-F_1 \times 15 - 1{,}900 \times 7.5 - 1{,}900 \times 15 - 1{,}900 \times 22.5 - 950 \times 30 + 7{,}600 \times 30 = 0; \text{ or,}$$

$$F_1 = \frac{-1{,}900 \times 7.5 - 1{,}900 \times 15 - 1{,}900 \times 22.5 - 950 \times 30 + 7{,}600 \times 30}{15}$$

$$= 7{,}600 \text{ pounds}$$

Since the sign of F_1 is plus, the stress in *rk* is tensile.

Now lay off KR to represent the value of the stress in *kr* just found, and then construct the polygon for joint 4. The polygon is KNORK, NO and OR representing the stresses in *no* and *or*. Next draw the polygon for joint 5; it is ONMCDPO, DP and PO representing the stresses in *dp* and *po*. Next draw the polygon for joint 6 or joint 7; for 6 it is PDEQP, EQ and QP representing the stresses in *eq* and *qp*. At joint 7 there is now but one unknown force, namely, that in *qr*. The polygon for the three others at that joint is ROPQ; and since the unknown force must close the polygon, QR must represent that force, and must be parallel to *qr*.

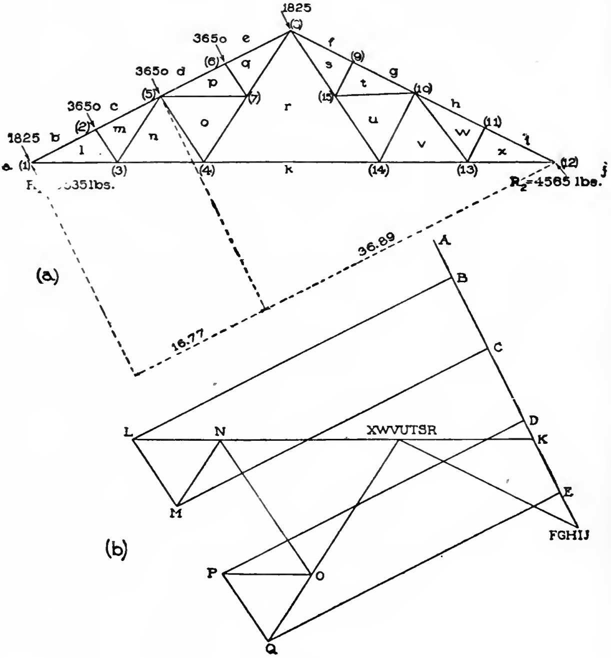


Fig. 45.

On account of the symmetry of loading, the stress in any member on the right side is just like that in the corresponding member on the left; hence, it is not necessary to draw the diagram for the right half of the truss.

Snow-Load Stress. The area of horizontal projection of the roof which is supported by one truss is $60 \times 15 = 900$ square feet; hence the snow load borne by one truss is $900 \times 20 = 18,000$ pounds, assuming a snow load of 20 pounds per horizontal square foot. This load is nearly 1.2 times the dead load, and is applied similarly to the latter; hence the snow load stress in any member equals 1.2 times the dead load stress in it. We record, therefore, in the third column of the stress record, numbers equal to 1.2 times those in the second as the snow-load stresses.

Wind Load Stress. The tangent of the angle which the roof makes with the horizontal equals $\frac{15}{30}$ or $\frac{1}{2}$; hence the angle is 26° 34′, and the value of wind pressure for the roof equals practically 29 pounds per square foot, according to Art. 19. As previously explained, the area of the roof sustained by one truss equals 1,006.2 square feet; and since but one-half of this receives wind pressure at one time, the wind pressure borne by one truss equals

$$503.1 \times 29 = 14,589.9, \text{ or practically } 14,600 \text{ pounds.}$$

When the wind blows from the left, the apex loads are as represented in Fig. 45*a*, and the resultant wind pressure acts through joint 5. To compute the reactions, we may imagine the separate wind pressures replaced by their resultant. We shall suppose that both ends of the truss are fixed; then the reactions will be parallel to the wind pressure. Let R_1 and R_2 denote the left and right reactions respectively; then, with respect to the right end, the arms of R_1 and the resultant wind pressure (as may be scaled from a drawing) are $16.77 + 36.89$ and 36.89 feet respectively; and with respect to the left end, the arms of R_2 and the resultant wind pressure are $16.77 + 36.89$ and 16.77 feet respectively.

Taking moments about the right end we find that

$$-14,600 \times 36.89 + R_1 \times (16.77 + 36.89) = 0;$$

or,
$$R_1 = \frac{14,600 \times 36.89}{16.77 + 36.89} = 10,035 \text{ pounds.}$$

Taking moments about the left end, we find that

$$14{,}600 \times 16.77 - R_2 \times (16.77 + 36.89) = 0;$$

or,
$$R_2 = \frac{14{,}600 \times 16.77}{16.77 + 36.89} = 4{,}565 \text{ pounds.}$$

To determine the stresses in the members, we construct a stress diagram. In Fig. 45*b*, AB, BC, CD, DE, and EF represent the wind loads at the successive joints, beginning with joint 1. The point F is also marked G, H, I, and J, to indicate the fact that there are no loads at joints 9, 10, 11, and 12. JK represents the right reaction, and KA the left reaction.

We may draw the polygon for joint 1 or 12; for 1 it is KABLK, BL and LK representing the stresses in *bl* and *lk*. We may next draw the polygon for joint 2; it is LBCML, CM and ML representing the stresses in *cm* and *ml*.

Stress Record.

MEMBER.	STRESSES.					
	Dead Load.	Snow Load.	Wind Left.	Wind Right.	Resultant.	Resultant.
bl	-14,700	-17,600	-16,400	15,000	-48,700	-32,300
cm	-13,700	-16,400	-15,900	15,000	-46,000	-30,100
dp	-12,600	-15,100	-15,400	15,000	-43,100	-28,000
eq	-11,600	-13,900	-14,900	15,000	-40,400	-26,500
lm	- 1,650	- 2,000	- 3,700	0	- 7,350	- 5,350
mn	+ 1,650	+ 2,000	+ 3,700	0	+ 7,350	+ 5,350
no	- 3,300	- 4,000	- 7,400	0	-14,700	-10,700
op	+ 1,850	+ 2,200	+ 4,100	0	+ 8,150	+ 5,950
pq	- 1,650	- 2,000	- 3,700	0	- 7,350	- 5,350
rq	+ 5.000	+ 6,000	+11,000	0	+22,000	+16,000
ro	+ 3,400	+ 4,100	+ 7,400	0	+14,900	+10,800
kl	+13,300	+16,000	+18,300	+ 6,100	+47,600	+31,600
kn	+11,300	+13,600	+14,200	+ 6,100	+39,100	+25,500
kr	+ 8,000	+ 9,600	+ 6,100	+ 6,100	+23,700	+17,600
kv	+11,300	+13,600	+ 6,100	+14,200	+39,100	+25,500
kx	+13,300	+16,000	+ 6,100	+18,300	+47,600	+31,600
ru	+ 3,400	+ 4,100	0	+ 7,400	+14,900	+10,800
rs	+ 5,000	+ 6,000	0	+11.000	+22,000	+16,000
st	- 1,650	- 2,000	0	-3,700	- 7,350	- 5,350
tu	+ 1,850	+ 2,200	0	+ 4,100	+ 8,150	+ 5,950
uv	- 3,300	- 4,000	0	- 7,400	-14,700	-10,700
vw	+ 1,650	+ 2,000	0	- 3,700	+ 7,350	+ 5,350
wx	- 1,650	- 2,000	0	- 3,700	- 7,350	- 5,350
fs	-11,600	-13,900	15,000	-14,900	-40,400	-26,500
gt	-12,600	-15,100	15,000	-15,400	-43,100	-28,000
hw	-13,700	-16,400	15,000	-15,900	-46,000	-30,100
ix	-14,700	-17,600	15,000	-16,400	-48,700	-32,300

We may draw next the polygon for joint 3; it is KLMNK, MN and NK representing the stresses in *mn* and *nk*. No polygon for a joint on the left side can now be drawn, but we may begin at the right end. For joint 12 the polygon is JKXIJ, KX and XI representing the stresses in *kx* and *xi*.

At joint 11 there are three forces; and since they are balanced, and two act along the same line, those two must be equal and opposite, and the third must equal zero. Hence the point X is also marked W to indicate the fact that XW, or the stress in *xw*, is zero. Then, too, the diagram shows that WH equals XI. Having just shown that there is no stress in *xw*, there are but three forces at joint 13. Since two of these act along the same line, they must be equal and opposite, and the third zero. Therefore the point W is also marked V to indicate the fact that WV, or the stress in *wv*, equals zero. The diagram shows also that VK equals XK. This same argument applied to joints 9, 15, 10, and 14 successively, shows that the stresses in *st*, *tu*, *uv*, *ur*, and *sr* respectively equal zero. For this reason the point X is also marked UTS and R. It is plain, also, that the stresses in *sf* and *tg* equal those in *wh* and *xi*, and that the stress in *kr* equals that in *kv* or *kx*. Remembering that we are discussing stress due to wind pressure only, it is plain, so far as wind pressure goes, that the intermediate members on the right side are superfluous.

We may now resume the construction of the polygons for the joints on the left side. At joint 4, we know the forces in the members *kn* and *kr*; hence there are only two unknown forces there. The polygon for the joint is KNORK, NO and OR representing the stresses in *no* and *or*. The polygon for joint 5 may be drawn next; it is ONMCDPO, DP and PO representing the stresses in *dp* and *po*. The polygon for joint 6 or joint 7 may be drawn next; for 6 it is PDEQP, EQ and QP representing the stresses in *eq* and *qp*. At joint 7 there is but one unknown force, and it must close the polygon for the known forces there. That polygon is ROPQ; hence QR represents the unknown force. (If the work has been correctly and accurately done, QR will be parallel to *qr*).

When the wind blows upon the right side, the values of the reactions, and the stresses in any two corresponding members, are reversed. Thus, when the wind blows upon the left side, the stresses in kl and kx equal 18,300 and 6,100 pounds respectively; and when it blows upon the right they are respectively 6,100 and 18,300 pounds. It is not necessary, therefore, to construct a stress diagram for the wind pressure on the right. The numbers in the fifth column (see table, Page 72) relate to wind right, and were obtained from those in the fourth.

41. Combination of Dead, Snow, and Wind-Load Stresses. After having found the stress in any member due to the separate loads (dead, snow, and wind), we can then find the stress in that member due to any combination of loads, by adding algebraically the stresses due to loads separately. Thus, in a given member, suppose:

Dead-load stress = + 10,000 pounds,
Snow-load " = + 15,000 "
Wind-load " (right) = – 12,000 "
" " (left) = + 4,000 "

Since the dead load is permanent (and hence the dead-load stress also) the resultant stress in the member when there is a snow load and no wind pressure, is

$$+10{,}000 + 15{,}000 = +25{,}000 \text{ pounds (tension)};$$

when there is wind pressure on the right, the resultant stress equals

$$+10{,}000 - 12{,}000 = -2{,}000 \text{ pounds (compression)};$$

when there is wind pressure on the left, the resultant stress is

$$+10{,}000 + 4{,}000 = +14{,}000 \text{ pounds (tension)};$$

and when there is a snow load and wind pressure on the left, the resultant stress is

$$+10{,}000 + 15{,}000 + 4{,}000 = +29{,}000 \text{ pounds (tension)}.$$

If all possible combinations of stress for the preceding case be made, it will be seen that the greatest tension which can come upon the member is 29,000 pounds, and the greatest compression is 2,000 pounds.

In roof trusses it is not often that the wind load produces a "reversal of stress" (that is, changes a tension to compression, or *vice versa*); but in bridge trusses the rolling loads often produce reversals in some of the members. In a record of stresses the reversals of stress should always be noted, and also the value of the greatest tension and compression for each one.

The numbers in the sixth column of the record (Page 72) are the values of the greatest resultant stress for each member. It is sometimes assumed that the greatest snow and wind loads will not come upon the truss at the same time. On this assumption the resultant stresses are those given in the seventh column.

EXAMPLE FOR PRACTICE.

1. Compile a complete record for the stresses in the truss of Fig. 24, for dead, snow, and wind loads. See Example 1, Article 27, for values of dead-load stresses, and Example 2, Article 29, for values of the wind-load stresses. Assume the snow load to equal 1.2 times the dead load.

After the record is made, compute the greatest possible stress in each member, assuming that the wind load and snow load will not both come upon the truss at the same time.

The greatest resultant stresses are as follows:

Member.	*af*	*fe*	*bg*	*fg*	*gh*	*hi*	*hc*	*ie*	*id*
Resultant....	-14,950	+17,800	-10,400	-8,875	+7,820	-8,875	-11,800	+11,500	-13,850

42. Truss Sustaining a Roof of Changing Slope. Fig 46 represents such a truss. The weight of the truss itself can be estimated by means of the formula of Art. 19. Thus if the distance between trusses equals 12 feet, the weight of the truss equals

$$W = 12 \times 32 \left(\frac{32}{25} + 1\right) = 875 \text{ pounds.}$$

The **weight of the roofing** equals the product of the area of the roofing and the weight per unit area. The area equals 12 times the sum of the lengths of the members $\overline{12}$, $\overline{23}$, $\overline{34}$, and $\overline{45}$, that is, $12 \times 36\frac{1}{2} = 438$ square feet. If the roofing weighs 10 pounds per square foot, then the weight of roofing sustained by one truss equals $438 \times 10 = 4{,}380$ pounds. The total dead load then equals

$$875 + 4{,}380 = 5{,}255 \text{ pounds;}$$

and the apex dead loads for joints 2, 3, and 4 equal:

$$\frac{1}{4} \times 5{,}255 = 1{,}314 \text{ (or approximately 1,300) pounds;}$$

while the loads for joints 1 and 5 equal

$$\frac{1}{8} \times 5{,}255 = 657 \text{ (or approximately 650) pounds.}$$

The **snow loads** for the joints are found by computing the snow load on each separate slope of the roof. Thus, if the snow weighs 20 pounds per square foot (horizontal), the load on the portion $\overline{12}$ equals 20 times the area of the horizontal projection of the portion of the roof represented by $\overline{12}$. This horizontal projection equals 8×12 ($= 96$) square feet; snow load equals 96×20 ($= 1{,}920$) pounds. This load is to be equally divided between joints 1 and 2.

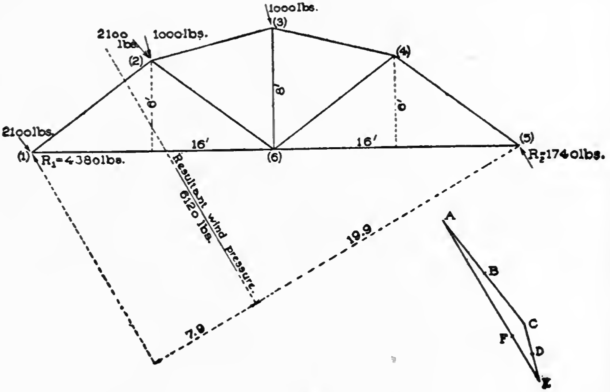


Fig. 46.

In a similar way the snow load borne by $\overline{23}$ equals 20 times the area of the horizontal projection of the roof represented by $\overline{23}$; this horizontal projection equals 8×12 ($= 96$) square feet as before, and the snow load hence equals 1,920 pounds also. This load is to be equally divided between joints 2 and 3.

Evidently the loads on parts $\overline{34}$ and $\overline{45}$ also equal 1,920 pounds each; hence the apex loads at joints 1 and 5 equal 960 pounds and at joints 2, 3 and 4, 1,920 pounds.

The wind load must be computed for each slope of the roof separately. The angles which $\overline{12}$ and $\overline{23}$ make with the horizontal, scale practically 37 and 15 degrees. According to the table of wind pressures (Art. 19), the pressures for these slopes equal about 35 and 20 pounds per square foot respectively. Since member $\overline{12}$ is 10 feet long, the wind pressure on the 37-degree slope equals $10 \times 12 \times 35 = 4{,}200$ pounds.

This force acts perpendicularly to the member $\overline{12}$, and is to be equally divided between joints 1 and 2 as represented in the figure. Since the member $\overline{23}$ is $8\frac{1}{4}$ feet long, the wind pressure on the 15-degree slope equals

$$8\tfrac{1}{4} \times 12 \times 20 = 1{,}980 \text{ or approximately } 2{,}000 \text{ pounds.}$$

This pressure acts perpendicularly to member $\overline{23}$, and is to be equally divided between joints 2 and 3 as represented.

The stress diagram for dead, snow, or wind load for a truss like that represented in Fig. 46, is constructed like those previously explained; but there are a few points of difference in the analysis for wind stress, and these will be explained in what follows.

Example. Let it be required to determine the stresses in the truss of Fig. 46, due to wind loads on the left as represented.

It is necessary to ascertain the reactions due to the wind loads; therefore, find the resultant of the wind pressures, see Art. 37; it equals 6,120 pounds and acts as shown. Now, if both ends of the truss are fastened to the supports, then the reactions are parallel to the resultant wind pressure, and their values can be readily found from moment equations. Let R_1 and R_2 denote the left and right reactions respectively; then, since the arms of R_1 and the resultant wind pressure with respect to the right end equal 27.8 and 19.9 feet respectively,

$$R_1 \times 27.8 = 6{,}120 \times 19.9 = 121{,}788\,;$$

hence, $$R_1 = \frac{121{,}788}{27.8} = 4{,}380 \text{ pounds approximately.}$$

Since the arms of R_2 and the resultant wind pressure with respect to the left support are 27.8 and 7.9 feet respectively,

$$R_2 \times 27.8 = 6{,}120 \times 7.9 = 48{,}348\,;$$

hence, $R_2 = \frac{48{,}348}{27.8} = 1{,}740$ pounds approximately.

The next step is to draw the polygon for the loads and reactions; so we draw lines AB, BC, CD, and DE to represent the loads at joint 1, the two at joint 2, and that at joint 3, respectively; and then EF to represent the right reaction. (If the reactions have been correctly determined and the drawing accurately done, then FA will represent the left reaction.)

The truss diagram should now be lettered (agreeing with the letters on the polygon just drawn), and then the construction of the stress diagram may be begun. Since this construction presents no points not already explained, it will not be here carried out.

EXAMPLE FOR PRACTICE.

Analyze the truss of Fig. 46 for dead, snow, and wind loads as computed in the foregoing, and compute the greatest resultant stress in each member due to combined loads, assuming that the snow and wind do not act at the same time.

Stress Record.

Ans.

Member.	Dead.	Snow.	Wind Left.	Wind Right.	Resultant.
12	-3,250	-4,800	-3,450	-2,500	-8,050
23	-2,700	-4,000	-2,850	-3,100	-6,700
16	+2,600	+3,850	+3,750	+1,150	+6,450
26	0	0	-2,000	+1,250	-2,000 +1,250
36	0	0	+ 450	+ 450	+ 450
46	0	0	+1,250	-2,000	+1,250 -2,000
56	+2,600	+3,850	+1,150	+3,750	+6,450
43	-2,700	-4,000	-3,100	-2,850	-6,700
54	-3,250	-4,800	-2,500	-3,450	-8,050

RAILROAD STATION, NEW YORK CITY

ROOF TRUSSES

1. Classes of Roof Trusses. Roof trusses may be divided into three classes according to the shape of their upper chord. These three classes are:

(1) Triangular roof trusses;
(2) Crescent roof trusses;
(3) Roof trusses other than these.

Fig. 1 shows various forms of triangular roof trusses. The *Pratt* and *Howe* trusses are shown respectively by *a* and *b*. These trusses obtain their name on account of their web bracing being of the Pratt or Howe type. The triangular truss in most common use is the *Fink*, next to which is the *Saw-tooth*. The Fink truss is built in a variety of forms, as shown in Fig. 1 (*c, d, e,* and *f*), *c* being for spans up to 60 feet; *e* for spans up to 70 feet, and *d* and *f* for spans up to 80 feet and over. The great advantage of this style of truss is that many of its members have the same stress, and therefore it can be constructed more cheaply on account of the fact that a large amount of the same sized material can be purchased at once.

When the top chord of a roof truss becomes bent as shown in Fig. 2, the truss is called a *crescent* roof truss. The bracing in the crescent roof trusses is not of any particular form, being as a usual thing built of members which can take either tension or compression. This is made necessary by the fact that the curved upper chord may cause either tension or compression in the webbing, according to the angle of its inclination with the horizontal.

Roof trusses which do not come under either of the above classes may be regarded in a class of their own. To this class belong those trusses which are somewhat like a bridge truss in that the two chords are horizontal or nearly so. The ends of these trusses may be rectangular or not. For various types of this class of truss, see Fig. 3.

In addition to the above classification, which is based on the form of the chords, roof trusses may be divided according to the manner in which their members are connected. This classification

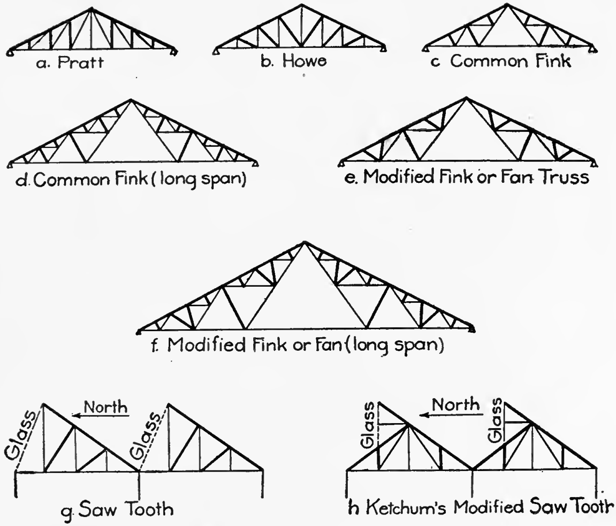


Fig. 1. Triangular Roof Trusses.

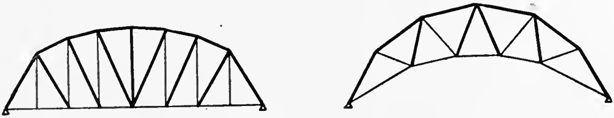


Fig. 2. Crescent Roof Trusses.

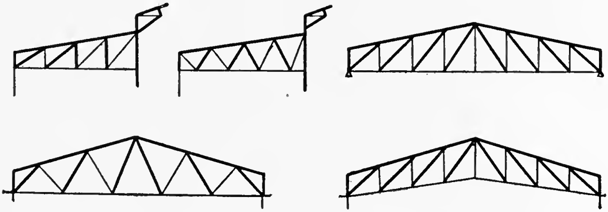


Fig. 3. Trusses with Chords Almost Parallel.

is that of *pin-connected* and *riveted.* For a definition of this, and for figures showing such joints, see "Statics," pp. 22 and 23.

Trusses are seldom built as pin-connected unless they are of long span, since roof trusses are comparatively light, and pin-connected trusses, unless of considerable weight, do not give very great stiffness.

Fig. 4. Chord Section for Heavy Stresses.

Riveted roof trusses are used for nearly all practical purposes, since they give great rigidity under the action of wind and of moving loads, such as cranes, which may be attached to them.

2. **Physical Analysis of Roof Trusses.** In pin-connected roof trusses, the tension members consist of I-bars or rods; and the compression members are made of channels or angles and plates, either plain or latticed. In riveted trusses, both tension and compression members are made up of angles and plates or a combination of the two. The top chords of roof trusses of medium span usually consist of two angles placed back to back. If the stress becomes too great to be taken up by two angles larger than 5 by 3½ inches, then two angles and a plate are used (see Fig. 4). In case the roof truss is of great size and the stresses are exceedingly large, the chord member may be built up in a manner somewhat similar to a bridge truss, being constructed of two channels and a plate, or four angles and three plates. Figs. 5 and 6 show cross-sections of chords for long-span riveted trusses. These cross-sections may also be used for pin-connected trusses.

Fig. 5.

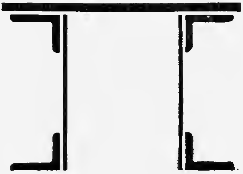


Fig. 6

Chord Sections for Trusses of Long Span.

The web members of a truss usually consist of one angle; and if this is insufficient, two angles back to back are used. Fig. 80, page 65, gives a diagram of a roof, and shows not only the roof trusses but also various other parts which will be referred to in the succeeding articles.

3. **Wind Pressure and Snow Loads.** The wind pressure on a flat surface varies, of course, with the velocity of the wind, and is very closely given by the formula:

$$P = 0.004V^2$$

By substituting in this formula, the values shown in Table I are determined for given velocities in miles per hour.

TABLE I

Wind Pressure at Various Velocities

VELOCITY (Miles per hour)	PRESSURE (Lbs. per square foot)	REMARKS
10	0.4	Breeze
20	1.6	Strong breeze
30	3.6	Strong wind
40	6.4	High wind
50	10.0	Storm
60	14.4	Heavy storm
70	19.6	Hurricane
80	25.6	"
100	40.0	"

The pressures indicated in Table I are perpendicular to the direction of the wind. When the wind blows on an inclined surface, the wind is assumed to be acting horizontally, and the normal component on the inclined surface is determined. This component is not equal to the horizontal pressure times the sine of the angle of inclination, as one would suppose (see Fig. 7), but is greater by a small amount. Roofs are usually figured on a basis of 40 pounds pressure on a vertical surface. The value of the normal component for a horizontal wind pressure of 40 pounds per square foot, is given on page 24 of "Statics," and is here, for convenience, reduced to the normal pressure for any given pitch.

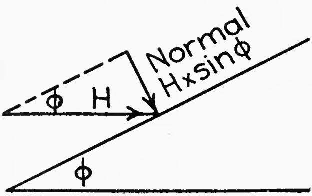


Fig. 7. Theoretical Determination of Normal Component.

PITCH	NORMAL WIND PRESSURE
$\frac{1}{3}$	34 pounds per square foot.
30°	32 " " " "
$\frac{1}{4}$	30 " " " "
$\frac{1}{5}$	26 " " " "
$\frac{1}{6}$	22 " " " "

If the normal pressure on a roof making any other angle with the horizontal is desired, see "Statics," p. 24.

The determination of these values is based for the most part on data obtained by experiment. In the computations relative to the design of buildings, the wind is usually assumed to exert a pressure on the walls of 30 pounds per square foot.

The snowfall varies with the locality. The heaviest snow loads which come upon a roof are not always in the locality of the heaviest snowfall, since a comparatively light snowfall may occur, and if this is followed by wind and sleet, the result will be a load greatly in excess of the snowfall itself. The snow load per square foot of roof surface varies with the pitch of the roof, and will be greater the smaller the pitch. The ice and sleet will be comparatively constant. Fig. 8* gives values of snow and sleet loads which are recommended for use. It is customary to figure the snow load by taking it as so much per square foot of horizontal projection.

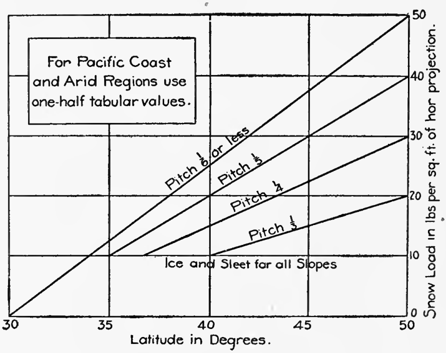


Fig. 8. Unit Snow Loads.

EXAMPLES FOR PRACTICE

1. Compute the wind panel load on a roof whose pitch is $\frac{1}{4}$, and whose panel length is 15 feet, the distance between trusses being 16 feet.

2. Compute the snow panel load for the truss of Problem 1, above.

---

*Ketchum's "Steel Mill Buildings," p. 11.

4. **Weights of Roof Trusses.** The weight of a roof truss varies with the material of which it is constructed, the span, the distance between trusses, the pitch, and the capacity of the truss. The actual weight, of course, cannot be determined until after the truss is designed; but an approximate weight may be obtained from any of the empirical formulæ which are now in use. Table II gives the most common and best of the empirical formulæ, together with the names of their authors.

TABLE II

Formulæ Giving Weights of Roof Trusses

Formula	Author
$W = \frac{3}{4}\,al\left(1 + \frac{l}{10}\right)$	Mansfield Merriman
$W = al\left(1 + \frac{l}{25}\right)$	E. R. Maurer, (p. 23, "Statics")
$W = al^2\left(\frac{1}{25} + \frac{l}{6\,000}\right)$, wooden trusses.	N. C. Ricker
$W = \frac{Pal}{45}\left(1 + \frac{l}{5\sqrt{a}}\right)$	Milo S. Ketchum*
$W = 2a\left(4 + \frac{l}{25}\right)\sqrt{l^2 + r^2}$	C. W. Bryan
$W = al\,(0.06\,l + 0.6)$ for heavy loads $W = al\,(0.04\,l + 0.4)$ " light "	C. E. Fowler

In the above formulæ,

W = Weight of steel in truss, in pounds;
P = Capacity of truss in pounds per square foot of horizontal projection of roof;
r = Rise of peak, in feet;
a = Distance center to center of trusses, in feet;
l = Span of truss, in feet.

ROOF COVERINGS

5. The roof is covered with some material which will protect the interior of the building from the action of the elements. This covering may consist of any one or more of the materials which, together with their weights per square foot, are indicated in Table III. The weights here given for materials which must be laid upon sheathing, do not include the weight of the sheathing, which is given separately. A short description, together with necessary information for use in estimates, will now be given.

---

* "Steel Mill Buildings," p. 5.

TABLE III

Approximate Weights of Roof Coverings

MATERIAL	WEIGHT PER SQUARE FOOT
White pine sheathing 1 inch thick	3 lbs.
Yellow pine sheathing 1 inch thick	4 "
Batten sheathing, 4-in. by 1-in.	2½ "
Slate	10 "
Skylight glass, including frame	10 "
Tin	1 "
Shingles	3 "
Corrugated steel	2 "
Flat tiles	12 to 25 "
Corrugated tiles	10 "
Concrete slabs	35 to 50 "
Felt, asphalt and gravel	10 "
Felt and gravel	10 "
Patent roofings	½ to 1¼ "
Sheet steel	1½ "
Non-condensing base	1 "

Sheathing. Sheathing is generally laid directly upon the purlins (see Article 6); and upon this are laid the shingles, slate, tin, or tile. Sheathing is usually made of a single thickness of planks, 1 to 2½ inches thick, laid close together. In some cases, however, when batten sheathing is used, it is spaced from 2 to 4 inches apart. This has the advantage of being cheap and at the same time allowing good circulation of air beneath the roof covering, and consequently dampness due to any cause will soon dry out. Batten sheathing is much used where the roof covering consists of slate, shingles, or tile.

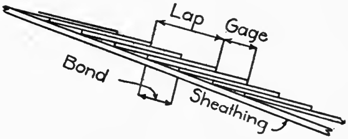


Fig. 9. Method of Laying Slate.

Slate. Roofing slate is generally of the characteristic slaty color, but may be obtained in nature in greens, purple, reds, and other colors. It is made in thicknesses of from $\frac{1}{8}$ to $\frac{1}{4}$ inch, in widths from 6 to 24 inches, and in lengths from 12 to 44 inches. The 12 by 18 by $\frac{3}{16}$-in. slate is probably the most commonly used. Slate should be laid as shown in Fig. 9, and the pitch of the roof should not be less than $\frac{1}{4}$. If the pitch of the roof is less than this, the lap should be made greater than 3 inches, as is shown in Fig. 9. The lap should be increased at least $\frac{1}{2}$ inch for every $\frac{1}{100}$ in pitch; and the minimum pitch should never be less than $\frac{1}{5}$, since it is practically impossible to prevent roofs with a smaller pitch than this from leaking, especially if a strong wind is blowing.

The number of different sizes of slate required to lay 100 square feet of surface, and also their weight, are given in the handbooks of the various slate companies. With a 3-inch lap, it takes 160 of the size and thickness mentioned above to lay 100 square feet, and the total weight of this square is 650 pounds. Slate is one of the most durable of roofing materials. Its first cost is high, being from 5 to 8 dollars per hundred square feet; but the cost of maintenance is almost nothing, since it is affected neither by the elements nor by the action of gases or acids. In case the roof would be subjected to the action of gases or acids, it is advisable to use copper slating nails.

Skylight Glass. Skylights usually consist of glass about $\frac{3}{16}$ to $\frac{3}{8}$ inch in thickness, supported on light members of iron or galvanized iron which act as a framework. The actual weight of glass of different kinds can be accurately obtained from manufacturers' catalogues, and the student is referred to these; they may be had by addressing the manufacturers (see Figs. 73 and 74).

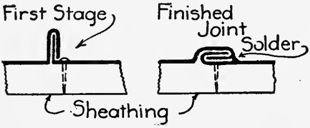


Fig. 10. Tin Laid with Flat Seam.

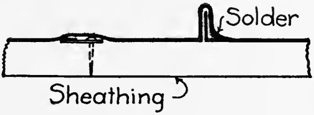


Fig. 11. Tin Laid with Standing Seam.

Tin. This is made by coating thin, flat sheets of iron or steel, either with tin alone or with a mixture of tin and lead. In the first case the product is called *bright tinplate,* and in the second case *terne plate.* Terne plate must not be used where it will be subjected to the action of acids or corrosive gases, since the lead coating is rapidly destroyed, and then of course the iron also.

Tin plates come in various sizes and thicknesses; but usually 112 come in one box. The most commonly used is a sheet 20 by 28 inches, and of sheet iron of No. 27 gauge, which weighs 10 ounces to the square foot. This is marked "IX." If the box were marked "IC," it would indicate that the sheets were of No. 29 gauge metal, which weighs 8 ounces to the square foot. The value of the roofing depends to a great extent upon the amount of tin used in the coating. This will vary from 8 to 50 pounds for a box of the 20 by 28-inch sheets.

A tin roof is formed by fixing together a number of these sheets. The sheets may be connected as shown in Fig. 10, or as shown in Fig. 11. In the first case, they are said to be laid with a *flat seam,* and in the second case they are said to be laid with a *standing seam.* Tin roofs rot out very readily unless they are kept painted. If a new coat is given them every couple of years, they will last from twenty to thirty years.

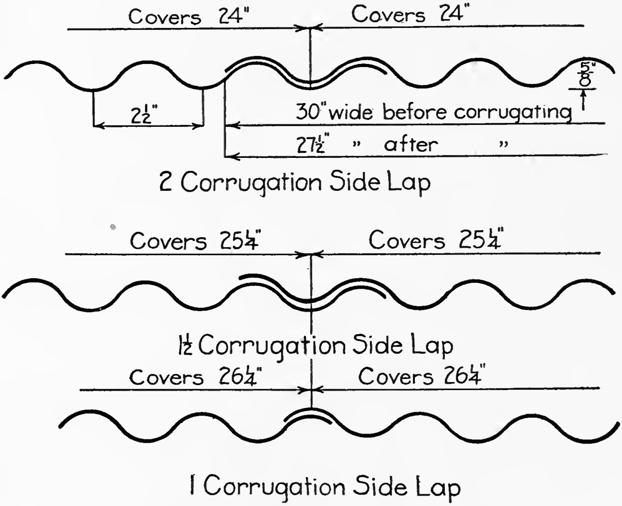


Fig. 12. Lapping of Corrugated Steel.

Tin can be laid on roofs whose pitch is very small, say $\frac{1}{10}$. The first cost is about as much as that of slate, but the cost of maintenance is very high.

Shingles. Shingle roofs are very seldom used on buildings for manufacturing purposes, for the reason that they take fire quite readily, leak quite easily, and require renewal quite often. Shingles are from 18 to 24 inches long, and usually run from 2 to 8 inches in width, although they can be obtained of a uniform width of from 4 to 6 inches. They are laid like slate, the lap being made 4 inches or more. They should never be laid on roofs whose pitch is less than $\frac{1}{3}$. It takes about from 800 to 1,000 shingles to lay 100 square feet of roof. The cost is about $5.00 per 100 square feet; but under the best conditions, the life of shingles is only about ten years.

Corrugated Steel. Corrugated steel is made from flat sheets of standard gauges, and may be either galvanized or left as it comes from the rolls. The corrugations are of different sizes and widths; the total width of the plates runs from 24 to 28 inches, and their length from 5 to 10 feet, varying by $\frac{1}{2}$ foot. The sheet most used for roof construction has $2\frac{1}{2}$-inch corrugations; is 26 inches wide after corrugating; and will cover a width of 24 inches with one lap and $21\frac{1}{2}$ inches with two laps. This roofing should be laid with a pitch of not less than $\frac{1}{4}$, and should have from 6 to 8 inches lap at the ends. For further information regarding the method of lapping and the width covered, see Fig. 12.

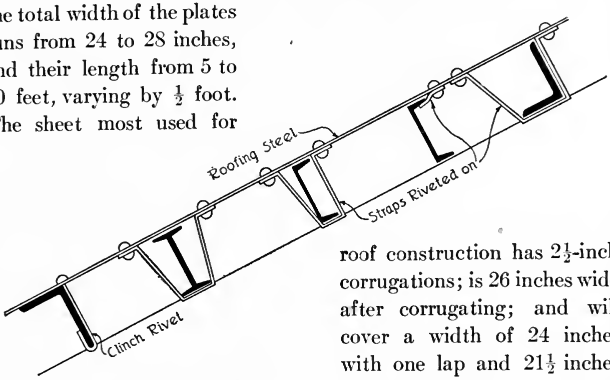


Fig. 13. Showing How Steel Roofing is Fastened to Purlins.

Corrugated steel is fastened either directly to wooden purlins by means of nails, or directly to iron purlins either by means of a bolt and clip or by a clinch nail (see Fig. 13).

It is often advisable to know the strength of corrugated steel when supported at certain distances apart by supports perpendicular to the corrugations. This unsupported length determines in many cases the spacing of the purlins. The load in pounds per square foot which can be carried by a plate of span l, parallel to the corrugation, is given by the formula:

$$W = \frac{330\,S\,d\,t}{l^2},$$

in which,

l = Unsupported length of sheet, in inches;
t = Thickness of sheet, in inches;
S = Allowable unit-stress;
d = Depth of corrugation, in inches.

Table IV, giving data relative to corrugated sheets, is taken from page 172 of the Pocket Companion of the Carnegie Steel Company (edition of 1902), where also other valuable information is given.

TABLE IV

Corrugated Steel Data

No. by Birmingham Gauge	Thickness (Inches)	Weight in lbs. per 100 Sq. Ft. of Roof when Laid with 6-in. End Lap and One Corrugation, 2½-in., Side Lap, and Length of:					
		5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.
16	0.065 in.	365	358	353	350	348	346
18	0.049 "	275	270	267	264	262	261
20	0.035 "	196	192	190	188	186	185
22	0.028 "	156	154	152	150	149	148
24	0.022 "	123	121	119	118	117	117
26	0.018 "	101	99	97	97	96	95

Tiles. One of the most common sizes of plain roofing tile is 10½ inches long by 6¼ inches wide and ⅝ inch thick. Tile of this size weigh about 2¼ pounds each. They are laid with a lap equal to one-half their length. They may be laid directly upon plank sheathing in a manner similar to shingles or slate, or they may be laid directly upon purlins (see Figs. 14, 15, and 16). In the first case they are nailed directly to the sheathing, and in the second case they are connected with the purlins either with copper wire or clinch nails. Flat tiles are usually laid in cement; corrugated tiles are made so as to interlock, and consequently in most cases require no cement. One convenience of the tile roof is that the skylights may be formed by laying glass tile in place of the other.

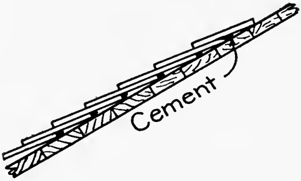


Fig. 14. Method of Laying Flat Tile on Plank Sheathing.

Tile roofs are very substantial; but are very costly, in regard not only to the tiles themselves, but also in regard to the additional weight required in the trusses by reason of the great weight to be supported. Tile weigh from 700 to 1,000 pounds per 100 square feet of roof surface. They cost from $12.00 to $40.00 per 100 square feet on the roof.

Concrete Slabs. These are usually moulded directly in place by suspending forms from the roof trusses. They may or may not be reinforced, and in any case are usually not over 4 inches in thickness. Their weight is about 50 pounds per square foot. Their cost is from $16.00 to $30.00 per hundred square feet of roof surface. They are expensive, not only on their own account, but also from the fact that the weight of the roof trusses must be increased in order to carry the weight of the slabs. Concrete roofing may be used on roofs which are practically flat, $\frac{1}{2}$ inch to 1 foot being sufficient pitch.

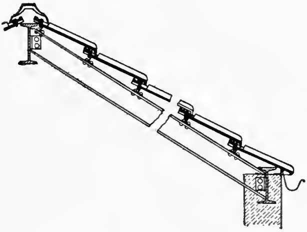


Fig. 15. Ludowici Tile on Steel Purlins.

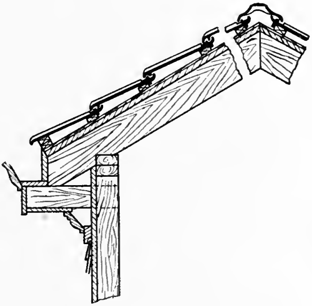


Fig. 16. Ludowici Tile on Sheathing.

Felt and Asphalt. This roofing is laid upon shingles, and consists of one thickness of dry felt, three or four thicknesses of roofing felt well cemented together with asphalt cement, and laid with good laps where they join, and a coating of from 100 to 200 pounds of asphalt per 100 square feet of roof surface. Upon this asphalt, while hot, gravel screened through a $\frac{5}{8}$-inch mesh is spread in the quantity of about $\frac{1}{5}$ of a cubic yard per 100 square feet. This class of roofing should never be laid on roofs whose pitch is greater than $\frac{1}{5}$, since, when heated by the rays of the sun, the asphalt will run and destroy the surface. It gives good satisfaction on roofs whose pitch is $\frac{1}{12}$. This class of roofing can be bought in rolls, and in this case the gravel is exceedingly fine, being screened through a $\frac{1}{8}$-inch mesh.

Felt and Gravel Roofing. This roofing is similar to the above; only, in this case, tar instead of asphalt is used for the cementing constituent. This roofing does well on roofs of flat pitch, and should never be used on roofs whose pitch exceeds $\frac{1}{6}$. It can also be bought in rolls ready for laying, in which case the gravel is screened through a $\frac{1}{8}$-inch mesh. The prepared roofings are cheaper than those laid by hand; but they do not give good service unless great care is taken to fasten them down securely. In economy of first cost and maintenance, they are equal to or better than tin.

Sheet Steel. This should not be laid on a pitch less than $\frac{1}{4}$, unless the ends are cemented together where they lap. It comes in sheets 28 inches wide and from 4 to 12 feet long, or it may be purchased in rolls 26 inches wide and about 50 feet long. When used in sheets, it may be had with standing crimped edges, in which case it is laid as shown in Fig. 17. In case it comes in rolls, it may be laid in the same manner as tin, with either standing seams or horizontal flat ones as shown in Figs. 10 and 11. Like corrugated steel, it comes in different gauges, No. 28 being that most commonly used. It can be laid cheaper than tin, on account of the long lengths obtainable.

Fig. 17. Method of Laying Sheet Steel with Crimped Edges.

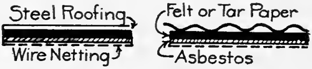


Fig. 18. Method of Laying Roofing on an Anti-Condensing Base.

Patent roofings of many kinds are on the market. These come in rolls usually from 2 feet to 3 feet wide, and cover about 200 square feet of roof surface. The basis of most of these covers is asbestos, felt, magnesia, or rubber; and this is treated with either asphalt, tar, or some other preparation, and in some cases is covered with fine gravel.

Non-Condensing Roofing. In cases where a metal, slate, or tile roof is used without sheathing, moisture is liable to condense upon the under side and drip on the floor beneath. This can be prevented by laying the material upon an anti-condensing base consisting of a layer of wire netting on top of which are placed one or more sheets of asbestos paper about $\frac{1}{16}$ inch thick (see Fig. 18).

6. **Rafters and Purlins.** Roof trusses are usually connected by beams running from one to the other. These beams are called *purlins.* In case the purlins are spaced too far apart to lay the roof covering directly upon them, beams are placed upon the purlins, and on these beams the roof covering is placed. These beams are called *rafters.* Rafters are usually made of wood, while purlins are made of channels, I-beams, Z-bars, and, if the trusses are spaced sufficiently close together, *tees* or *angles.* Figs. 19 and 20 show how rafters and purlins are placed. Fig. 21 illustrates the use of purlins made of tees. As purlins are more rigid about an axis perpendicular to their webs, they are liable to sag toward the eaves at their center. In this case, *sag rods* are used, as shown in Fig. 22.

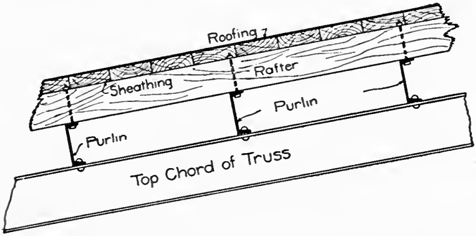


Fig. 19. Roof Construction in which Rafters Supporting the Sheathing are Laid on the Purlins which Connect the Trusses.

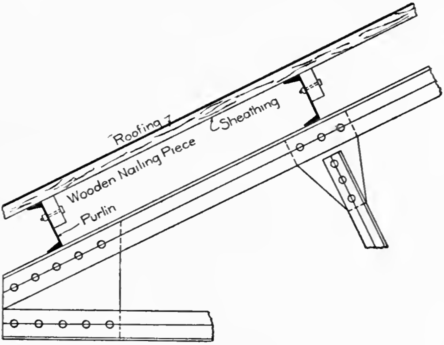


Fig. 20. Sheathing Laid Directly on Purlins.

EXAMPLES FOR PRACTICE

1. Compute the roof rafters if the purlins are spaced 10 feet apart, the roof covering weighs 10 pounds, the sheathing 4 pounds, and the snow load per square foot of roof surface 12 pounds.

This problem may be solved, either by assuming the size of the rafters and computing their spacing, or by assuming the spacing and computing the size of the rafters. The latter method is the one most commonly used. The spacing of rafters is from 18 inches to 4 feet.

The common spacing is 2 feet. The weight of the rafter itself is neglected in its design.

The total weight per square foot which comes on the rafter is $12 + 10 + 4 = 26$ pounds. Since each rafter carries a portion of the roof 10 by 2 feet, the total weight on one rafter is $10 \times 2 \times 26 = 520$ pounds. The moment created by this weight is $(520 \times 10 \times 12) \div 8 = 7\,800$ pound-inches. This should be equated to $\frac{S\,I}{c}$. Allowing 1 000 pounds to the square inch as the unit-stress on the extreme fibre, and noting that $I \div C = \frac{b\,d^3}{12} \div \frac{d}{2} = \frac{b\,d^2}{6}$ there results:

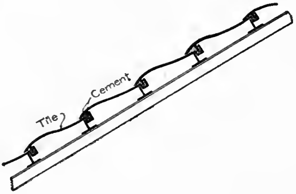


Fig. 21. Use of Purlins Made of Tees.

$$\frac{1\,000\,bd^2}{6} = 7\,800$$

$$d = \sqrt{46.8 \div b}$$

The market widths of rafters are $1\frac{1}{2}$, 2, 3, and 4 inches, 2 inches being the size usually employed. Substituting in the above formula, we have:

$$d = \sqrt{46.8 \div 2} = 4.8 \text{ inches.}$$

The rafters will be made 2 by 6 inches, since this is the nearest market size. If a 3-foot spacing of rafters was used, the required depth would be 5.92 inches, and a 2 by 6-inch would still be used. This spacing and this size of rafter would be the one to employ in the solution of the above problem.

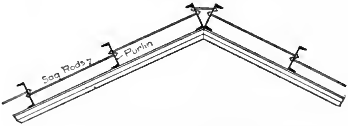


Fig. 22. Use of Sag Rods to Prevent Sagging of Purlins at their Center.

2. Design the purlin for the roof of Problem 1, above, if the trusses are spaced 16 feet apart.

The rafters are spaced so close together that their own weight, the weight of the roof covering, and the snow load may be considered as uniformly distributed over the purlin. The total weight which comes upon one purlin is the weight of snow and roof covering on a space 16 feet long and 10 feet wide. This weight is:

Snow load = 10 × 16 × 12	1 920	pounds
Roof covering = 10 × 16 × 14	2 240	"
16 rafters 6 by 2-in., 10 feet long, at 3 lbs. per 144 cu. in.	480	"
Total	4 640	pounds

The moment caused by this weight is:

$$(4\,640 \times 16 \times 12) \div 8 = 111\,360 \text{ pound-inches.}$$

The determination of the beam which will be used to withstand this bending moment is made by means of its section modulus. The formula $\frac{M}{S} = \frac{I}{c}$ is used in the design of beams. The values of I and c are constant for any given beam, and therefore the value of $I \div c$ for any particular beam is a constant, and this constant is called the *section modulus.* It is therefore evident that if we have a certain bending moment and a certain allowable unit-stress, we can obtain the value of the section modulus by dividing the moment by the allowable unit-stress. Then, looking into one of the steel handbooks, the beam can be determined which will have a section modulus equal to or slightly in excess of the value that has been obtained by dividing the bending moment by the unit-stress. This beam will be the beam which, with a unit-stress equal to the one assumed, will withstand the bending moment under consideration.

The handbooks issued by many of the steel companies are indispensable to the intelligent design of structural steel. That issued by the Carnegie Steel Company (edition of 1903) is one of the most convenient; and since it will be frequently referred to in this text, its purchase by the student is desired. This book may be obtained by addressing the Carnegie Steel Company at its offices in any of the larger cities. The cost to students has usually been 50 cents; to others, $2.00.

Assuming an allowable unit-stress of 18 000 pounds per square inch on the extreme fibre, the section modulus required to withstand the bending moment of 111 360 pound-inches is:

$$\frac{111\,360}{18\,000} = 6.19.$$

Looking in the Carnegie Handbook at column 11 on page 100, column 11 on page 102, and column 9 on page 104, it will be seen that any one of the following shapes will be sufficient:

One 5-inch 14.75-pound I-beam;
One 7-inch 9.75 " channel;
One $4\frac{1}{8}$ by $3\frac{3}{16}$ by $\frac{9}{16}$-inch Z-bar weighing 17.9 pounds per linear foot.

PIPE-ARCH BRIDGE OVER SUDBURY RIVER, NEAR SAXONVILLE, MASS.

Part of the waterworks system of Boston. Width of span 80 feet, central part of arch rising 5½ feet above horizontal. Arch consists of double-riveted sections of steel pipe, ⅝ inch thick and 7½ feet in diameter, sustaining both its own weight and that of the water it contains. Stone abutment reinforced with a backing of 40 feet of solid concrete. A larger bridge built on same principle, supported by two arched mains, spans Rock Creek, between Washington and Georgetown, D. C.

Instead of the 5-inch I-beam as given above, a 6-inch 12.25-pound I-beam with a section modulus of 7.3 could be used, and would be more economical, since it is less in weight; and it would also be stiffer, since its depth is greater and its section modulus is greater. A comparison of the above weights shows the channel to be the most economical, since its weight is considerably less than either of the other two shapes. Channels usually make the most economical purlins; and for this reason no other shapes are usually inspected, the channels being used in the first case without being compared with other sections. Inspection of column 11, page 110, Carnegie Handbook, shows that a 6 by 4 by ¾-inch angle could have been used for the purlin, since it gives a section modulus of 6.25. The weight of this angle, 23.6 pounds per linear foot, shows it to be far too uneconomical to employ.

EXAMPLES FOR PRACTICE

1. Design the rafters when the total weight of the snow and roof covering is 30 pounds per square foot, and the purlins are spaced 15 feet apart. Use 1 000 pounds per square inch as the allowable unit-stress.

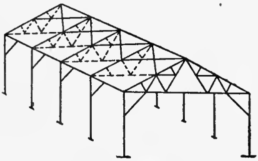
2. Design the purlins if the trusses are 12 feet center to center; the purlins are spaced 8 feet apart; the roof covering, which weighs 6 pounds per square foot, is laid upon 1-inch yellow pine sheathing resting directly upon the purlins; and the snow load is 10 pounds to the square foot of roof surface. Use 18 000 pounds per square inch as the allowable unit-stress, and use a channel for the purlin section.

7. **Bracing.** In order to keep the roof trusses erect, bracing is employed to join together their top chords and also their bottom chords. This bracing may consist either of small round or square rods, or it may consist of angles. The latter is the best practice, since it gives great rigidity to the structure; and in fact it should be used in all cases where machinery of any kind is attached to the trusses. One disadvantage of the rod bracing is that good connections with the trusses are usually difficult. The bracing between the lower chords is lighter than that between the top chords, since its office is merely to prevent vibration, while that between the upper chords must take up the stresses caused by the wind blowing upon the ends of the building. The stresses in each of these classes of bracing can only be approximately determined; and for that reason it has become customary to determine their section by judgment rather than by computation. For lower chord bracing, single angles 3 by

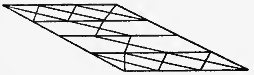
2 by $\frac{5}{16}$-inch are recommended; and for upper chord bracing, 3 by 3 by $\frac{5}{16}$-inch angles should be used.

It is not customary to place bracing between each pair of trusses, but to place them between each alternate pair or between every third pair of trusses. Fig. 23 shows several ways in which the bracing may be inserted.

8. **Economical Spacing and Pitch of Trusses.** The term pitch which has been used in the preceding pages is the fraction obtained by dividing the span into the height of the truss at the center of the span. For example, if a truss has a span of 60 feet, and a rise of 12 feet at the center, it would be said to have a pitch of $\frac{1}{5}$; if the rise were 15 feet, the pitch would be $\frac{1}{4}$; and if the rise were 20 feet, the pitch would be $\frac{1}{3}$. The pitch of a truss is seldom expressed in degrees by giving the angle that the top chord makes with the horizontal. One exception is very common. It is to use the 30° pitch. This has the advantage of making the height of the center equal to one-half the length of one side of the top chord—a fact which lends itself to ease in making the shop drawings.



Upper Chord Bracing



Looking Upward - The Lower Chord Bracing

Fig. 23. Methods of Inserting Bracing between Trusses.

The maximum or minimum allowable pitch for any given roof depends to a great extent upon the class of roof covering employed. For pitches required for any given class of roof covering, see Article 5, p. 6. It might be noted that most of the patent roofings, or any roofing in which tar or asphalt is an ingredient, should not be laid upon roofs with a pitch greater than $\frac{1}{5}$ or $\frac{1}{6}$; while most of the coverings which consist of steel or clay products require pitches of $\frac{1}{5}$ or over.

Pitches varying from $\frac{1}{6}$ to $\frac{1}{3}$ have very little effect upon the weight of the trusses. This is true only for trusses with horizontal lower chords. If the lower chord is *cambered*—that is, raised above the horizontal position—it greatly increases the stresses in the truss, and consequently the weight of the truss. The greater the camber, the greater the weight of the truss, the pitch remaining the same. If the camber is constant, then the greater the stresses (and consequently the weight of the truss), the smaller the pitch. It is advisable not to camber the lower chord unless it is positively necessary. A camber of 5 per cent of the span will increase the weight of the truss from 10 to 40 per cent, according to the pitch.

Taking all things into consideration, a pitch of $\frac{1}{3}$ or $\frac{1}{4}$ is to be preferred over that of $\frac{1}{5}$ or less, since, after the pitch becomes less than $\frac{1}{5}$, the weight of the truss increases quite rapidly, the span being constant.

For any given roof, there is an economical spacing of the trusses. As the spacing of the trusses increases, the weight of the purlins and bracing per square foot of area increases, while the weights of the trusses, the columns that support them, and the girts, or members which run from one column to the other and on which the siding of the building is placed, decrease. The most economical spacing of the trusses is such as will make the *cost* of the above quantities a minimum. It is evident that this spacing for trusses which rest upon masonry supports will be different from the spacing in case they rest upon steel columns. Attention is called to the statement that the sum of the costs, instead of the sum of the weights of the above-mentioned quantities, should be a minimum. This is due to the fact that the unit-cost of the purlins is considerably less than that of the trusses, it being in some cases only about one-half.

The spacing of trusses is sometimes governed by local conditions, such as the placing of the machinery in the building and the probable position of future additions. Considering the spacing from a purely economical standpoint, it is probably well to space trusses about as indicated in Table V.

TABLE V

Spacing of Trusses

Span, in Feet	Spacing, in Feet
10 to 30	12
30 to 60	15
60 to 75	20
75 to 150	21 to 25

The spacing indicated in Table V is for triangular roof trusses of equal size and span. For other conditions—such as when the main roof consists of one span, and the side roofs consist of different spans and different classes of trusses—the economical spacing may be somewhat different, and is usually less.

The best method of determining the economical spacing is either to make a comparative design or to consult the back volumes of *The Engineering Record, Engineering News,* or some other good engineering periodicals. Designs of buildings which have been constructed are frequently given in these periodicals; and from these the student may, in addition to the spacing of the trusses, obtain much other valuable information regarding roof construction.

Bulletin No. 16 of the University of Illinois Experiment Station gives a systematic study of roof trusses, and shows the effect on the variation in the weights of rafters and purlins due to a variation in the length of span. This bulletin, which can be had free for the asking, should be in the hands of the student. It may be had by addressing "The Director," Engineering Experiment Station, University of Illinois, Urbana, Illinois. A most valuable book giving a systematic and extensive study of roof trusses and mill buildings, is "Steel Mill Buildings," by M. S. Ketchum, Engineering News Publishing Company, New York, N. Y.

9. **Stresses in Roof Trusses, and Sizes of Members.** Stresses in roof trusses of any form can be computed by the methods of "Statics" (pp. 23 to 73). On account of the ease and economy of manufacture, some form of truss is usually used in which there are many members with equal stresses. The Fink truss, or some modification of it, is almost universally used (see Fig. 1, *c, d, e, f*). On pages 21 and 22 are shown some forms of trusses, together with the pitches which are commonly used.

The stresses in the various members due to a vertical panel load of one pound are given. To obtain the stress in that member due to any other vertical panel load, multiply the stress here given by the vertical panel load.

For example, if the stresses in U_2L_2 (Fig. 24) or L_0L_1 (Fig. 31) due to a panel load of 3 000 pounds, were required, they would be determined as follows:

$U_2 L_2$ (Fig. 24) $3\,000 \times -1.73 = -5\,190$ pounds.
$L_0 L_1$ (Fig 31) $3\,000 \times +5.00 = +15\,000$ pounds

These diagrams are especially useful, since it is the custom of many engineers not to compute the stresses due to wind, snow, and

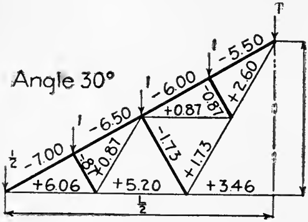


Fig. 24.

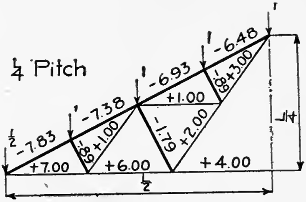


Fig. 25.

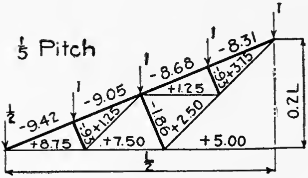


Fig. 26.

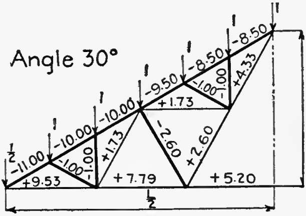


Fig. 27.

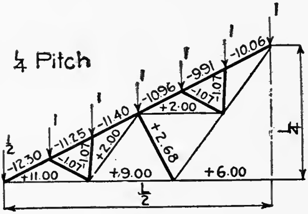


Fig. 28.

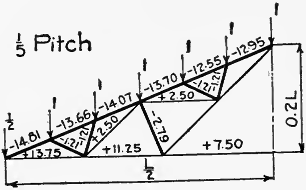


Fig. 29.

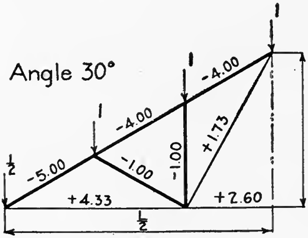


Fig. 30.

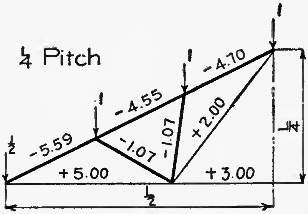


Fig. 31.

Analysis of Stresses in Various Members of Fink Truss Due to Unit-Loads.

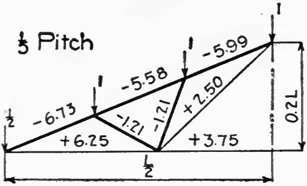


Fig. 32.

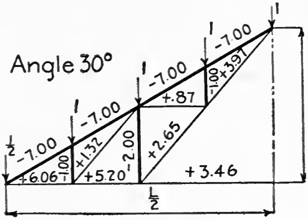


Fig. 33.

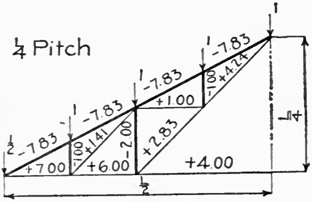


Fig. 34.

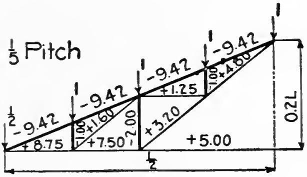


Fig. 35.

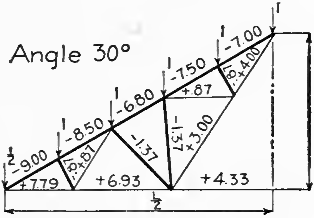


Fig. 36.

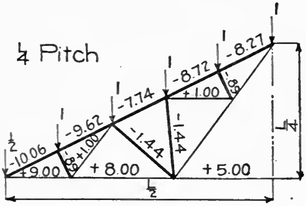


Fig. 37.

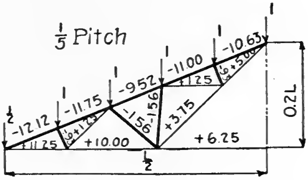


Fig. 38.

Analysis of Stresses in Various Members of Fink Truss Due to Unit-Loads.

dead weight of roof trusses and coverings, but to compute the stresses due to a dead panel load caused by 40 pounds per square foot of horizontal projection. The stresses resulting from this procedure are very nearly equal to those produced by considering the various loads—as snow, dead load, and wind—separately or together. Whenever differences occur, they are on the safe side, except as noted below, and in the next article, in case of the stresses produced by the use of knee-bracing.

The panel load to be used when 40 pounds per square foot of horizontal projection is considered, may be computed from the formula:

$$P = \frac{40 \times a \times l}{n},$$

in which,

a = Distance between trusses, in feet;
l = Span of truss, in feet;
n = Number of panels in top chord of truss.

For example, let it be required to compute the panel load P for the truss of Fig. 24 when the span is 70 feet and the distance between trusses is 16 feet. Here $a = 16$; $l = 70$; and $n = 8$.

$$P = \frac{40 \times 16 \times 70}{8} = 5\,600 \text{ pounds.}$$

The truss would then be computed for a vertical panel load of 5 600 pounds, and the members designed to withstand the stresses thus obtained.

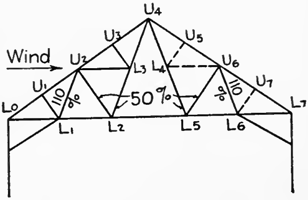


Fig. 39. Allowance for Stresses Due to Wind.

This method is applicable to all spans up to 100 feet when the truss is set on masonry walls (or steel columns built in masonry walls) and the roof covering is of corrugated steel or any of the ordinary materials. Where clay tile or slate are used, 50 pounds should be taken; and in case of concrete slabs, 65 pounds would be about right. It is better practice to compute the stresses due to wind, snow, and dead loads when clay tile, slate, or concrete are used.

In cases where the roof truss is placed on steel columns and is connected with the column by a knee-brace at the first joint (see Fig. 39), stresses caused by the overturning action of the wind take place in those members shown by heavy lines. In this case the stresses caused by 40 pounds per square foot of horizontal projection are not large enough; but the truss will be safe enough if the stresses as determined by the 40 pounds are increased by the amounts indicated in Fig. 39.

For example, let the truss of Fig. 24 be supported by steel columns and knee-bracing. Let the span be 60 feet, and the distance between trusses 16 feet; and let it be required to compute the stresses in $L_1 U_2$ and $L_3 U_4$. Here $P = (40 \times 16 \times 60) \div 8 = 4\,800$, and the stresses will be:

$$L_1 U_2 \quad (0.87 \times 4\,800) \times 2.10 = +\ 8\,770 \text{ pounds.}$$
$$L_3 U_4 \quad (2.60 \times 4\,800) \times 1.50 = +18\,700 \text{ pounds.}$$

In addition to the above conditions, shafting, heating apparatus, small cranes, and electric wiring and other conductors are often attached to the lower chord of the truss. These cause additional stresses. The case is that of a concentrated load or loads at the lower chord, and the stresses may be computed by the methods given in "Statics."

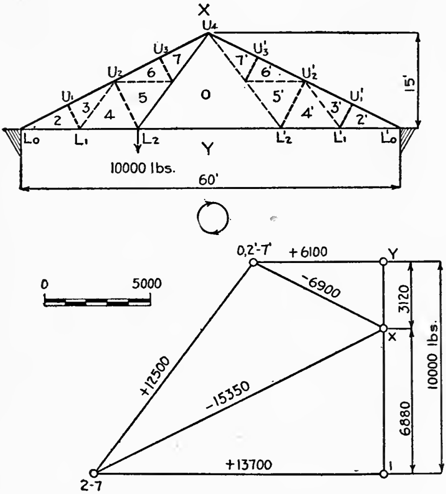


Fig. 40. Fink Truss Loaded with 5-Ton Hoist; also Stress Diagram of Same.

For example, let a 5-ton hoist be connected as shown in Fig. 40 This hoist runs longitudinally of the shop, or perpendicularly to the plane of the roof truss. The maximum stress in the truss due to this cause will occur when the hoist is directly beneath the truss. The stresses will be those caused by a load of 10 000 pounds at the second panel point of the lower chord. Fig. 40 gives the stress diagram for

TABLE VI

Hoist Stresses in Fink Truss

Member	Stress	Member	Stress
$L_0 U_4$	−15 350	$L_2 U_4$	+12 500
$L_0 L_2$	+13 700	$U_4 L'_0$	− 6 900
$L'_2 L'_0$	+ 6 100	All Others	0

this condition, and Table VI gives the stress record. From this it is seen that the hoist does not affect all members of the truss. The stresses due to the hoist should be added to those caused by the 40 pounds per square foot of horizontal projection, and the member designed accordingly. Of course, if the stress caused by the hoist decreases the stress caused by the 40 pounds, the member must be designed for the stress due to the 40 pounds.

Note that concentrated loads, as in the case of the hoist, cause different stresses in symmetrical members on the two sides of the truss. In the final design, the members are made the same, being designed for the greatest stress. This is done for the sake of economy in manufacture; and besides, it might be desirable to change the hoist to the other side of the truss.

For Fink trusses with pitches of from ⅙ to ⅓, and spans of less than 100 feet, very light angles are usually required for the members, unless heavy, concentrated loads are placed on the lower chord. The thickness of the connection plates is seldom more than ⅜ inch, the top chord angle seldom greater than 5 by 3½-inch, the lower chord angle seldom greater than 3 by 3-inch; and the web members are usually composed of angles either 2 by 2-inch or 2½ by 2½inch. It appears to be the rule, in present practice, to make the sizes such that the thickness shall be ¼ or 5/16 inch. Connection plates for spans up to 60 or 70 feet are usually ¼ inch thick, except in the case of that at point L_0.

The stresses in knee-braces depend upon the height and also the width of the building. The stresses may be computed according to the methods of the next article, and the knee-bracing should be designed accordingly. The inspection of a number of plans seems to indicate that the sizes of knee-braces vary from two angles 2½ by 2½ by ¼-inch for spans of 30 feet and a height of building of 35 feet, to two angles 4 by 3 by $\frac{5}{16}$-inch for a span of 70 feet and a height of building to the top of the truss of 75 feet.

In case of roof trusses with the chords nearly parallel (see Fig. 3, p. 2), the stresses, on account of the small depth, are usually quite large, and much heavier members than above mentioned are required. In some cases, 6 by 6-inch angles with 8-inch plates are used, and connection plates of ⅜ to ½ inch are common.

In cases where the trusses are subjected to the action of corrosive gases, the thickness of the members should be made greater than that required by the design alone, since corrosion will decrease the section considerably, and this should be allowed for.

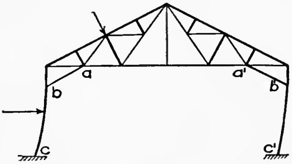


Fig. 41. Bending Tendency, Ends Free.

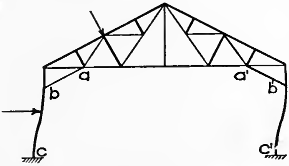


Fig. 42. Bending Tendency, Ends Fixed.

10. **The Steel Truss-Bent.** When a truss is connected to steel columns at its ends and by means of knee-bracing (see Fig. 39), it forms what is called a *steel truss-bent.* The stresses in the truss due to the roof covering and snow loads are the same as when it is supported by a masonry wall; but the wind stresses are different. The wind blowing on the roof and also on the sides of the building, causes stresses in the truss. The wind on the building is transferred to the columns, which, by means of the knee-braces, cause stresses in the truss. The whole bent tends to bend as shown in Fig. 41 if the ends of the columns rest on masonry pedestals. If the ends of the columns are securely bolted to heavy masonry pedestals so that the ends of the post will remain vertical, they will tend to bend as shown in Fig. 42. In the first case, the overturning is resisted by the bending of the post as shown at *b* and *b'* (Fig. 41); in the second case, by bending as at *b*, *c*, *b'*, and *c'* (Fig. 42). Since the post is the same size throughout, and the bending caused by the wind the same in both cases, the bend-

ing moment in the post at *b* and *b′* (Fig. 42) is less than it is at *b* and *b′* (Fig. 41), as in the first case there are only one-half the number of points to withstand the total bending that there are in the second case.

The wind blowing on one side of the building causes a compressive stress in the column on the *leeward* side (the side opposite that on which the wind blows) and a tensile stress in the column on the *windward* side (the same side on which the wind blows). It also creates a bending moment as mentioned above; and this, as well as the direct stresses, must be taken into account when the post is designed. The case is that of a member under direct compression and bending at the same time.

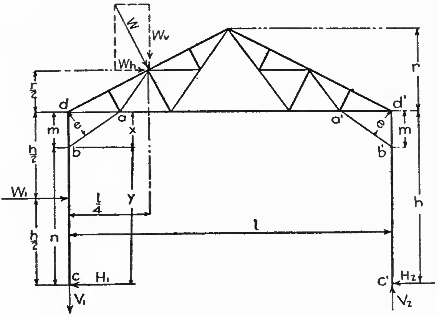


Fig. 43. Notation for Formulæ, Ends Free.

The stresses in the knee-braces and the columns, and the bending in the columns when the ends of the posts are not fixed, may be computed from the following formulæ, in which,

W = Total wind load perpendicular to the roof;
W_h = Horizontal component of W;
W_v = Vertical component of W;
W_1 = Total wind load on the side of the building;
w = Unit wind load normal to the roof;
w_1 = Unit wind load normal to the side of the building;
a = Distance between trusses, in feet.

These and other characters are shown in Fig. 43.

$$W = wa\sqrt{r^2 + (\frac{l}{2})^2}$$

$$W_1 = w_1\, ah$$

$$H_1 = H_2 = \frac{W_h + W_1}{2}$$

$$S_{b'c'} = -\frac{W_1\frac{h}{2} + W_h\left(h + \frac{r}{2}\right) + W_v\frac{l}{4}}{l} = V_2$$

$$S_{bc} = +\frac{W_1\frac{h}{2} + W_h\left(h + \frac{r}{2}\right) - W_v\frac{3l}{4}}{l} = V_1$$

$$S_{a'b'} = -\frac{H_2 h}{e}$$

$$S_{ab} = +\frac{H_1 h - W_1\frac{h}{2}}{e}$$

Bending moment at $b = H_1 n - W_1\left(\frac{h}{2} - m\right)$

Bending moment at $b' = H_2 n.$

The stresses in the truss caused by the wind are the same as if it were under the action of the normal wind load W, and in addition two concentrated loads equal in intensity and direction to the stresses in the knee-braces and at the same point of application, and two forces E_1 and E_2, which may be computed as follows:

$$E_1 = \frac{H_2 n}{m}$$

$$E_2 = \frac{H_1 n - W_1\left(\frac{h}{2} - m\right)}{m}$$

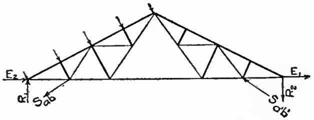


Fig. 44. Application and Direction of the Exterior forces.

For the points of application for these loads and for their direction, see Fig. 44. The stresses can now be computed by the method of Statics.

The diagram for such a truss-bent is given in Fig. 45. The span is 60 feet, the rise $\frac{1}{4}$, the distance between trusses 16 feet; and the wind pressure is taken as 18 pounds per square foot normal to the roof surface, and 20 pounds per square foot normal to the sides. In this case, $w = 18$ pounds; $a = 16$ feet; $r = 60 \div 4 = 15$ feet; $w = 20$ pounds; $h = 20$ feet; $n = 14$ feet; $m = 6$ feet; and $l = 60$ feet. The length of L_0U_4 is readily computed to be 33.5 feet; L_0L_1, 9.1 feet; and $e = 5$ feet. The values of the quantities and stresses are computed as follows (see Fig. 46):

$$W = 18 \times 16\sqrt{30^2 + 15^2} = 9\,650 \text{ pounds.}$$
$$W_1 = 16 \times 20 \times 20 = 6\,400 \text{ pounds.}$$
$$W_h = (9\,650 \div 33.5) \times 15 = 4\,320 \text{ pounds.}$$
$$W_v = (9\,650 \div 33.5) \times 30 = 8\,650 \text{ pounds.}$$
$$H_1 = H_2 = (4\,320 + 6\,400) \div 2 = 5\,360 \text{ pounds.}$$

$$S_{ab} = +\frac{5\,360 \times 20 - 6\,400 \times 10}{5} = +8\,640 \text{ pounds.}$$

$$S_{a'b'} = -\frac{5\,360 \times 20}{5} = -21\,440 \text{ pounds.}$$

$$E_1 = \frac{5\,360 \times 14}{6} = 12\,520 \text{ pounds.}$$

$$E_2 = \frac{5\,360 \times 14 - 6\,400 \times 4}{6} = 8\,240 \text{ pounds.}$$

The horizontal and vertical components of the stresses in the knee-bracing should now be computed. They are:

For *ab*: horizontal, 7 240; vertical, 4 760 pounds.

For *a'b'*: horizontal, 17 900; vertical, 11 800 pounds.

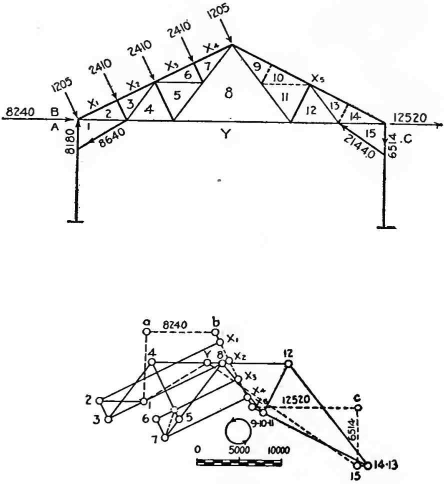


Fig. 45. Stress Diagram of Truss-Bent under Wind Load.

As a check upon the computations, the sum of the values of E_1, E_2, and W_h should be equal to the sum of the horizontal components of the knee-braces. By summing up the above values, it will be seen that they check by 80 pounds, which is less than 0.4 of one per cent and is a close enough check (see Figs. 46 and 47).

To obtain the vertical reactions, proceed as with a simple truss. For R_2, take the center of moments at L_0 (see Fig. 47). Then:

$$R_2 = \frac{1}{60}\left\{8\,650 \times 15 + 4\,320 \times 7.5 + 4\,760 \times 9.1 - 11\,800 \times (60 - 9.1)\right\}$$
$$= -6\,514 \text{ pounds.}$$

The negative sign indicates that the reaction acts downward; that is, the truss must be riveted to the post at L_8, or the end of the post would be lifted off the top of the column.

For R_1, the center of moments is at L_8, and the resulting equation is:

$$R_1 = \frac{1}{60}\left\{-11\,800 \times 9.1 + 8\,650\,(60 - 15) - 4\,320 \times 7.5 + 4\,760\,(60 - 9.1)\right\}$$
$$= +8\,180 \text{ pounds.}$$

The bending moment at b is:

$$M_b = 14 \times 5\,360 - 4 \times 6\,400 = 49\,440 \text{ pound-feet;}$$

and the bending moment at b' is:

$$M_{b'} = 5\,360 \times 14$$
$$= 75\,040 \text{ pound-feet.}$$

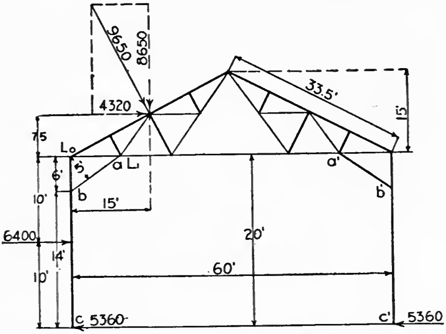


Fig. 46. Position, Direction, and Intensity of Wind Forces, Ends Free.

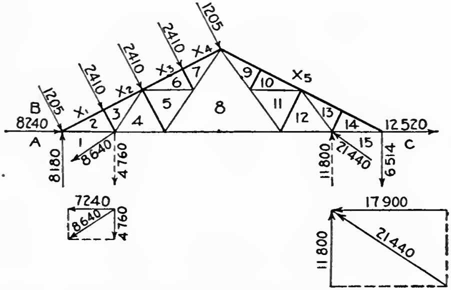


Fig. 47. Position, Direction, and Intensity of Exterior Forces.

The forces in their proper direction are now placed on a diagram of the truss (Fig. 47), and the stresses are solved by the method of Statics. The stress diagram is given in Fig. 45, and the stress record in Table VII.

The above formulæ are for cases when the columns are free at the lower end. When the columns are not free, they are called *fixed;* that is, they are supposed to be so tightly connected that they cannot move when the post bends as shown in Fig. 42. In such cases the result is the same as if the columns were shortened by an amonut $n \div 2$, and the following formulæ result (see Fig. 48):

TABLE VII

Stress Record of Truss-Bent under Wind Load

Member	Stress	Member	Stress
X-2	−15 700	9-10, 11-12	+ 6 500
X-3	−15 700	12-13, 14	−15 300
X-6	−10 700	Y-4	+ 6 500
X-7	−10 700	Y-8	− 1 900
X-9	+ 1 500	Y-12	− 9 600
X-13	+15 400	13, 14-15	− 1 300
1-2	+ 5 200	1-Y	+ 8 640
2-3	− 2 410	15-Y	−21 440
3-4	+ 8 500	A-1	− 8 180
4-5	− 7 500	c-15	+ 6 514
5-6	+ 2 700	b-c	− 3 457
6-7	− 2 410	b'-c'	− 5 193
7-8	+11 000	9-10-11	0
8-9	− 7 600	13-14	0

$$W = wa\sqrt{r^2 + \left(\frac{l}{2}\right)^2}$$

$$W_1 = w_1 a\left(m + \frac{n}{2}\right)$$

$$H_1 = H_2 = \frac{W_h + W_1}{2}$$

$$S_{ab} = +\frac{H_1\left(m + \frac{n}{2}\right) - W_1\left(\frac{m + \frac{n}{2}}{2}\right)}{e}$$

$$S_{a'b'} = -\frac{H_2\left(\frac{m}{2} + \frac{n}{4}\right)}{e}$$

$$S_{bc} = +\frac{W_1\left(\frac{m}{2} + \frac{n}{4}\right) + W_h\left(m + \frac{n}{2} + \frac{r}{2}\right) - W_v\frac{3l}{4}}{l}$$

$$S_{b'c'} = +\frac{W_1\left(\frac{m}{2} + \frac{n}{4}\right) + W_h\left(m + \frac{n}{2} + \frac{r}{2}\right) + W_v\frac{l}{4}}{l}$$

$$E_1 = H_2\frac{n}{2m}$$

$$E_2 = \frac{H_1 \frac{n}{2} - W_1 (\frac{n}{4} - \frac{m}{2})}{m}$$

Bending moment at $b = M_b = H_1 \frac{n}{2} - W_1 (\frac{n}{4} - \frac{m}{2})$

Bending moment at $b' = M_{b'} = H_2 \frac{n}{2}$.

For the truss-bent of Fig. 45, when the columns are fixed at the base, the stresses are the same as if the columns were shortened by an amount $n \div 2$, as above mentioned. The bent would then appear as in Fig. 49, and the values of the various stresses and the quantities, together with their points of application, are:

$W = 18 \times 16\sqrt{30^2 + 15^2} = 9\,650$ pounds, as before.

$W_1 = 13 \times 16 \times 20 = 4\,160$ pounds.

$H_1 = H_2 = \frac{4\,160 + 4\,320}{2} = 4\,240$ pounds.

$S_{ab} = +\frac{4\,240 \times 13 - 4\,160 \times 6.5}{5} = +5\,616$ pounds.

$S_{a'b'} = -\frac{4\,240 \times 13}{5} = -11\,024$ pounds.

$S_{bc} = +\frac{4\,160 \times 7 + 4\,320 \times 20.5 - 8\,650 \times 45}{60} = -4\,526$ pounds.

$S_{b'c'} = -\frac{4\,160 \times 7 + 4\,320 \times 20.5 + 8\,650 \times 15}{60} = -4\,124$ pounds.

$E_1 = \frac{4\,240 \times 7}{6} = 4\,947$ pounds.

$E_2 = \frac{4\,240 \times 7 - 4\,160 \times 0.5}{6} = 4\,600$ pounds.

$M_b = 4\,240 \times 7 - 4\,160 \times 0.5 = 27\,600$ pound-feet.

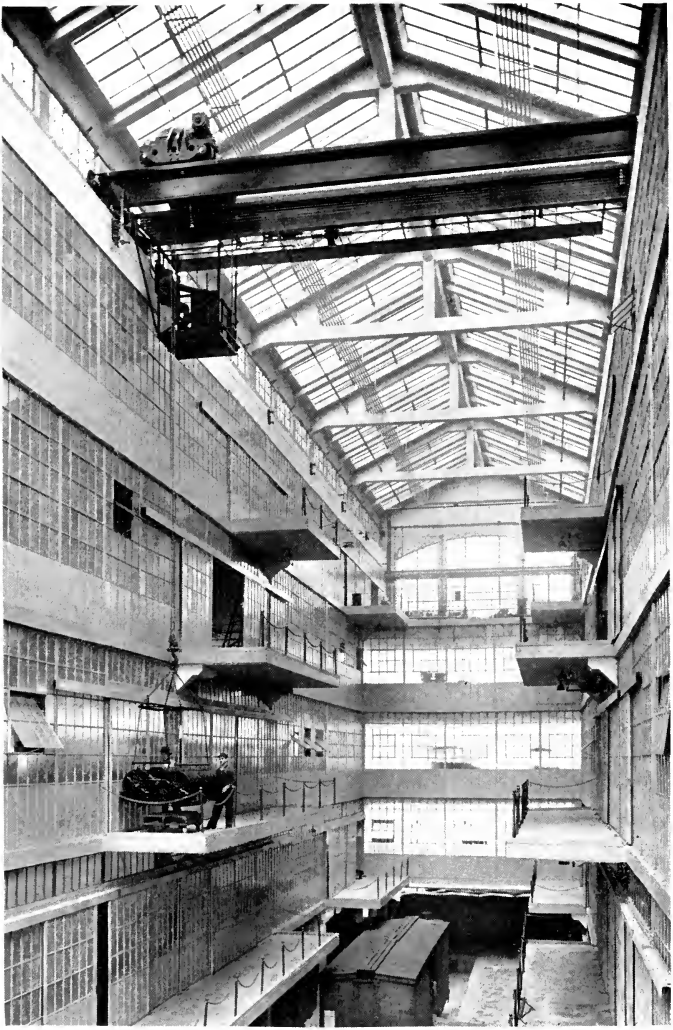
$M_{b'} = 4\,240 \times 7 = 29\,680$ pound-feet.

The stresses in the bent are then computed in a manner similar to that used when the columns are fixed, E_1, E_2, and the stresses in the knee-braces being attached to the truss as concentrated loads.

Since in this case, E_1, E_2, and the stresses in the knee-braces are less than they are when the columns are free at the base, the wind stresses throughout the truss will be less when the columns are fixed than when they are free.

On account of the difficulty of fixing the ends rigidly, it is advisable always to consider the ends free and to compute the stresses accordingly.

The student is advised not to take the trouble of determining



CHICAGO SERVICE BUILDING OF FORD MOTOR COMPANY, SHOWING MODERN CONCRETE CONSTRUCTION

The roof trusses are of concrete, and flat-slab floor construction is used throughout.

Courtesy of the Condron Company, Chicago the wind stresses in trusses of steel truss-bents by the method given above, but to use the 40 pounds per square foot of horizontal projection and to correct the stresses as previously mentioned (see Fig. 39).

The formulæ of this article giving the stresses in the knee-bracing and the bending moment in the columns, should be used in all cases, and the posts and knee-braces designed according to the stresses so determined.

In cases where the 40 pounds per square foot is used, the direct stress in each column is:

$$S = \frac{40 \times a \times l}{2};$$

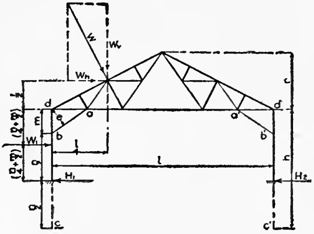


Fig. 48. Notation for Formulæ, Ends Fixed.

and the column should be designed for this stress, together with the stress due to the bending at the point where the knee-brace joins the column. See "Strength of Materials," pp. 85 and 86.

In case a crane is attached to either the truss or the column, the stresses due to its action must be considered in the design.

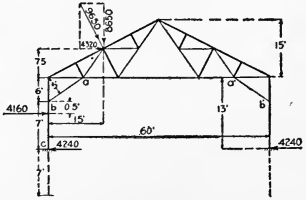


Fig. 49. Position, Direction, and Intensity of Wind Forces, Ends Fixed.

11. **Suspended Loads.** Under this head come any loads which may be suspended from the lower chord of the truss. The load may not be actually suspended from the underneath part, but may be placed above, and the connections so arranged as to bring the weight on the lower chord. This weight should preferably be concentrated at a panel point. In case it cannot be brought directly to the panel point, it may be distributed over a portion or all of the panel. In this case the portions distributed to the adjacent panel points are computed, and they are, for purposes of computation, considered as concentrated loads at the panel points. The sections of the chord over which these loads are distributed are in the condition of direct

tension and bending, and must be designed for such stresses (see "Strength of Materials," pp. 85 and 86).

The suspended loads may consist of small hand cranes; shafting for transmission of power; heating apparatus, such as steam or hot-air pipes; water or compressed-air tanks; or platforms on which stand the operators for the cranes or hydraulic lifts. Figs. 50 and 51 show trusses with various forms of suspended loads attached.

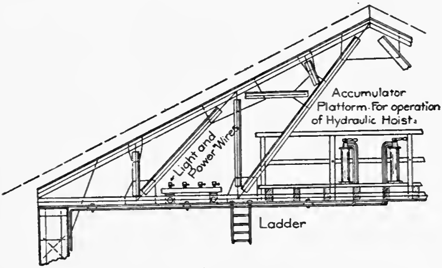


Fig. 50.

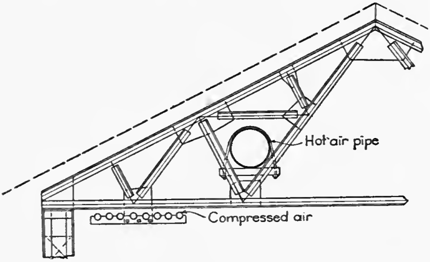


Fig. 51.
Various Kinds of Suspended Loads.

12. **Details of Roof Trusses.** The spans of triangular roof trusses of the Fink type are usually less than 100 feet, and the spans of roof trusses with chords nearly horizontal are seldom greater than 50 feet. For trusses of such spans the details are almost standard. Since these spans and trusses constitute a large majority of those built, only the details of such trusses will be considered in this text.

Where trusses rest on masonry walls or on light columns in masonry walls, provision is made for expansion due to temperature. For trusses up to 75 or 80 feet, slotted holes are placed in the end-bearing, and the bearings rest directly upon another plate. Bolts are fastened to the masonry, and extend upward through the slotted holes and have nuts on their ends. The nuts hold the truss securely to the wall, while the slotted holes allow the bearing to move backward and forward when the temperature falls or rises. *The slotted holes* *should be $\frac{1}{8}$ inch in length for every ten feet of span.* The bolts should not be less than $\frac{1}{2}$ inch in diameter, and should be buried in the masonry at least 6 inches. Fig. 52 shows details of an expansion bearing of this character. In case the span of the truss is greater than 75 or 80 feet, a roller or a rocker bearing is used. Figs. 53 and 54 show details of this class of bearings.

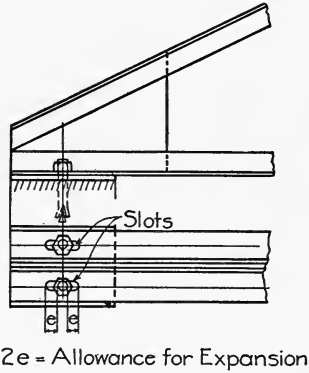


Fig. 52. Slotted-Hole Expansion Bearing.

For convenience in references to the common Fink truss, the following notation will be used: the points in the upper chord are given the letter U, with a subscript corresponding to the number of the joint from the left end. The lower chord and interior joints are given the letter L, with a subscript corresponding to the number of the joint from the left end (see Figs. 24 to 38). The advantage of this system of notation is that it enables one to refer to any particular joint by the use of the letter and its subscript, and its position will at once be apparent to the mind without the use of a figure.

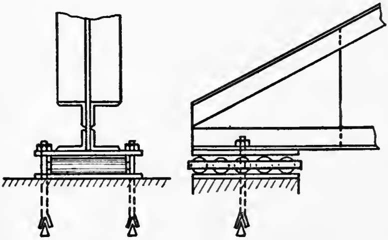


Fig. 53. Roller Expansion Bearing.

If a truss rests on masonry walls, three methods of making the details at L_0 are in common use. These are shown in Figs. 55, 56, and 57. The detail shown in Fig. 55 is the most commonly used; but its use is not advised unless a sufficient number of rivets are placed in the members to take up both the direct stress and that due to the fact that the point of application of the reaction does not coincide with the intersection of the center lines of the chord members.

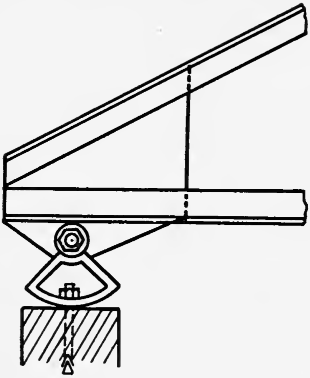


Fig. 54. Rocker Expansion Bearing.

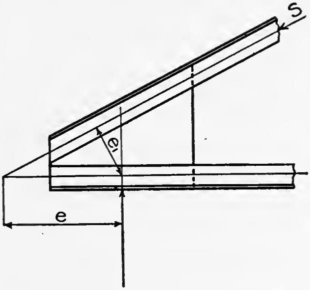


Fig. 55.

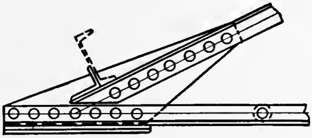


Fig. 56.

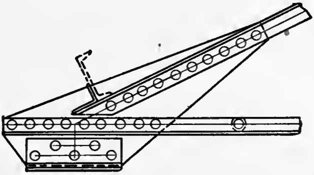


Fig. 57.
Details of Ends of Roof Trusses.

In case the bearing shown in Fig. 55 is used, the number of rivets in $L_0\ L_1$ may be calculated from the equation:

$$n^2v - Rn = \frac{6\,Re}{p},$$

in which,

n = Number of rivets required;
v = Allowable stress on one rivet;
R = Vertical reaction;
p = Rivet spacing, in inches;
e = Distance as shown in Fig. 55.

If the number of rivets in $L_0\ U_1$ is desired, it may be calculated from the equation:

$$n^2v - Sn = \frac{6\,S\,e_1}{p},$$

in which S is the stress in $L_0\ U_1$, e the distance shown in Fig. 55, and the remaining notation as above.

If the point of application of the reaction coincides with the intersection of the center lines of the top and bottom chords, the number of rivets required to withstand the direct stress, which is the only stress would be equal to the stress in that member divided by the allowable stress in one rivet.

In order to illustrate the use of the above equation, and to bring out the fact that more rivets are required when the point of application of the reaction does not coincide with the intersection of the upper and lower chords than when it does coincide, an example will be solved. The stresses, the thickness of the connection plate, and the distance of the point of application of the reaction from the intersection of the chord, are as shown in Fig. 58.

It will be assumed that the chords consist of two angles each; and since this is the case, the allowable unit-stress in one rivet will be 3 750 pounds, the value of a $\frac{3}{4}$-inch rivet in bearing in a $\frac{1}{4}$-inch plate when the allowable unit bearing stress is 20 000 pounds per square inch. If the point of application of the reaction coincides with the intersection of the two chords, the number of rivets required will be:

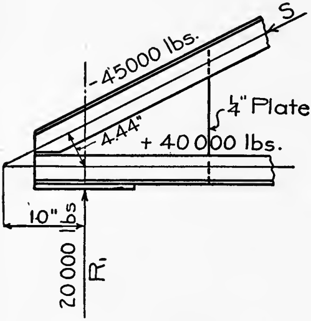


Fig. 58. Data for Example on Page 37.

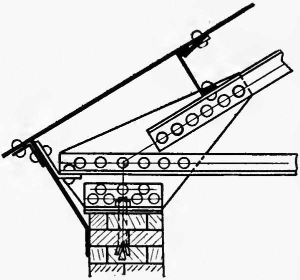


Fig. 59. Eave Detail for Fig. 57.

$$\text{For } L_0\,U_1 \quad \frac{45\,000}{3\,750} = 12.00 \text{ rivets.}$$

$$\text{For } L_0\,L_1 \quad \frac{40\,000}{3\,750} = 10.67 \text{ rivets.}$$

Since the point of application of the reaction does not coincide with the intersection of the chord, the number of rivets required in $L_0\,U_1$ is:

$$3\,750\,n^2 - 45\,000\,n = \frac{6 \times 45\,000 \times 4.44}{3},$$

the spacing being 3 inches; dividing by 3 750, we have:

$$n^2 - 12n = 106.56.$$

Completing the square and solving for n, there is obtained:

$$n = 6 + \sqrt{142.56} = 17.9, \text{ say 18 rivets.}$$

The number of rivets required in $L_0 L_1$ is:

$$3\,750\,n^2 - 20\,000\,n = \frac{6 \times 20\,000 \times 10}{3};$$

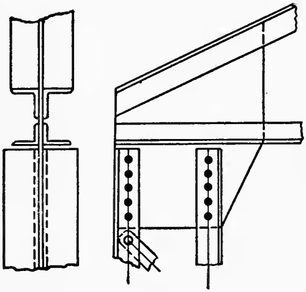


Fig. 60.

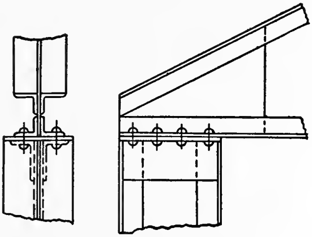


Fig. 61.

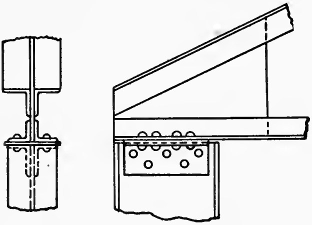


Fig. 62.

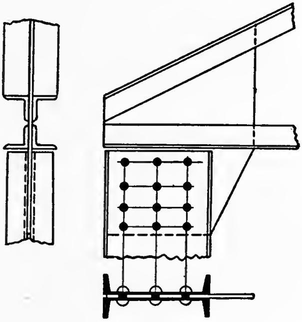


Fig. 63.

Details of Tops of Columns.

and dividing by 3 750 and completing the square, there results:

$$n = 2.67 + \sqrt{113.75} = 13.32, \text{ say 14 rivets.}$$

Inspection of the above results shows that when the point of application of the reaction is placed 10 inches from the intersection of the chords, it requires 6 more rivets in the upper chord and 3 more rivets in the lower chord than would be required if the point of application of the reaction coincided with the intersection of the chords.

The detail just discussed is a very convenient one, and is very commonly used; but in most cases no allowance is made for the additional rivets required because of the fact that the reaction does not coincide with the intersection of the chord members. The student should always compute the rivets by the formulæ given above, since it is very evident that neglect to do so causes the joint to be exceedingly weak, in some cases as much as 50 per cent, as is shown in the case of $L_0 L_1$ in the above problem.

Fig. 56 is excellent, but the length of the bearing plate, which should be as long as the connection plate, is liable to become greater than the width of the wall. In such cases the detail shown in Fig. 57 is to be used. The objection raised to these details is that the end connection plate prevents the placing of a purlin near the end of the roof truss. In case sheathing is used, this objection does not hold good, since the overhanging sheathing will reach to the end of the truss and form a good eave detail, as shown in Fig. 59.

When the roof truss rests on steel columns which are composed of latticed angles, the connections may be made as shown in Figs. 60 and 61. Fig. 60 is preferable, because it gives a more rigid connection than is given by Fig. 61. If the columns consist of two panels placed close together, back to back, the same details may be used. If the column consists of one I-beam or of two channels placed back to back at some distance apart, then details shown in Figs. 62 and 63 may be used.

Where one member is joined to another and makes an angle or is perpendicular to it, then details as shown in Figs. 64 and 65 may be used. It is not good practice to cut the angles as shown at *b* in Fig. 65; *a* is a better detail. No joints should have less than two rivets.

In places where three members meet, and two make the same angle with one of the others, the details should be made as shown in Fig. 66. The leg of the angle which is not joined to the plate should always be upward. This prevents the dust and dirt from becoming mixed with the moisture and running or jarring down into joints at the lower ends of the members.

At L_1 and L_3, square plates (see at left, Fig. 67) should be used where possible. If the stresses are such that more rivets are required in one member than in the other, then the plate should be cut as shown at right in Fig. 67.

At L_2 the splice occurs, since Fink trusses are usually shipped in two parts. In addition to the vertical connection plate, which also acts as a splice plate, the bottom plate is used (see Fig. 68). Rivets shown in black indicate that the holes are left open, the pieces in which they occur are shipped separately, and then are riveted together at the place where the truss is put up.

In some cases where the member $L_2 L_5$ is long enough to sag considerably, or where it is desired to connect a load (such as a hand hoist) at its center, a vertical $U_4 M$ is run from U_4 and connected to the lower chord. No stress is caused in this member by any load except the load at M, in which case the stress is equal to that load. If a load is at M, it will cause stresses in other members of the truss, the stresses in the truss being the same as if the dead panel load at U_4 were increased by an amount equal to the load at M.

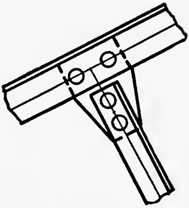


Fig. 64.

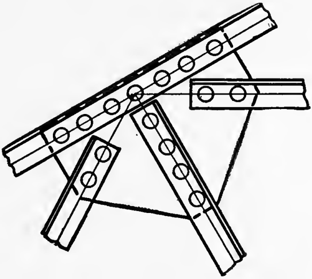


Fig. 66.

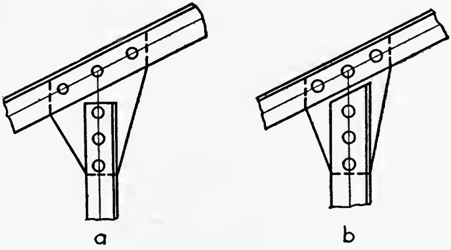


Fig. 65.

Details of Roof Truss Connections. See also Figs. 67 and 68.

The general details of a Fink truss are shown in Plate I (p. 43), Plate II (p. 60), and Plate III (p. 61).

In case the building is devoted to some purpose wherein no smoke or noxious gases are produced, some form of *patent ventilator* may be used. One very excellent make is shown in Fig. 69—called the *Star* ventilator (Merchant & Co., Philadelphia, Pa.). These ventilators are made from 2 to 60 inches in diameter at the lower portion, where they fit to the ridge of the roof. Fig. 70 shows one of them in position on a roof. The number and size of these ventilators depend of course upon the number of times per hour it is desirable to change the air in the shop.

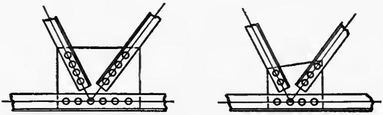


Fig. 67.

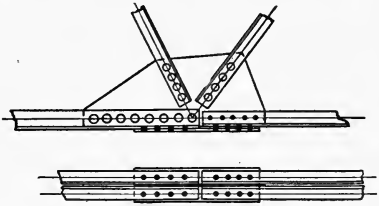


Fig. 68.

Details of Roof Truss Connections. See also Figs. 64, 65, and 66.

In case the shop is for such purposes that smoke, gases, or noxious fumes of any kind are produced, it is desirable to have some channel for ventilation which is considerably larger than those given by the patent ventilators. In such cases the ventilation is usually obtained by a small house-shaped construction called a *lantern, monitor,* or *ventilator* (see Fig. 71). The sides of these ventilators may be fitted with *louvres* or windows, or left open. Louvres may be made either of wood or of corrugated or plain bars. For details of monitors and louvres, see Figs. 124, 125, and 126.

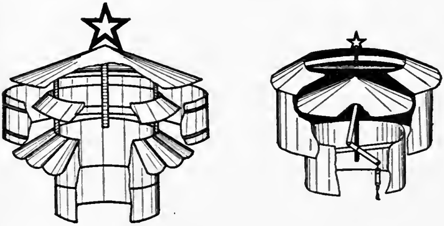


Fig. 69. Details of "Star" Ventilators.

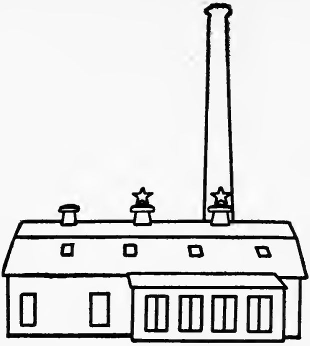


Fig. 70. "Star" Ventilators on a Roof.

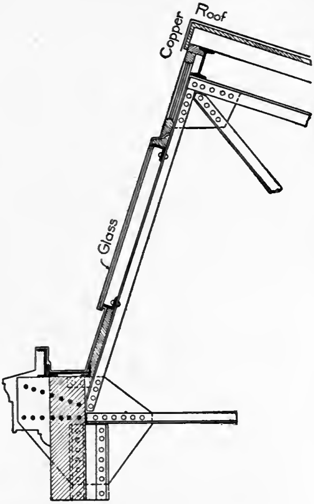


Fig. 72. Detail of Window in Saw-Tooth Roof.

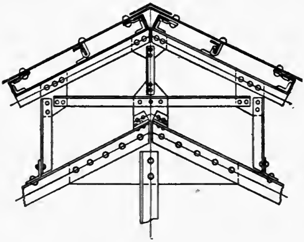


Fig. 71. Detail of a Monitor Ventilator.

In order to admit sufficient light into the building, part of the roof of buildings over 80 feet wide must be made of glass, since the amount of light admitted from the sides of the building is not sufficient to light up those parts of the shop near the center of the trusses. In some cases the saw-toothed truss is used, in which case the entire surface of the short rafter is covered with glass. In case the ordinary triangular roof truss is used, a portion of the roof covering must be made of glass, so put on as to prevent leakage and also to prevent the moisture which forms on the under side of the glass from dropping in the shop. Fig. 72 shows the glass in place on a saw-toothed roof; and Figs. 73 and 74 give the details of several methods of securing glass on the roof so that no leakage or condensation will get onto the shop floor. The glass area should be from $\frac{1}{10}$ to $\frac{1}{4}$ of the floor area.

13. **Specifications for Roof Trusses and Steel Buildings.** In case of an important structure, special specifications are written, embody-

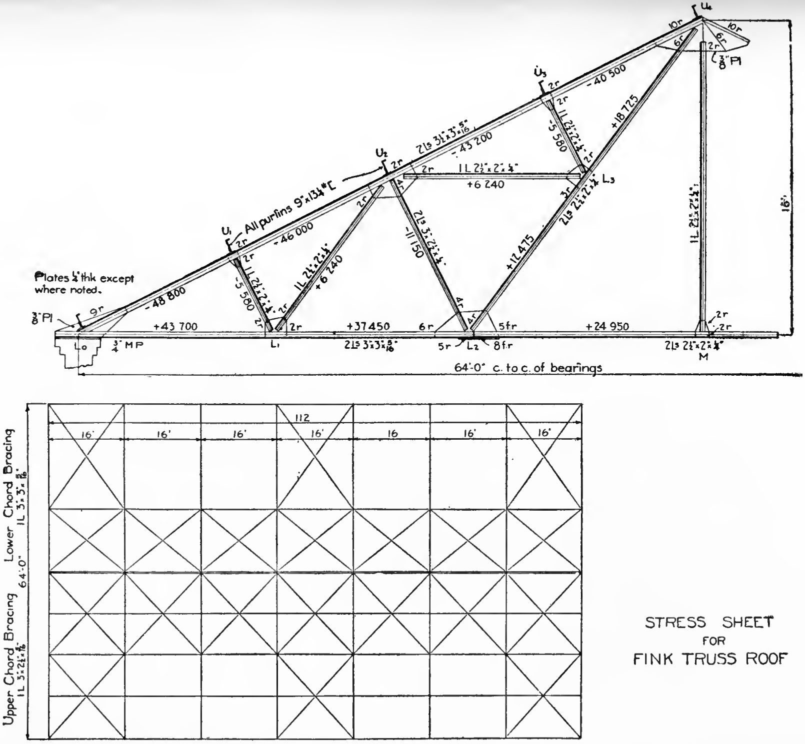


Plate I. Stress Sheet for a Fink Truss Roof.

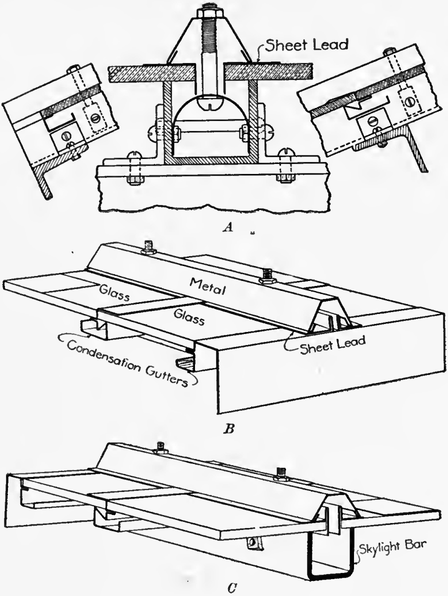


Fig. 73. "Paradigm" Method of Glazing.

ing certain features which the experience of the engineer in charge indicates as necessary. For ordinary structures, however, several very satisfactory specifications are on the market. These consist of from 15 to 20 pages, bound in paper, and may be had for twenty-five cents a copy. Two very satisfactory specifications are those of Charles Evan Fowler and Milo S. Ketchum. Either may be had by addressing the Engineering News Publishing Company, New York City. Fowler's specifications, in addition to giving specifications for load stresses and workmanship, give much valuable information regarding the stresses in different kinds of trusses, besides various details showing the use of corrugated steel.

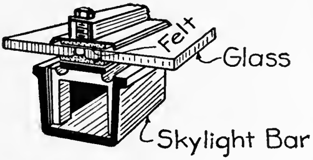


Fig. 74. "Anti-Pluvius" Method of Glazing.

An extended set of specifications is not required for the design of ordinary roof trusses. In addition to the information regarding the weight of trusses, the weight of roof covering, the snow load, and the wind load, the use of Table VIII will be found to be all that is necessary in order to design cross-sections of the various members, once the stresses are determined.

TABLE VIII

Allowable Unit-Stresses, Medium Steel

For Shear	10 000	pounds per square inch.
For Bearing	20 000	" " " "
For Tension	15 000	" " " "
For Bearing of Steel on Masonry	250 to 400	" " " "
For Compression	$P = 24\,000 - 110\frac{l}{r}$.	

In case the stresses are those due to crane loads, the unit-stresses in tension and compression indicated in Table VIII should be reduced $\frac{1}{3}$ and $\frac{1}{2}$ respectively. Members of the lateral bracing and their connections may be allowed an increase of 25 per cent over the unit-stresses there indicated.

In the equation above given "For Compression," l is the length of the member in inches, and r the least radius of gyration. The ratio of $\frac{l}{r}$ should never be greater than 120.

The *gauge line* or *gauge* is the line on the flange of a shape, on which the rivets are placed. In angles and channels it is located by giving its distance from the back of the shape; in the case of I-beams the distance between two gauge lines on opposite sides of the web is indicated. Some angles have double gauge lines, in which case the rivets are placed first on one and then on the other; this is called *staggering*. Fig. 75 shows gauge lines for various shapes.

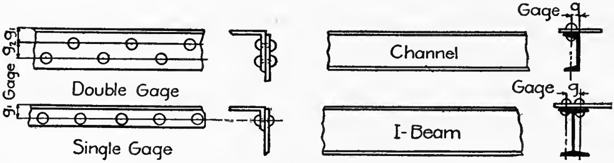


Fig. 75. Gauges for Angles, Channels, and I-Beams.

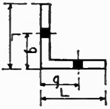
Rivets $\frac{3}{4}$ inch in diameter are generally used in legs of angles 3 to 4 inches long or greater. For the gauge lines and the maximum sizes of rivets to be used in angles, see Table IX. For similar data for channels and I-beams, see Carnegie Handbook, pp. 177–185.

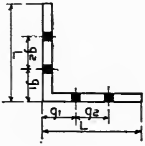
It is often desirable to express the length in feet instead of inches, in which case the formula becomes:

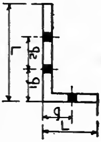
$$P = 24\,000 - 1\,320\,\frac{L}{r}.$$

TABLE IX

Gauges and Maximum Allowable Rivets for Angles







L	g	Maximum Rivet or Bolt	L	g	Maximum Rivet or Bolt	L	g	Maximum Rivet or Bolt
8	$4\frac{1}{2}$	$\frac{7}{8}$	$3\frac{1}{2}$	2	$\frac{7}{8}$	2	$1\frac{1}{8}$	$\frac{1}{2}$
7	4	$\frac{7}{8}$	3	$1\frac{3}{4}$	$\frac{7}{8}$	$1\frac{3}{4}$	1	$\frac{1}{2}$
6	$3\frac{1}{2}$	$\frac{7}{8}$	$2\frac{3}{4}$	$1\frac{5}{8}$	$\frac{3}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{3}{8}$
5	3	$\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{3}{8}$	$\frac{5}{8}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{8}$
4	$2\frac{1}{4}$	$\frac{7}{8}$	$2\frac{1}{4}$	$1\frac{1}{4}$	$\frac{5}{8}$	1	$\frac{9}{16}$	$\frac{1}{4}$

L	g_1	g_2	L	g_1	g_2
8	3	3	6*	$2\frac{1}{2}$	$2\frac{1}{4}$
7	$2\frac{1}{2}$	3	5	2	$1\frac{3}{4}$
6	$2\frac{1}{4}$	$2\frac{1}{2}$			

* When thickness is $\frac{3}{4}$ inch or over.

For convenience in designing, the values of $L \div r$ should be plotted as ordinates, and the resulting values of P as abscissæ, on cross-section paper, and the curve drawn in. Then the value of P for any given value of $L \div r$ may be taken at once from the diagram without the labor of substituting in the above formula.

The bearing value of a rivet in a plate of given thickness is equal to the thickness of the plate, *times* the diameter of the rivet, *times* the allowable unit bearing stress. The value of a rivet in single shear is equal to the area of the cross-section of the rivet, *times* the allowable unit shearing stress. The bearing values of rivets of different diameter in plates of different thickness, and the shearing values of rivets of different diameter, are given in Table X, the unit-stresses being as given above.

TABLE X

Bearing and Shearing Values of Rivets

Diameter of Rivet (Inches)	Single Shear (at 10 000 lbs. per sq. in.)	Bearing in Different Thicknesses of Plates (at 20 000 lbs. per sq. in.)							
		$\frac{1}{4}$ in.	$\frac{5}{16}$ in.	$\frac{3}{8}$ in.	$\frac{7}{16}$ in.	$\frac{1}{2}$ in.	$\frac{9}{16}$ in.	$\frac{5}{8}$ in.	$\frac{11}{16}$ in.
$\frac{1}{2}$	1 960	2 500	3 130	3 750					
$\frac{9}{16}$	2 480	2 810	3 520	4 210	4 920				
$\frac{5}{8}$	3 070	3 130	3 910	4 690	5 470				
$\frac{11}{16}$	3 710	3 440	4 290	5 160	6 010	6 880			
$\frac{3}{4}$	4 420	3 750	4 690	5 630	6 560	7 500	8 440		
$\frac{13}{16}$	5 180	4 070	5 080	6 090	7 110	8 120	9 150	10 160	
$\frac{7}{8}$	6 010	4 380	5 470	6 570	7 660	8 750	9 840	10 940	12 040

DESIGN OF A RIVETED ROOF TRUSS

14. Let it be required to design a Fink roof truss of 64 feet span and $\frac{1}{4}$ pitch, the distance between trusses being 16 feet. The roof covering is taken as 12 pounds per square foot of roof surface, and the total snow and wind load will be taken as 30 pounds per square foot of horizontal projection. The weight of the steel in the roof truss will be computed from Merriman's formula (see Art. 4, p. 6). The total weight is now found to be:

Weight of truss, $\frac{3}{4} \times 16 \times 64 \left(1 + \frac{l}{10}\right) =$ 5 580 pounds.
Weight of roof cover, $35.6 \times 2 \times 16 \times 12 =$ 13 650 pounds.
Weight of wind and snow $64 \times 16 \times 30 =$ 30 700 pounds.
Total 49 930 pounds.

Each apex load is therefore $49\,930 \div 8 = 6\,240$ pounds. By multiplying this value by each of the stresses as given in Fig. 25, the stress in each member is computed as follows:

$L_0 U_1 = 7.83 \times 6\,240 = 48\,800$ pounds
$L_0 L_1 = 7.00 \times 6\,240 = 43\,700$ "
$U_1 L_1 = 0.89 \times 6\,240 = 5\,580$ "
$U_1 U_2 = 7.38 \times 6\,240 = 46\,000$ "
$L_1 U_2$ and $U_2 L_3 = 1.00 \times 6\,240 = 6\,240$ "
$L_1 L_2 = 6.00 \times 6\,240 = 37\,450$ "
$U_2 L_2 = 1.79 \times 6\,240 = 11\,150$ "
$U_2 U_3 = 6.93 \times 6\,240 = 43\,200$ "
$L_2 L_5 = 4.00 \times 6\,240 = 24\,950$ "
$L_2 L_3 = 2.00 \times 6\,240 = 12\,475$ "
$U_3 L_3 = 0.89 \times 6\,240 = 5\,580$ "
$L_3 U_4 = 3.00 \times 6\,240 = 18\,725$ "
$U_3 U_4 = 6.48 \times 6\,240 = 40\,500$ "

In the design of this truss, no material thinner than ¼-inch, and no angles smaller than 2½ by 2-inch, will be allowed.

Fig. 76 shows an outline diagram of the truss, with the stresses placed upon it. A positive sign signifies a tensile stress, and a negative sign signifies a compressive stress. The length of the top chords is $\sqrt{32^2 + 16^2} = 35.6$ feet; and the length of each panel is ¼ of this, or 8.9 feet. The horizontal projection of one panel is ¼ of half the span, or $32 \div 4 = 8$ feet.

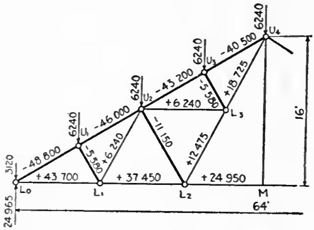


Fig. 76. Stresses in a Fink Truss.

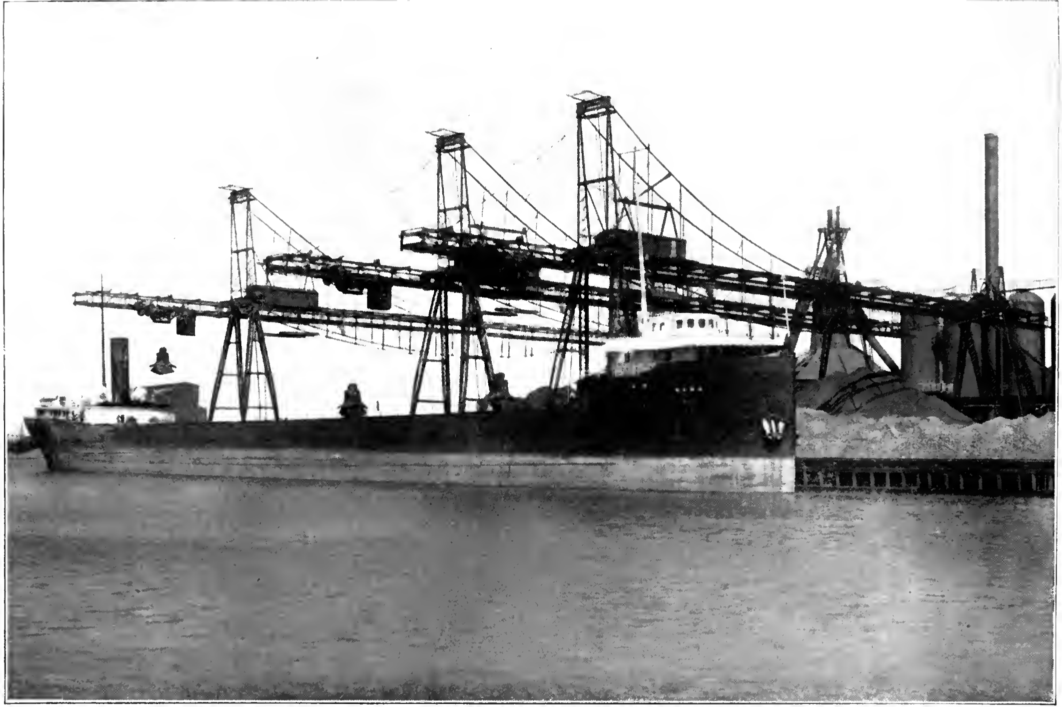
Design of the Purlins. The distance between the trusses is 16 feet, and the distance between the purlins is 8.9 feet; therefore the load coming on one purlin is:

Roof covering, 8.9 × 16 × 12 = 1 710 pounds
Snow and wind, 8 × 16 × 30 = 3 840 "
Total = 5 550 pounds

This should be resolved in two components, V and H, perpendicular and parallel to the truss chord. These are determined by the proportions of similar triangles, as follows:

$$V : 5\,550 = 32 : 35.6$$
$$V = 4\,990 \text{ pounds.}$$
$$H : 5\,550 = 16 : 35.6$$
$$H = 2\,495 \text{ pounds.}$$

The bending moment caused by V is $M_V = (4\,990 \times 16) \div 8 = 9\,980$ pound-feet. The bending moment caused by H is $M_H = (2\,495 \times 16) \div 8 = 4\,990$ pound-feet. The stress caused by V is $= \frac{M_V c}{I}$; and the stress caused by H is $\frac{M_H c^1}{I'}$; and there is also the condition that the sum of these two stresses shall not be greater than 15 000 pounds. Since the above formula involves the moment of inertia and half the depth of the beam, a beam must be chosen, and its moment of inertia and half-depth substituted in the above equation, and the equation solved. In case the sum of the stresses is in excess of 15 000 pounds, or very much smaller, a re-computation must be made, using a larger or a smaller beam.



THREE-BRIDGE UNLOADING PLANT AT SOUTH CHICAGO

Transferring ore from lake ore steamer to the shore. A furnace with its battery of "stoves" may be seen in the background.

Courtesy of Brown Hoisting and Machinery Company, Cleveland, Ohio

A 15-inch 42-pound I-beam will be assumed, and will be examined to see if it fulfils the necessary conditions. The value of I and I' are taken from the Carnegie Handbook, p. 97. The value of c is $\frac{15}{2} = 7\frac{1}{2}$ in the first case, and $\frac{5.50}{2} = 2.75$ in the second case. The quantity 5.50 is the width of the flange of the I-beam. Substituting in the above formula, there results:

$$\frac{9\,980 \times 12 \times 7\frac{1}{2}}{441.8} + \frac{4\,990 \times 12 \times 2.75}{14.62} = 13\,330 \text{ pounds}$$

The above I-beam could be used; but in case the sheathing is laid closely and nailed tightly, we may consider it acting as a beam of a span of 16 feet, 8.9 feet deep, and of a thickness equal to that of the sheathing, which in this case will be assumed as $1\frac{1}{2}$ inches. The sheathing will then take up the moment caused by the force H; and the purlin will take up the vertical bending moment alone. The stress in the sheathing due to the force H is $\frac{M_H c}{I}$. Here $M = 4\,990 \times 12$; $c = 8.9 \times 12 \div 2$; and $I = \frac{1.5\,(8.9 \times 12)^3}{12}$. Therefore,

$$S = \frac{4\,990 \times 12 \times 8.9 \times 12 \times 12}{2 \times 1.5\,(8.9 \times 12)^3}$$
$$= 20.95 \text{ pounds per square inch, which is insignificant.}$$

The vertical bending moment taken up by the purlin is $9\,980 \times 12 = 119\,760$ pound-inches, and this requires a section modulus of $119\,760 \div 15\,000 = 7.98$. By consulting pages 101 and 102 of the Carnegie Handbook, the following is found to be true:

An 8-inch 11.25-pound channel is just too small.

A 7-inch 17.25-pound channel gives the nearest section modulus.

An 8-inch 13.75-pound channel would be lighter and stiffer.

A 9-inch 13.25-pound channel would be still lighter and stiffer; and since it weighs less than any of the others, it will be more economical.

A 9-inch 13.25-pound channel will accordingly be used for the purlins.

On account of one half-panel load coming on the purlin at the ends and ridge of the truss, these purlins must theoretically be only one-half as strong as the other; but, on account of the fact that all purlins must be of the same height, these purlins are made of the lightest weight channel of the same height as the others. In this case it happens that the lightest weight 9-inch channel is required for the intermediate purlins as well as for the end ones. To illustrate the above, suppose that the purlins were required to be 10-inch 25-pound channels, then the end purlins would be made of 10-inch 15-pound channels.

In case sheathing is not used, then some other method must be employed to take up the bending moment due to the force H. The usual method of doing this is to bore holes in the center of the purlins at the middle point of their span, and to connect them with rods which run from one eave up over the ridge and down to the other eave (see Fig. 22).

Design of Tension Members. *For Member* $L_0\ L_1$: The required net area is $43\,700 \div 15\,000 = 2.92$ square inches. By consulting the Carnegie Handbook, p. 118, it is seen that two 3 by 3 by $\frac{5}{16}$-inch angles give a gross area of $1.78 \times 2 = 3.56$ square inches. From this must be subtracted the rivet-hole made by a $\frac{3}{4}$-inch rivet. Since all rivet-holes are punched $\frac{1}{8}$ inch larger in diameter than the rivet, the amount to be substracted from the above gross area is $\frac{5}{16} \times (\frac{3}{4} + \frac{1}{8}) \times 2 = 0.54$, there being two rivet-holes taken out of the section. This gives a total net area of $3.56 - 0.54 = 3.02$ square inches. As this is but slightly larger than the required net area, these angles will be used for this member. Since the stress in this member is the greatest stress in the bottom chord, and since the bottom chord is made of the same section up to the splice at L_2, on account of economical construction, it being cheaper to run the same sized angle throughout than it would be to change the size of each panel and make a splice at each panel point, the size of angle as determined above will be used for the first two panels of the bottom chord at each end.

For Member $L_2\ L_5$: The required net area is $24\,950 \div 15\,000 = 1.67$ square inches. From Carnegie Handbook, p. 115, two angles $2\frac{1}{2}$ by 2 by $\frac{1}{4}$-inch give a gross area of $2 \times 1.06 = 2.12$ square inches; and taking out two $\frac{5}{8}$-inch rivets, the net area is $2.12 - \frac{1}{4}\,(\frac{5}{8} + \frac{1}{8}) \times 2 = 1.74$ square inches. This coincides very closely with the required area, and this angle will be used. Even if this angle should have been in excess of the required area, it would still be necessary to use it, since it is the smallest angle and of the least thickness allowed.

For Member $L_3 U_4$: The required net area is 18 725 ÷ 15 000 = 1.25 square inches. Two angles $2\frac{1}{2}$ by 2 by $\frac{1}{4}$-inch give a gross area of 2.12 square inches, and a net area of 1.74 square inches, as above computed. Although they give an area considerably larger than that required, nevertheless they must be used, since they are the smallest allowed.

For Members $L_1 U_2$ and $U_2 L_3$: The required net area is 6 240 ÷ 15 000 = 0.42 square inch. One angle $2\frac{1}{2}$ by 2 by $\frac{1}{4}$-inch gives a gross area of 1.06 square inches. The amount to deduct from this is $\frac{1}{4} \times (\frac{5}{8} + \frac{1}{8}) = 0.19$ square inch, one $\frac{5}{8}$-inch rivet-hole being taken from the section. This gives a net area of $1.06 - 0.19 = 0.87$ square inch, which shows this angle to be sufficient.

Since the member U_4M has no other use than to prevent the bottom chord from sagging, it will be made of the lightest angle allowed. It will therefore be made of one angle $2\frac{1}{2}$ by 2 by $\frac{1}{4}$-inch.

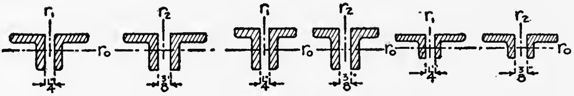
The member $L_2 L_3$ is made of the same section as the member $L_3 U_4$, since this is more economical than to change the section and to make a splice at L_3. It will be made of two angles $2\frac{1}{2}$ by 2 by $\frac{1}{4}$-inch.

Design of the Compression Members. The general method of procedure in the design of compression members is, first, to assume a cross-section, and then to determine the unit compressive stress allowable by inserting the length of the member and the radius of gyration of the assumed section in the formula given for the unit allowable compressive stress; then divide the stress in the member by the unit allowable compressive stress determined as above. This will give the required area. If this required area is equal to, or slightly less than, the area of the cross-section assumed, the section assumed will be the correct one. If the required area as computed above is greater than the area of the section, then a larger section must be assumed and the operation repeated. Usually only two operations are required in order to obtain a section whose area is correct. It should be noted that the area of the rivet-holes is not deducted from the section in compression members, since the rivet fills up the rivet-hole and makes a section as strong in compression as it was in the first place. Care should be taken to assume a section whose radius of gyration is equal to or greater than the length of the member divided by 120. This is due to the fact that $l \div r$ should not be greater than 120. Compression members of roof trusses for the usual spans are made of two angles placed back to back. The radius of gyration of such a section is equal to the radius of gyration of one angle, if it is referred to an axis perpendicular to the legs which are placed together. If it is referred to an axis through the center of the section and parallel to the legs which are placed together, it is equal to some value other than the radius of gyration of one angle. The radii of gyration for pairs of angles placed either directly back to back or a small distance apart, are given on pages 144 to 146 of the Carnegie Handbook and in Table XI, and should be used in the design. The value of the radius of gyration for sizes of angles other than those given, may be obtained by interpolation.

For example, let it be required to determine the radius of gyration of two 5 by $3\frac{1}{2}$ by $\frac{1}{2}$-inch angles placed $\frac{1}{2}$ inch apart and back to back, the 5-inch legs being horizontal (see p. 146, Carnegie Handbook). Since this value is not given in the tables, it must be interpolated from the values given for r_2 for the above sized angle, which are $\frac{5}{16}$ inch and $\frac{7}{8}$ inch thick. The difference between the two thicknesses given is $\frac{7}{8} - \frac{5}{16} = \frac{9}{16}$ inch. The difference between the two values given for the radius of gyration is $2.55 - 2.44 = 0.11$. This gives a difference of $.11 \div 9 = 0.0122$ for each $\frac{1}{16}$ inch difference in thickness in the angle. The difference between the thickest angle and the angle under consideration is $\frac{7}{8} - \frac{1}{2} = \frac{3}{8}$, or $\frac{6}{16}$. Therefore the amount to be subtracted from the radius of gyration of the thickest angle is $6 \times 0.0122 = 0.0732$; and the radius of gyration for two angles placed back to back as above stated is $2.55 - 0.07 = 2.48$. In case one angle is used for a member in compression, the least rectangular radius of gyration must be used; and if two angles are employed, placed back to back, care should be exercised to use the least radius of gyration; and if the angles have unequal legs, those legs should be placed back to back, which will make the rectangular radii of gyration as nearly equal as possible. The values of the radii of gyration will indicate whether the short legs or the long legs should be placed together. The tables given in the Carnegie Handbook give the radii of gyration for angles spaced at distances $\frac{1}{2}$ inch and $\frac{3}{4}$ inch apart; but since the connection plates of roof trusses are usually $\frac{1}{4}$ inch or $\frac{3}{8}$ inch thick, the values of the radii of gyration should be given for angles spaced $\frac{1}{4}$ inch and $\frac{3}{8}$ inch apart. Such values are given in Table XI.

TABLE XI

Radii of Gyration of Angles Placed Back to Back



Equal Legs			Unequal Legs				
Size (Inches)	r_1	r_2	Size (Inches)	r_1	r_2	r_1	r_2
$2 \times 2 \times \frac{3}{16}$	0.93	0.98	$2\frac{1}{2} \times 2 \times \frac{3}{16}$	0.88	0.92	1.19	1.24
$2 \times 2 \times \frac{7}{16}$	0.98	1.03	$2\frac{1}{2} \times 2 \times \frac{1}{2}$	0.94	0.99	1.25	1.30
$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	1.14	1.19	$3 \times 2\frac{1}{2} \times \frac{1}{4}$	1.09	1.13	1.40	1.45
$2\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{2}$	1.19	1.24	$3 \times 2\frac{1}{2} \times \frac{9}{16}$	1.15	1.20	1.46	1.51
$3 \times 3 \times \frac{1}{4}$	1.34	1.39	$3\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	1.04	1.09	1.67	1.72
$3 \times 3 \times \frac{5}{8}$	1.41	1.46	$3\frac{1}{2} \times 2\frac{1}{2} \times \frac{11}{16}$	1.13	1.18	1.75	1.80
$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{3}{8}$	1.56	1.61	$3\frac{1}{2} \times 3 \times \frac{5}{16}$	1.30	1.35	1.61	1.66
$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{13}{16}$	1.65	1.70	$3\frac{1}{2} \times 3 \times \frac{13}{16}$	1.40	1.45	1.71	1.76
$4 \times 4 \times \frac{5}{16}$	1.76	1.80	$4 \times 3 \times \frac{5}{16}$	1.25	1.30	1.88	1.93
$4 \times 4 \times \frac{13}{16}$	1.85	1.89	$4 \times 3 \times \frac{13}{16}$	1.35	1.40	1.97	2.02
$6 \times 6 \times \frac{7}{16}$	2.58	2.63	$5 \times 3 \times \frac{5}{16}$	1.17	1.22	2.42	2.47
$6 \times 6 \times \frac{7}{8}$	2.66	2.70	$5 \times 3 \times \frac{13}{16}$	1.27	1.32	2.52	2.57
			$5 \times 3\frac{1}{2} \times \frac{3}{8}$	1.42	1.46	2.36	2.41
			$5 \times 3\frac{1}{2} \times \frac{7}{8}$	1.51	1.56	2.45	2.50
			$6 \times 3\frac{1}{2} \times \frac{3}{8}$	1.34	1.39	2.90	2.95
			$6 \times 3\frac{1}{2} \times \frac{7}{8}$	1.44	1.49	3.00	3.05
			$6 \times 4 \times \frac{3}{8}$	1.58	1.62	2.83	2.87
			$6 \times 4 \times \frac{7}{8}$	1.67	1.71	2.92	2.97

r_0 = in all cases, the radius of gyration of one angle referred to neutral axis parallel to the horizontal leg as shown above.

For Member $L_0 U_1$: Two angles $3\frac{1}{2}$ by 3 by $\frac{5}{16}$-inch, long legs spaced back to back, and $\frac{1}{4}$ inch apart, will be assumed. The least radius of gyration is 1.10, and the length is 8.9 feet. The area of this section is $2 \times 1.93 = 3.86$ square inches. The unit allowable compressive stress is:

$$P = 24\,000 - \frac{110 \times 12 \times 8.9}{1.10} = 13\,400 \text{ pounds.}$$

The required area is $48\,800 \div 13\,400 = 3.65$ square inches. Since the angles given are of somewhat larger area than that required, it might be well to examine the next smallest angle.

Two angles $3\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{5}{16}$-inch, with a radius of gyration

1.11 and a total area of 3.56 square inches, will be assumed. The unit allowable compressive stress is:

$$P = 24\,000 - \frac{110 \times 12 \times 8.9}{1.11} = 13\,510 \text{ pounds.}$$

The required area is 48 800 ÷ 13 510 = 3.61 square inches. Since the required area is greater than the given area, it shows that these angles are too small. Two angles $3\frac{1}{2}$ by 3 by $\frac{5}{16}$-inch will therefore be used for this member, and also for all the members of the top chord, since it is more economical to run the same size throughout than to change the section and make splices at all the upper chord panel points.

For Member $U_2 L_2$: The length of this member is easily computed from similar triangles, and is found to be 8.9 feet. Two angles $2\frac{1}{2}$ by 2 by $\frac{5}{16}$-inch, with the long legs back to back, give a total area of 1.62 square inches and a radius of gyration of 0.78. The unit-stress is computed and found to be 8 950 pounds. The required area is 11 150 ÷ 8 950 = 1.25 square inches. These two angles would be used, but the least allowable radius of gyration is 8.9 × 12 ÷ 120 = 0.89. This is seen to be considerably greater than the radius of gyration given above, and therefore these angles cannot be used, according to Specifications. By consulting the tables, it is seen that two angles 3 by $2\frac{1}{2}$ by $\frac{1}{4}$-inch are the smallest angles that will give a radius of gyration nearest to the required amount (0.89) and still be standard size angles. Angles marked with a star in the tables are special angles, and can be procured only at a cost greatly in excess of the others, and then only with great delay in delivering except when large quantities are ordered. It may be said that special angles should never be used.

For Members $U_1 L_1$ and $U_3 L_3$: The length of these members is 4.45 feet. The radius of gyration must therefore not be less than 4.45 × 12 ÷ 120 = 0.45. One angle $2\frac{1}{2}$ by 2 by $\frac{1}{4}$-inch, with an area of 1.06 square inches and a least rectangular radius of gyration of 0.59, will be assumed. The allowable unit compressive stress is:

$$P = 24\,000 - \frac{110 \times 12 \times \frac{8.9}{2}}{0.59} = 14\,050 \text{ pounds.}$$

The required area is 5 580 ÷ 14 050 = 0.40 square inch. The angle chosen gives a much larger area than that required; but since it is the smallest one allowed by the Specifications, it must be used.

Many designers do not place a limit on the value of the radius of gyration, but simply use the compressive formula, and any section whose radius of gyration will bring the required area near to its own area. This should not be the case, since the formula here given is not applicable when the value of $l \div r$ is greater than 120.

Top and Bottom Lateral Bracing. Since the stresses in the lateral bracing are not susceptible of a well-defined mathematical analysis, it cannot be rationally designed. Experience indicates that it should be as in Article 7. The lower chord bracing will therefore consist of single angles 3 by $2\frac{1}{2}$ by $\frac{5}{16}$-inch; and the upper chord bracing, of 3 by 3 by $\frac{5}{16}$-inch angles. This bracing should not be placed between every truss, but should be placed as indicated on the stress sheet, Plate I. If one $\frac{3}{4}$-inch rivet is taken out of the section of the bottom lateral bracing, it will give a net area of $1.62 - 0.27 = 1.35$ square inches; this could withstand a stress of $1.35 \times 15\,000 \times 1.25 = 27\,000$ pounds, which is the stress the bracing is assumed to carry, and which is to be used in determining the number of rivets for the connection. The stress in the top lateral bracing may be assumed to be the same.

Determination of Number of Rivets Required. It is to be remembered that $\frac{5}{8}$-inch rivets are to be used in the $2\frac{1}{2}$ and 2-inch legs of the angles, and $\frac{3}{4}$-inch rivets in all larger legs. Field rivets are to have a value equal to $\frac{2}{3}$ of a shop rivet. Connection plates $\frac{1}{4}$ inch thick are to be used in all cases, except where the number of rivets required will be greater than 10. In such cases, use a $\frac{3}{8}$-inch connection plate. The correct number of field rivets may be determined by multiplying the required number of shop rivets by $\frac{3}{2}$.

Whenever two angles back to back join on a plate, the number of rivets is governed by the bearing on the connection plate; and when one angle is joined to a plate, the number of rivets is governed by single shear if the rivet is $\frac{5}{8}$ inch in diameter, and by single shear if the rivet is $\frac{3}{4}$ inch in diameter and the plate is over $\frac{1}{4}$ inch thick. The bearing and shearing value of the rivets are taken from Table X, p.47.

Lower End of L_0 U_1: Rivets $\frac{3}{4}$-inch. Plate $\frac{3}{8}$-inch.
$48\,800 \div 5\,630 = 9$ shop rivets required.
Upper End of U_3 U_4: Rivets $\frac{3}{4}$-inch. Plate $\frac{3}{8}$-inch.
$40\,500 \div 5\,630 = 8$ shop or 10 field rivets
Upper End of U_4 L_3: Rivets $\frac{5}{8}$-inch. Plate $\frac{3}{8}$-inch.
$18\,725 \div 4\,690 = 4$ shop or 6 field rivets.

Lower End of $L_2\,L_3$: Rivets ⅝-inch. Plate ¼-inch.
12 474 ÷ 3 130 = 4 shop rivets.
Each End of $U_2\,L_2$: Rivets ⅝-inch. Plate ¼-inch.
11 150 ÷ 3 130 = 4 shop rivets.
Each End of $L_1\,U_2$ *and* $U_2\,L_3$: Rivets ⅝-inch. Plate ¼-inch.
6 240 ÷ 3 070 = 2 shop rivets.
Each End of $U_1\,L_1$ *and* $U_3\,L_3$: Rivets ⅝-inch. Plate ¼-inch.
5 580 ÷ 3 070 = 2 shop rivets.

Where U_1L_1 and U_3L_3 join the top chord, two rivets will be required in the top chord.

Since the components of the two diagonals meeting at U_2 are parallel and equal, and opposite to the stress in $U_2\,L_2$, no rivets will be required, theoretically, to hold the plate to the top chord. A sufficient number, however, must be put in to take up the vertical reaction of the purlin. This number is 5 550 ÷ 3 130 = 2 shop rivets. In practice a greater number are usually put in to prevent vibration and to fill out the plate.

At L_3 a sufficient number of rivets must be placed in $L_2\,U_4$ to take up the difference in stress between $L_3\,U_4$ and $L_2\,L_3$. The number required is (18 725 − 12 475) ÷ 3 130 = 3 shop rivets.

At the end L_0 of the member $L_0\,L_1$, there is a horizontal stress of 43 700 pounds, and a vertical force equal to the reaction, which is 49 930 ÷ 2 = 24 965 pounds (see Fig. 76). The force acting on the rivets in this member is the resultant of these two forces, and is:

$$\sqrt{43\,700^2 + 24\,965^2} = 50\,300 \text{ pounds.}$$

Since the rivets are ¾-inch and the plates ⅜-inch, the number of rivets required is 50 300 ÷ 5 630 = 9 shop rivets. This number should be placed symmetrically with respect to the intersection of the two chords. In case the point of application of the reaction had not coincided with the intersection of the chords, the number of rivets must be computed according to the formula on page 36.

For the joint at L_1, a sufficient number of rivets must be put in, in order to take up the difference in stress between the members $L_0\,L_1$ and $L_1\,L_2$. The number required is (43 700 − 37 450) ÷ 3 750 = 2 shop rivets.

The purlins have a horizontal shear at each end, of $H \div 2 =$ 2 490 ÷ 2 = 1 245 pounds. This requires 1 245 ÷ 4 420 = 1 shop rivet or 1 field rivet, to keep them from sliding down on the top chord. Clip angles 5 by 3½ by ⅜-inch will be used as shown in Plate I.

These help in the erecting of the purlins, since they are shop-riveted to the truss and therefore hold the purlins in place while they are being field-riveted to the truss and to the clip angles (see Fig. 77).

Rivets in Lateral Bracing. The plates of the lateral bracing should be made $\frac{1}{4}$ inch thick. The 3-inch leg of the angle will be placed against the plate. Rivets $\frac{3}{4}$ inch in diameter can then be used, and the strength of the joint will be governed by bearing in the $\frac{1}{4}$-inch plate. The stress for which the rivets are to be determined is given on p. 55. It is 27 000 pounds. The number of field rivets in bearing in $\frac{1}{4}$-inch plate, required to withstand the stress, is $(27\,000 \div 4\,420) \times \frac{4}{3} = 9$. The size and shape of the plate can be determined only while making the detailed drawing (see Plate III, p. 61).

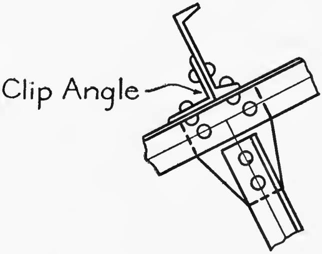


Fig. 77. Detail Showing Clip Angle Connection.

Design of the Splice. The general details of the splice will be as shown in Fig. 68. The plate underneath will be made $\frac{1}{4}$ inch thick, the same thickness as the vertical connection plate at this point. Note that the member on the left-hand side of the splice must have $\frac{3}{4}$-inch shop rivets, and the member on the right-hand side must have $\frac{5}{8}$-inch field rivets. The total number of rivets on either side of the splice must be sufficient to take up the entire stress of the member through which they are driven. If eight $\frac{5}{8}$-inch field rivets are driven through the horizontal legs and the bottom splice plate, and five $\frac{5}{8}$-inch field rivets are driven through the vertical plate and legs of the angles (see Fig. 78), the total strength of the joint, remembering that the rivets are $\frac{5}{8}$-inch, will be:

$$8 \times \tfrac{2}{3} \times 3\,070 = 16\,370 \text{ pounds.}$$
$$5 \times \tfrac{2}{3} \times 3\,130 = 10\,430 \text{ pounds.}$$
$$\text{Total} \quad 26\,800 \text{ pounds.}$$

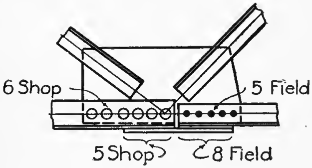


Fig. 78. Detail of Lower Chord Splice.

Note that the rivets through the bottom splice plates are governed by single shear; and those through the vertical plate, by bearing in the plate. Since 16 370 pounds is the value of the rivets through the bottom splice plate, this amount will be transmitted to the other side, where it must be taken up by shop rivets. Bearing in the plate governs the number of $\frac{3}{4}$-inch shop rivets required. This number is $16\,370 \div 3\,750 = 5$. Since 16 370 pounds of the stress in the member $L_1 L_2$ is taken up by these 5 shop rivets, the remainder, $37\,450 - 16\,370 = 21\,080$ pounds, must be taken up by the rivets through the vertical connection plate. This requires $21\,080 \div 3\,750 = 6$ shop rivets.

Since 16 370 pounds is transmitted from one side of the splice to the other by means of the bottom splice plate, this plate should be $16\,370 \div 15\,000 = 1.09$ square inches in net section. The net width, the plate being $\frac{1}{4}$ inch thick, is $1.09 \div 0.25 = 4.36$ inches. If two $\frac{3}{4}$-inch rivet-holes are taken out of the section, the entire width of the plate must be $4.36 + 2\left(\frac{3}{4} + \frac{1}{8}\right) = 6.11$, say 7 inches wide. The length of the plate must be sufficient to get in the number of rivets, and this length is determined in detailing.

Design of the Masonry Plate. If this truss rested upon a masonry wall, it would require a bearing of $(49\,930 \div 2) \div 250 = 100$ square inches. The width of the plate cannot be less than twice the width of the legs of the bottom chord angle, nor should it extend outside the legs of the chord angle more than 3 inches on each side. The masonry plate will be assumed as 12 inches wide, in which case it must be $100 \div 12 = 8.34$, say $8\frac{1}{2}$ inches long. The thickness should be $\frac{1}{2}$ inch.

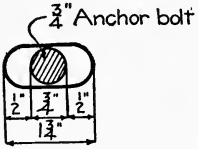


Fig. 79. Slotted Hole for Truss of Fig. 76.

Temperature Allowance. Slotted holes must be put in one end of the truss, to allow for a variation of 150 degrees in temperature. A common rule is to allow $\frac{1}{8}$-inch expansion for every ten feet of span. The total allowance for expansion is $64 \times \frac{1}{8} =$ say, 1 inch. Since the bolts which go through this hole are $\frac{3}{4}$ inch in diameter, the hole must be long enough to allow for $\frac{1}{2}$ the expansion on each side. The width of the hole should be $\frac{1}{4}$ inch greater than the diameter of the bolt (see Fig. 79).

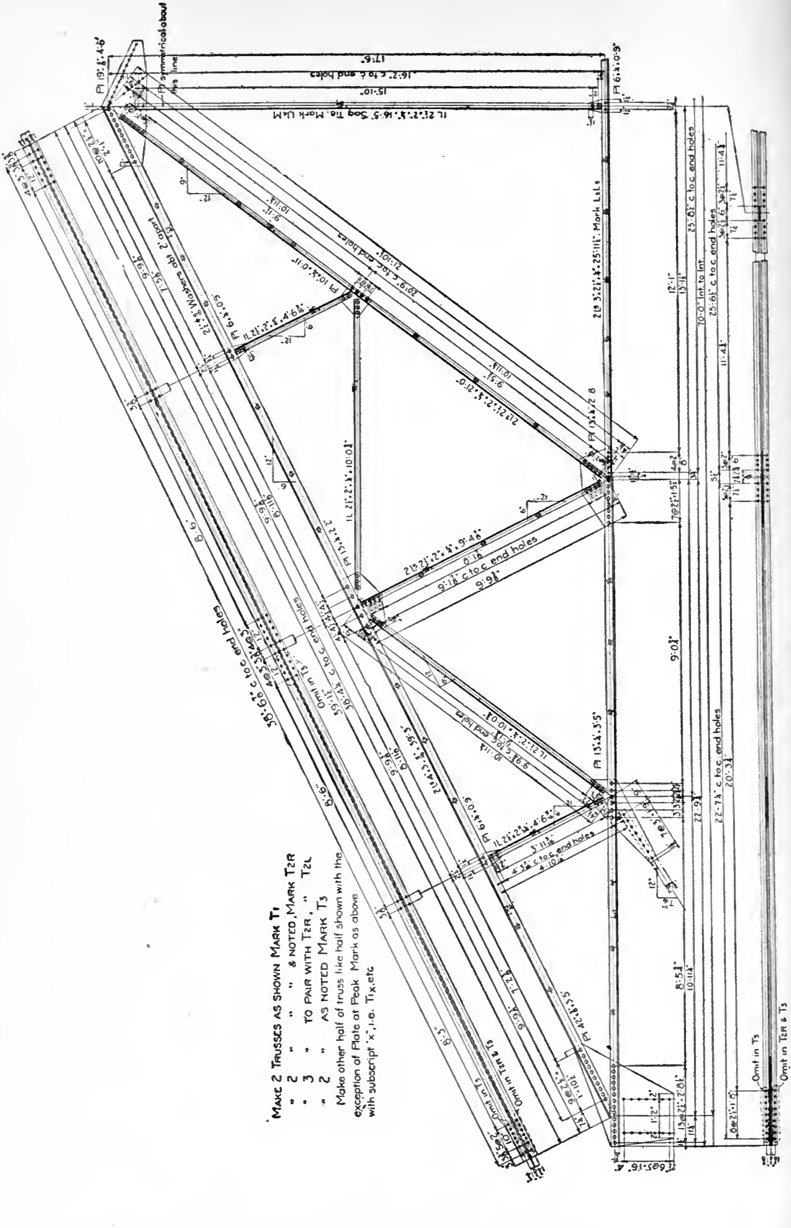
Connections to the Posts. If the truss rests upon posts at the end, sufficient rivets must be driven through the posts and the end connection plates to take up the end reaction, which (see page 38) is 24 970 pounds. Since the rivets are field rivets, this will require $24\,970 \div 3\,750 = 7$. This number is to be used in case the posts are built in masonry walls. In case the truss has knee-braces and the walls of the building consist of steel framework, the reaction due to the wind must be added to the above.

15. **The Stress Sheet.** This should also be somewhat of a general drawing, showing the details. It should give an outline sketch of the building, showing bays, the distances between trusses, and the bracing in the plane of the top and bottom chords. See Plate I, p. 43, which is a stress sheet of the truss designed in Article 14. While not necessary, it is very convenient to have the required number of rivets noted upon the stress sheet.

16. **The Detail Drawing.** The stress sheet, in the matter of sizes, gives general dimensions only. It would be impossible for the shop men to make a truss from the stress sheet.

The shop or detailed drawings must be prepared by the draftsman. These drawings must show the exact number of rivets, and their positions, the dimensions of every plate, member, and purlin. The placing of the dimensions so that it will be unnecessary to add or subtract in order to get another desired dimension, is quite an art, and can be attained only through experience or from the study of correctly detailed work. Plates II and III give the shop drawings for a roof truss and the bracing. These are made according to the latest and best practice, and a thorough study of them will be a help to an intelligent design of the trusses.

All members and plates which are to be riveted together in the field should be given a mark. This mark should be painted on the member or plate, and also marked on the *Marking* or *Erection Diagram* (see Plate IV). This diagram is a sketch, with the pieces in their proper position and the correct mark placed upon them. For example, if it is desired to rivet into place the first panel of the lower lateral system, the men look on the marking diagram and see that plates Pl_7, Pl_8, and Pl_9, and the laterals $BL1$, $BL2$, and $BL3$ are required. They would then go to the place where all the trusses are piled up, and pick out the plates and members with these marks upon them. They would then rivet Pl_7 at L_0, Pl_8 or Pl_9 at L_2, then $BL1$,



MAKE 2 TRUSSES AS SHOWN MARK T₁
" 2 " " & NOTED, MARK T₂R
" 3 " TO PAIR WITH T₂R, " T₂L
" 2 " AS NOTED MARK T₃
Make other half of truss like half shown with the exception of Plate at Peak. Mark as above with subscript 'x', i.e. T₁x, etc

Plate II. Working Shop Drawing of a Roof Truss.

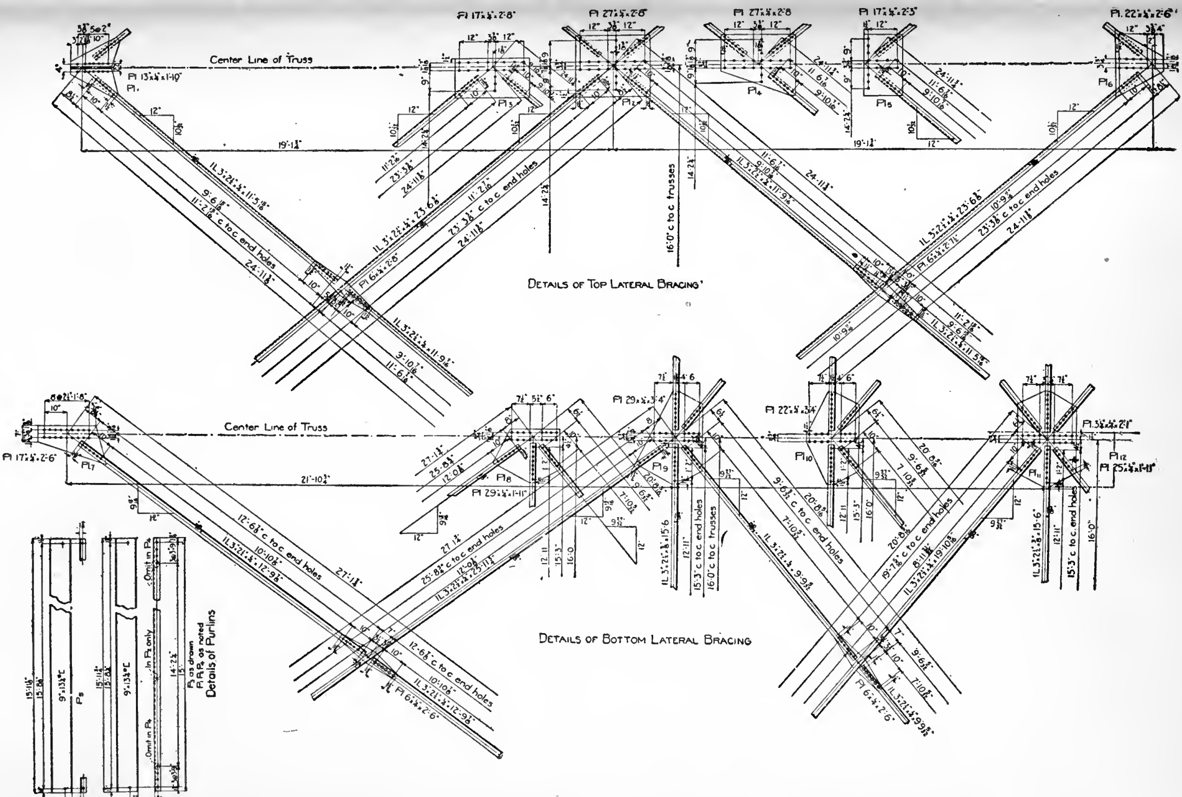


Plate III. Working Shop Drawing Showing Detail of Top and Bottom Lateral Bracing of a Roof Truss.

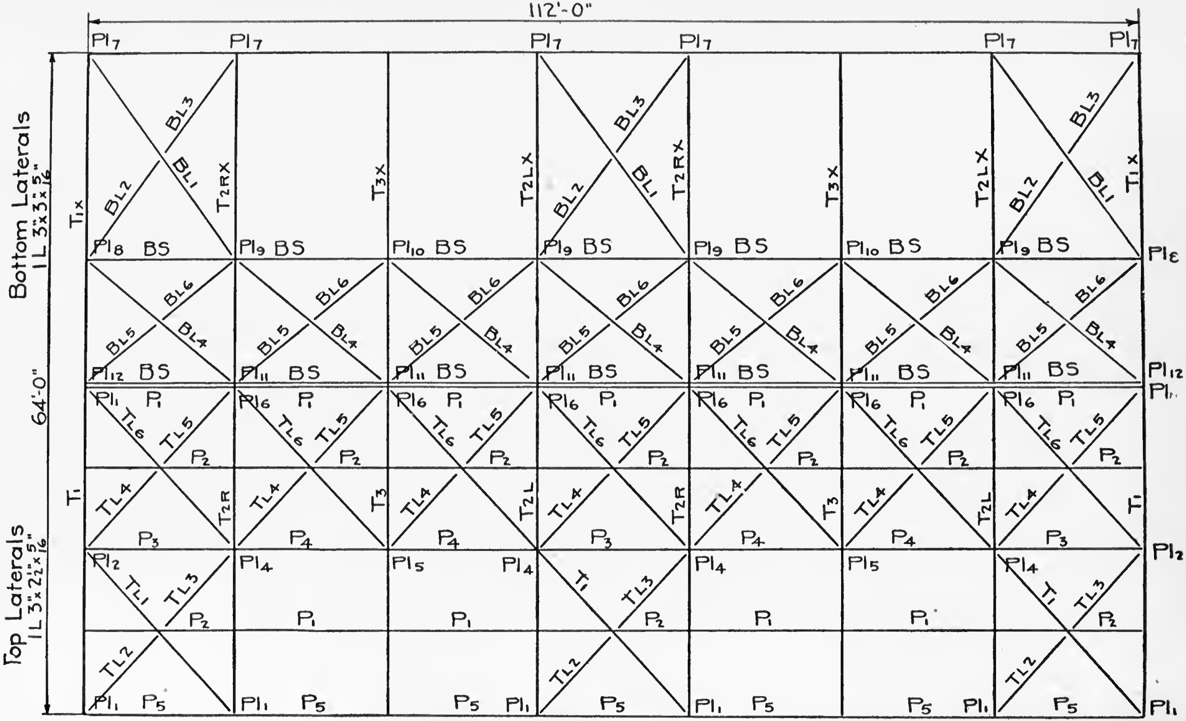


Plate IV. Marking or Erection Diagram.

then $BL3$, and finally $BL2$, all of which are shown on the Marking or Erection Diagram.

Care should be taken to give each piece that is different from others in any way whatsoever, a different mark. For instance, the purlins are the same size, and differ only in length and on account of the fact that one has holes in the bottom flange (see Plate III).

Plate IV gives the roof marking and erection diagram for the roof trusses of Plates II and III. Note that the roof truss on Plates II and III is not the same as that of which Plate I is a stress sheet.

17. **Estimate of Cost.** A rough estimate of the cost of steel in the roof may be obtained by multiplying the weight of the purlins, in pounds, by 2½ cents; then adding to this the result obtained by multiplying the weight of all the steel in the trusses and the bracing by 3½ cents. This will give the cost of the steel work in place with two coats of paint. This will give the cost closely enough for an Engineer's estimate; but should a Contractor desire to bid, a detailed estimate should be made as indicated in the remainder of this article.

The cost of the roof covering may be approximately determined according to the prices given in Article 5, but may be more accurately obtained by asking a Contractor for a figure which his experience will indicate as correct.

Paint of various kinds may be bought in open market. Table XII gives some of the kinds used in painting structural steel, together with the amount of surface one gallon will cover.

TABLE XII

Surface Covered per Gallon of Paint*

PAINT	SQUARE FEET	
	1 coat	2 coats
Iron Oxide (powdered)	600	350
" " (ground in oil)	630	375
Red Lead (powdered)	630	375
White Lead (ground in oil)	500	300
Graphite " " "	360	215
Black Asphalt	515	310
Linseed Oil	875	...

---

*Pencoyd Handbook, 1898, p. 293.

One gallon of paint will give two tons of structural steel the first coat, or 2½ tons the second coat. The cost of one coat of paint in the shop is 45 cents, and two coats after erection $1.80 per ton of structural steel.*

The detailed estimate of the cost of steel includes several items which are given in Table XIII. In each case the weight of the steel on which the work is done must be multiplied by the unit-cost, and the sum total of all the costs will be the total cost of the entire roof or building. Table XIII gives the various operations which go to make up the cost, and also the unit-costs. Note that the costs vary considerably. This table is given as a rough guide. In order to analyze intelligently the cost in this manner, great experience or access to the cost records of some structural steel company is necessary.

TABLE XIII

Analysis of Cost of Roof Trusses and Mill Buildings†

Operation		Cost per Ton
Raw Material		$37.00 to $40.00
Work done at Rolling Mills (mill work)		3.00 " 7.00
Work done in Bridge Shops	Columns	14.00 " 20.00
	Trusses	12.00 " 25.00
	Girders	12.00 " 25.00
Work done in Drafting Room	Purlins	.30 " 1.00
	Trusses and Buildings	2.00 " 8.00
Painting		1.50 " 3.00
Shipping (depends upon freight rates)		....
Erection		5.00 " 15.00

It is not to be supposed that all of the operations indicated in Table XIII are made on one piece. Usually pieces which have mill work done on them require no shop work. In such cases a saving of freight is effected, since the material may be shipped directly from the mill to the place of erection.

MILL BUILDING

18. **Definitions and Description.** A *mill building* consists of a roof supported either on steel columns, on steel columns built in

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*Pencoyd Handbook, 1898, p. 293.

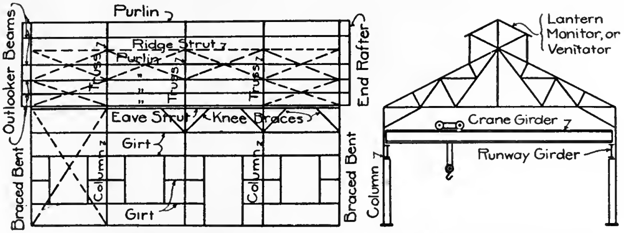
†Compiled from Ketchum's "Steel Mill Buildings."

HALF-VIEW DOWN CENTER AISLE OF MACHINE SHOP OF WESTINGHOUSE ELECTRIC & MFG. CO., EAST PITTSBURG, PA.

Length of building, 1,658 ft., in three bays. Crane runways in all bays. Total weight of steel work, 16,840,000 lbs.

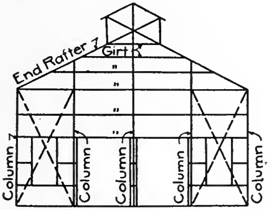
Courtesy of American Bridge Company.

masonry walls, or on masonry walls alone. The roof may consist of any of the forms of roof trusses that have previously been mentioned; and the roof covering, which may rest on purlins, or on rafters and purlins, may consist of any of the roof coverings mentioned in Article 5. In case the roof is supported on steel columns, the columns are connected at their tops by a strut called the *eave-strut*; and they are also connected at certain distances throughout their height by horizontal members called *girts*. The building may or may not have a monitor ventilator on top. See Fig. 80 for general form of mill buildings, together with the names of the various parts.



Side Elevation
Dotted Lines Indicate Lateral Bracing

Truss Bent (Intermediate).



Braced End Bent

Fig. 80. Physical Analysis of a Mill Building.

The eave-struts and the girts are used as a framework on which to place the covering for the walls of the building. This covering may be of wood, of wire lath and plaster, or of corrugated steel. The eave-strut may also act as the end purlin.

Since the majority of mill buildings have their roofs and sides covered with corrugated steel, the remainder of this text will be devoted to mill buildings with this kind of covering.

19. **Types of Buildings.** Mill buildings may be classified according to their width and the number of bays which they have. A building may consist of one center bay (see Fig. 81). In this case the span may vary from 30 to 100 feet. Usually side windows give sufficient light, no skylights being required in the roofs or monitor if the span is less than 80 feet.

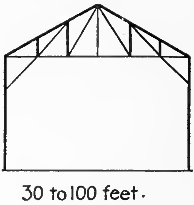


Fig. 81.

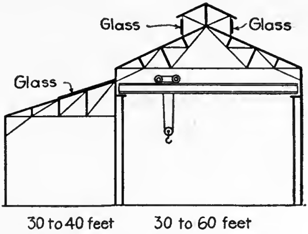


Fig. 82.

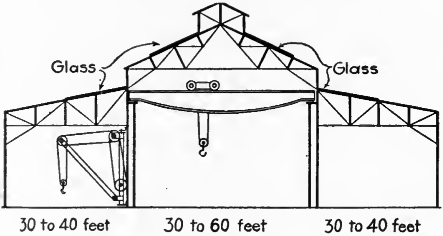


Fig. 83.

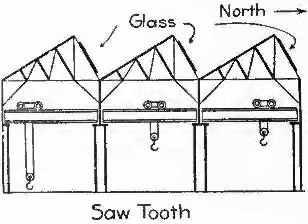


Fig. 84.

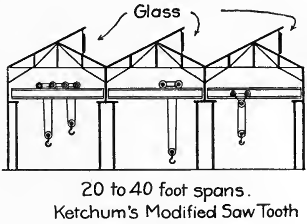


Fig. 85.

Cross-Sections of Mill Buildings.

The building may consist of one center bay and one or two side bays, as shown in Figs. 82 and 83. The truss of the center bay is usually of the Fink type, and in most cases is supplied with skylights and lights in the monitor. The side trusses for the most part consist of that type in which the chords are nearly parallel. The center bay is generally not more than 60 feet in span. This is due to the fact that the crane girder would be unnecessarily heavy if a longer span were used. The side spans are usually from 30 to 40 feet.

In case it is desirable to have the building wider than 150 feet, and still have it lighted by natural light, the common saw-tooth roof (Fig. 84) or Ketchum's modified saw-tooth (Fig. 85) is used. In such cases the bays are seldom greater than 40 feet. Cranes may be placed in one or all of the bays. One great advantage of this type of roof is that it gives a good light uniformly throughout the entire shop; and at any time it is desired to widen the shop, additional bays may be added. The shop may also be lengthened by adding additional trusses at the end. Of course, shops of the first two types mentioned may be widened by addition of extra bays; but the connection to the old work will be unsatisfactory, and skylights will have to be placed in the roofs both of the old bays and of the new ones. For views showing the interior of shops, see pages 77 to 84.

20. **General Requirements.** The general requirements of a mill building depend in detail on the purpose for which it is intended. The requirements which are common to all classes of buildings are ventilation, good light, and transportation facilities both inside and outside the shop. The question of light and ventilation is discussed on pp. 42 and 66. In regard to transportation facilities, it may be said that either the building should be placed so close to a railway track that the material may be unloaded by means of a crane and hauled into the shop, or the track must run into the shop so that the material may be unloaded and placed on the stock floor by means of a crane in the center bay and wall jib-cranes (see Fig. 109, p. 83) or by means of hand trucks.

21. **Layout.** The purpose for which the building is intended, and its relative location in regard to transportation facilities, will determine its layout. For manufacturing purposes, it should be so laid out that the materials will always pass *forward* in going from the raw material to the finished product. In general it may be said that the engines, machines (lathes, milling machines, drill presses, shears,

punches, etc.), and stock room, should be in the side bays; and the laying out, erection, and shipping floors should be placed in the center bay in the order mentioned. Fig. 86 gives a layout of a concern manufacturing frogs and switches.

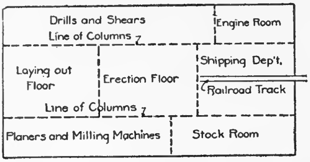


Fig. 86. Layout of a Frog and Switch Company's Building.

22. **Framing.** The framing of a mill building consists of the *roof framing,* which has been discussed in the preceding articles; the *columns,* which will be discussed in the next article; and the *girts* and *eave-struts.*

Eave-struts are a detail of cornice design. Various forms and methods of connections are shown in Article 29, p. 95, and the student is referred to this article.

Girts may be made of wood, angles, or channels. They should be designed for a pressure of from 20 to 30 pounds to the square foot on the side of the building. The spacing of the purlins depends upon the thickness of the corrugated steel used. On account of the fact that corrugated steel can be procured in lengths up to 10 feet and for spans of 5 feet, the stress per square inch due to 30 pounds per square foot is about 25 000 pounds. In No. 24 gauge corrugated steel, the spacing of the girts is limited to 5 feet or less.

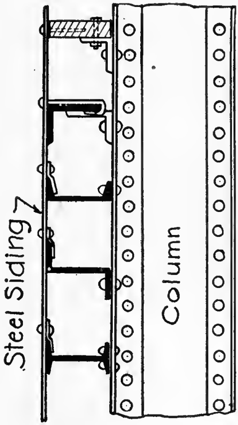


Fig. 87. Methods of Connecting Corrugated Steel to Girts.

Corrugated steel may be fastened to the girts by barbed roofing nails in case the girts are wood, or by clinch nails in case the girts are angles, or by clips fastened with rivets or $\frac{3}{16}$-inch stove bolts $\frac{3}{8}$ inch long. Nails and clinch nails should be spaced about 8 to 12 inches apart. Clips are made of No. 16 gauge steel from $\frac{5}{8}$ inch to $2\frac{1}{2}$ inches wide, and are spaced 8 to 12 inches apart. Fig. 87 shows girts, together with the method of attaching the corrugated steel. The number of nails, rivets, and stove bolts in a pound is to be found in the handbooks of various manufacturers.

Window-frames in mill buildings are, in general, similar to those placed in frame or brick buildings. These frames are fastened either directly to an iron framing or to wood nailing-pieces placed on the iron framing. The windows may be glazed in the usual fashion by means of putty, or may have the glass held in place by some of the methods shown in Fig. 73, p. 44. Windows in the side of the shop may be so fixed that they may be raised and lowered as the ordinary dwelling window; or they may slide horizontally; or, again, they may be fixed so that they cannot be moved. The windows in the monitors are usually fixed with a swinging sash which can be operated from the floor of the shop (see Fig. 89).

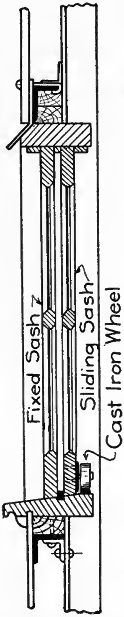


Fig. 88. Section of a Sliding-Sash Window.

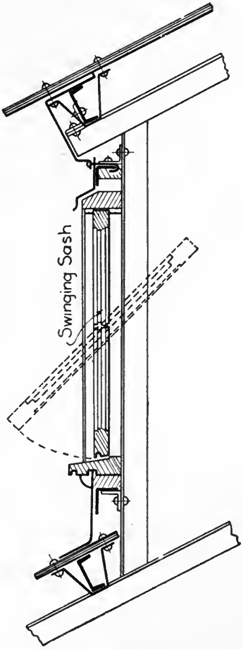


Fig. 89. Section of a Monitor Swing Window.

The glass in the windows may be the common window glass, common plate glass, ribbed or corrugated glass, wire glass, or prisms. Of these varieties, the prisms and the ribbed or corrugated are the best, since they give a more uniform light and are not easily broken. Wire glass, which is made of wire netting moulded in the middle of the sheet of glass, gives a very good light, and has the additional advantage that it does not crack and fall out under the action of fire and water. It is considered fireproof. Common window glass does not diffuse the light so well as most of the other glasses. It is very liable to fracture, and for this reason the inside of the window should be covered with wire netting. Prisms are made by the American Luxfer Prism Company, of Chicago. They may be obtained up to 84 inches in width and 36 inches in height. The width is parallel to the saw teeth. Figs. 88 and 89 give sections of windows, showing the framing. Attention is called to the fact that the roof on the monitor should overhang sufficiently to prevent the water from dropping upon the swinging window when it is fully opened.

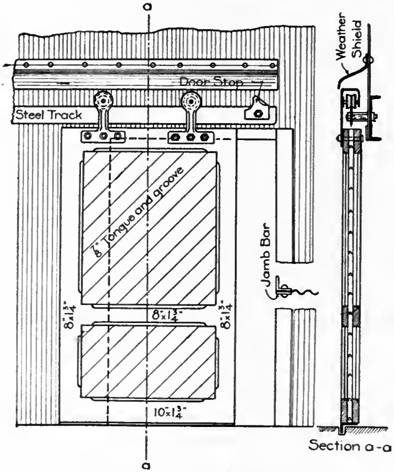


Fig. 90. Detail of a Wooden Door.

Doors may consist entirely of wood, of a frame of angles covered with corrugated steel, or of corrugated steel alone. The first two classes may be so fixed that they will slide, as in the folding doors of residences; open outward like a common door; lift vertically; or, in case they are made entirely of corrugated steel, roll up like a window-shade. This latter door is a patented one. Shop doors are seldom made to open outward or inward, on account of the space required—a space which can be devoted to better purposes. Figs. 90, 91, and 92 show details of the above doors.

Let it be required to design the girt when the trusses are 16 feet apart and the girts are 5 feet center to center. The moment is $\frac{5 \times 16 \times 30 \times 16 \times 12}{8} = 57\,600$ pound-inches; and the required section modulus is $\frac{57\,600}{15\,000} = 3.84$. By inspecting the tables in the Carnegie Handbook, pp. 97 to 119, it is found that the following shapes will be sufficient:

Shape	Section Modulus
One 5-inch 9.75-pound I-beam	4.80
One 6-inch 8.00-pound channel	4.30
One $4\frac{1}{16}$ by $3\frac{1}{8}$-inch 10.3-pound zee-bar	3.91
One 6 by 4 by $\frac{7}{16}$-inch 14.3-pound angle	3.83

From this it is evident that the channel is the most efficient and economical.

23. **Columns.** Columns may consist of almost any combination of shapes, either latticed or connected by plates. Some of the most common cross-sections are shown in Fig. 93, those illustrated in *b* and *c* being used to a great extent. The advantage of these forms is that they give a small radius of gyration about the axis *b–b*, and a larger one about the axis *a–a* (see Fig. 94). This is especially desirable, since, in addition to the direct stress due to the weight of the cranes, roof truss, and covering, the column must withstand the moment due to the wind and to the eccentricity of the runway girder. Both of these moments tend to bend the column around the axis *a–a*. The bending moment due to the eccentricity of the runway girder is equal to the reaction of the girder, *times* the distance from the center of the column (see Figs. 95 and 96). In case the details of the column are as given in Fig. 96, the direct load due to the reaction of the truss and its covering produces a moment due to its eccentricity. This moment is $R_1 \times e_1$. Since R_1 acts on the opposite side of the center of the column from the point of action of R_g, it tends to counteract the effect of the moment due to the eccentricity of the runway girder. The total moment due to eccentricity is $M_e = R_1 \times e_1 - R_g \times e$. If

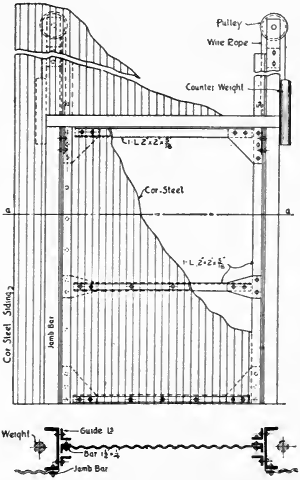


Fig. 91. Detail of Vertical Hoist Door.

the first term of this equation is less than the last term, the compressive stress on the side of the column with the runway girder is increased, and *vice versâ*. The stress in the column from the runway girder to the roof is that due only to the vertical reaction of the roof and the bending due to the wind. In that part of the column below the crane girder, the stress is that due to the direct action of the weight of the roof; its eccentricity, if there be any; the direct action and eccentricity of the runway girder; and the bending moment due to the wind. The bending moment due to the wind is less in this part of the column than it is at the foot of the knee-bracing, but it is customary to consider it the same.

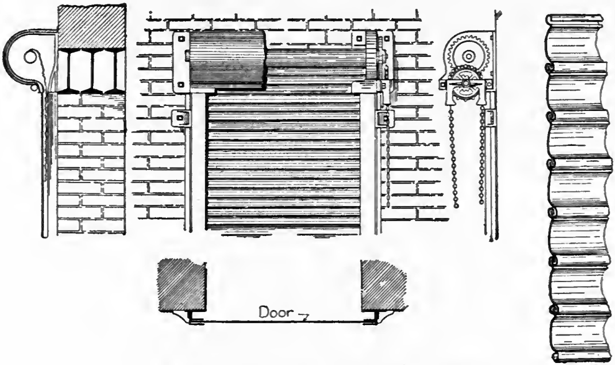


Fig. 92. Detail of Rolling Door of Corrugated Steel.
Courtesy of Kinnear Mfg. Co., Columbus, Ohio.

Fig. 93. Cross-Sections of Columns.

In order to prevent eccentric stresses due to the reaction of the runway girder, an extra column to carry the crane girder is placed alongside the roof column (see Figs. 100 and 117, pp. 75 and 88). This is much used by A. F. Robinson, Bridge Engineer of the Atchison, Topeka & Santa Fé Railroad System, who claims it to be a very

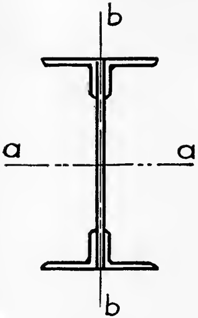


Fig. 94. Illustrating the Two Radii of Gyration.

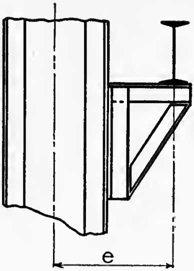


Fig. 95. Runway-Girder Eccentricity.

economical and efficient detail. One advantage of this is, that, if at any time it is desirable to use a heavier crane, this column can be removed and a stronger one put in its place, without in any way affecting the remainder of the building.

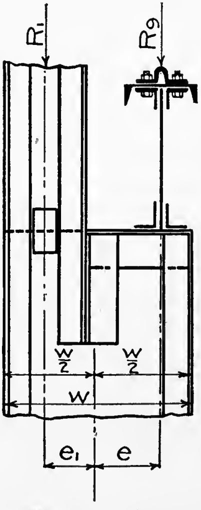


Fig. 96. Runway-Girder and Roof-Truss Eccentricity.

In order to illustrate the design of a column, let it be required to design a column with detail as shown in Fig. 95, the height being 20 feet, the distance of the runway girder from the face of the column 8 inches, the direct stress 15 600 pounds, and the bending moment due to the wind 924 000 pound-inches. The reaction of the runway girder is 20 000 pounds. The stress due to the bending moment caused by the wind and the eccentricity of the runway girder must be worked out by formula 8, "Strength of Materials," p. 86; and to this must be added the direct stress caused by the weight of the roof and the crane-girder reaction.

Since, according to Article 13, the unit-stress must be reduced one-half in determining the section to withstand stresses due to crane loads, the moment due to the crane loads and also its direct action must be

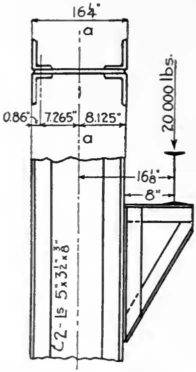


Fig. 97. Illustrating Problem on Page 73.

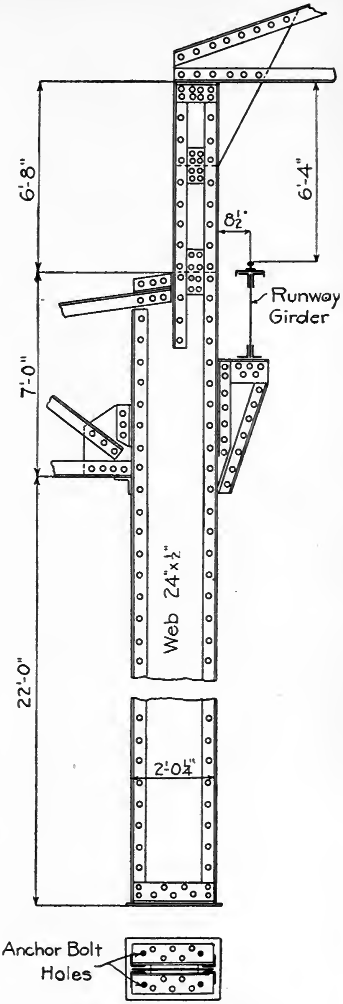


Fig. 98. Detail of Column.

multiplied by 2 in order that the same formula for the unit-stress may be used throughout in the design of the column.

Let four 5 by 3½ by ⅜-inch angles with a 16 by ⅜-inch web plate be assumed, and placed as shown in Fig. 97. These angles have an area of 3.05 square inches each; and a moment of inertia parallel to the long leg, of 3 18. Then (see "Strength of Materials," pp. 48–53), the moment due to crane reaction is 20 000 × (8.125 + 8) = 322 500 pound-inches. Accordingly, in using this in the formula, it will be 2 × 322 500 = 645 000 pound-inches; and this, added to the 924 000 pound-inches due to the wind, will make a total bending moment of 1,569,000 pound-inches.

$$I_{a-a} = 4 \times 3.18 + 4 \times 3.05 \times 7.265^2 + \frac{\frac{3}{8} \times 16^3}{12} = 784.72,$$

$$r_{a-a} = \sqrt{\frac{784.72}{4 \times 3.05 + \frac{3}{8} \times 16}} = 6.56$$

The allowable unit-stress is:

$$P = 24\,000 - 110 \times \frac{20 \times 12}{6.56} = 19\,975 \text{ pounds per square inch.}$$

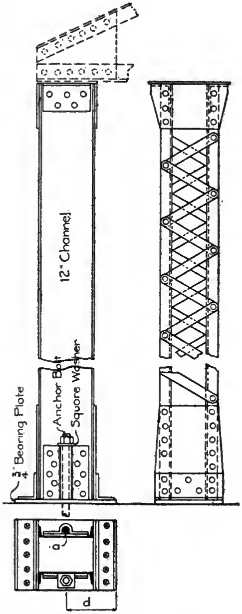


Fig. 99. Detail of Column.

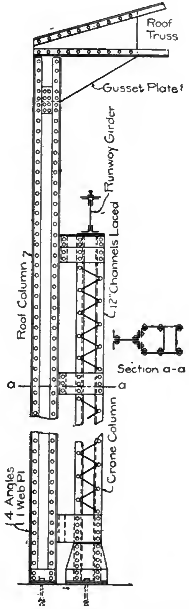


Fig. 100. Detail of Column.

The actual unit-stress (see "Strength of Materials," p. 86), is:

$$S = \frac{15\,600 + 2 \times 20\,000}{4 \times 3.05 + \frac{3}{8} \times 16} + \frac{1\,569\,000 \times \frac{16.25}{2}}{784.72 - \frac{(15\,600 + 2 \times 20\,000)\,(20 \times 12)^2}{10 \times 28\,000\,000}}$$

$$= 3\,024 + 16\,420$$

$$= 19\,444 \text{ pounds per square inch.}$$

Since this is slightly less than the allowable stress, 19 975 pounds per square inch, this section is the correct one.

Details of columns are shown in Figs. 98, 99, and 100. In case the column is considered fixed at its base, the base of the column is usually made as shown in Fig. 99. Long bolts deeply imbedded in the masonry are run up through the holes *a*; a heavy washer is placed over the bolt, and the nut screwed down tightly. Each bolt must be designed to withstand a stress of $H_2 \times n \div 2d$ (see Figs. 43 and 99).

24. **Knee-Braces.** The determination of the stresses in knee-bracing has been made in Article 9. Knee-braces consist of two angles placed back to back, and are joined to the column and roof truss as shown in Fig. 101 and in the figures showing cranes. They must be designed to withstand the greatest compressive stress; and must also be examined to see if they are safe in tension, since they are under either tensile or compressive stresses according to the direction in which the wind blows.

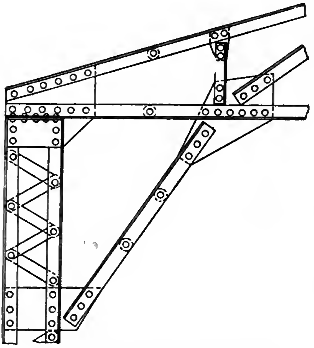


Fig. 101. Detail of Knee-Brace and Connections.

The knee-brace for the truss-bent of Article 9 will now be designed. The maximum compressive stress is 21 440 pounds. The radius of gyration must be at least $131 \div 120 = 1.09$. Two angles $3\frac{1}{2}$ by 3 by $\frac{5}{16}$-inch, placed back to back with their longer legs $\frac{1}{4}$ inch apart, will be assumed, since they are the smallest size to be used with $r = 1.09$ or greater. The radius of gyration about an axis perpendicular to the longer legs is 1.10; and the allowable unit-stress is $P = 24\,000 - \frac{110 \times 131}{110} = 10\,900$ pounds per square inch, the length being 131 inches. The required area is $\frac{21\,440}{10\,900} = 1.97$ square inches. Since this is less than the given area, and since the angles are the smallest allowed, these angles are sufficient. The maximum tensile stress is 8 640 pounds, and the required net area is $8\,640 \div 15\,000 = 0.58$ square inch. The net area given by the angles is 3.86 − 0.55 = 3.31 square inches, two ¾-inch rivet-holes being taken out. This shows the angles to be amply safe in tension, and they will therefore be used for the section of the knee-braces.

25. **Runway Girders.** The runway girders extend from column to column on each side of the bay in which the girder runs. An inspection of the figures of this article will give a clear idea of their position and their details. Along these girders run the wheels which support the end of the crane. The crane may be a small hoist, as indicated in Figs. 102, 103, and 104, in which case the crane girder consists of a simple I-beam supported by two wheels at the ends, and these are placed close together. In other cases the crane consists of

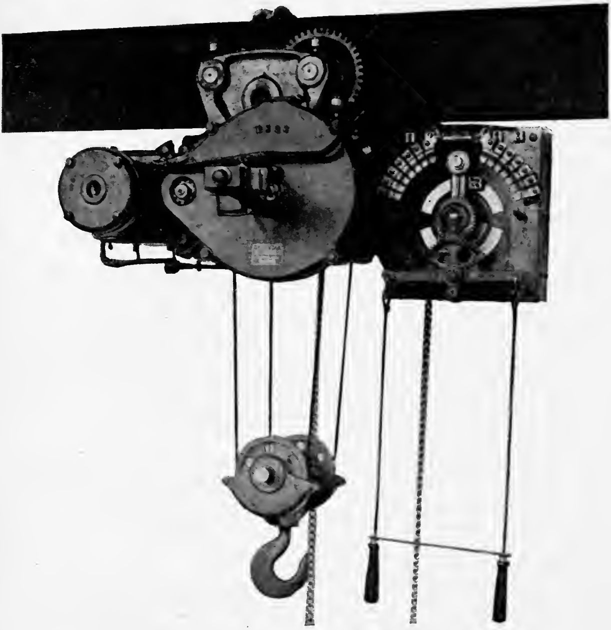


Fig. 102. Electric I-Beam Hoist, One-Motor.
Courtesy of Case Manufacturing Company, Columbus, Ohio.

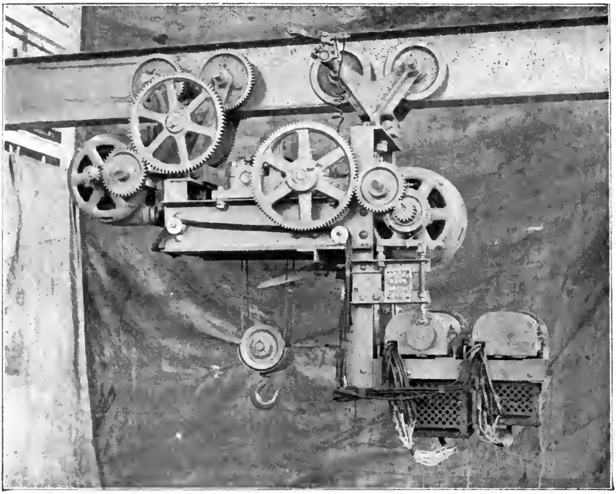


Fig. 103. Electric I-Beam Hoist.
Courtesy of Maris Brothers, Philadelphia, Pennsylvania.

two girders placed side by side, upon which runs the carriage carrying the hoist. This type of crane is supported upon four to eight wheels (see Figs. 105, 106, 107, 108, 109, and 110).

The maximum bending moment and shear in a runway girder

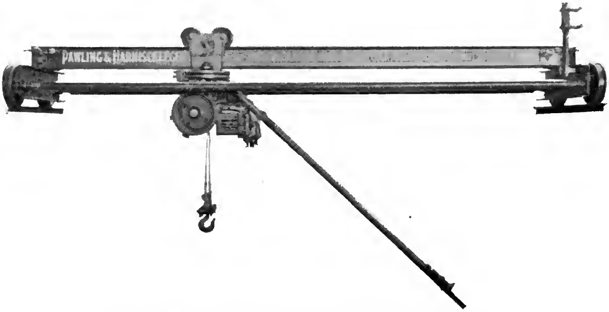


Fig. 104. Small Electric I-Beam Hoist; Capacity 500 Lbs.
Courtesy of Pawling & Harnischfeger, Milwaukee, Wis.

Fig. 105. Ten-Ton Three-Motor Electric Traveling Crane.
Courtesy of Case Manufacturing Company, Columbus, Ohio.

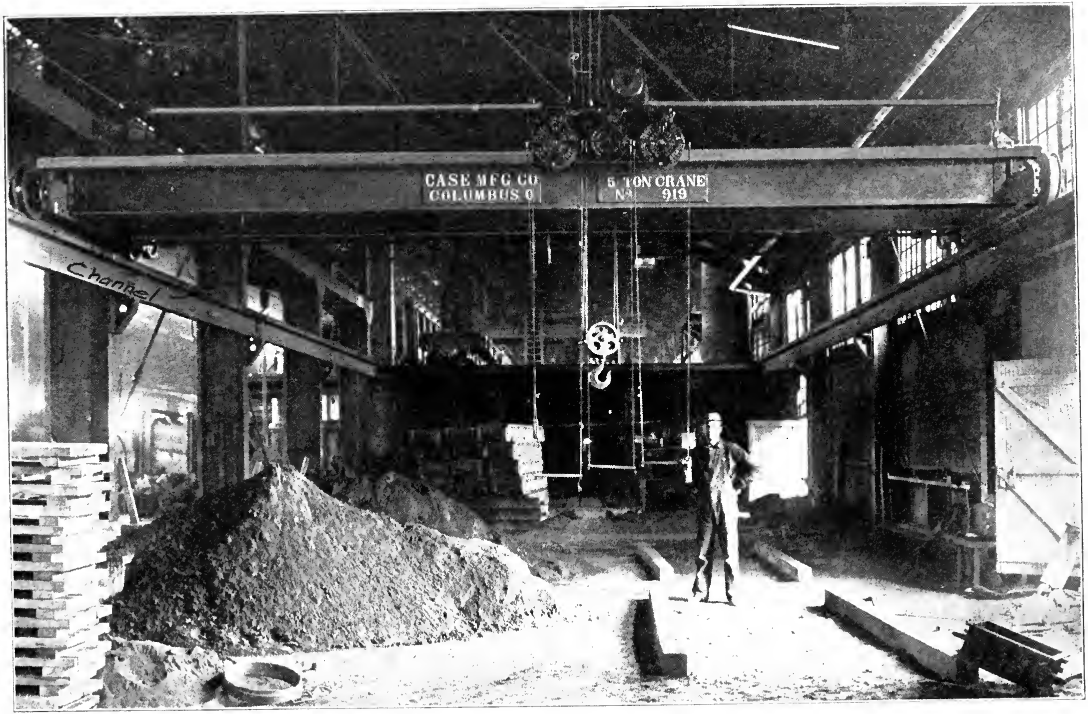


Fig. 106. Five-Ton Three-Motor Electric Traveling Crane. Operated from Floor.
Courtesy of Case Manufacturing Company, Columbus, Ohio.

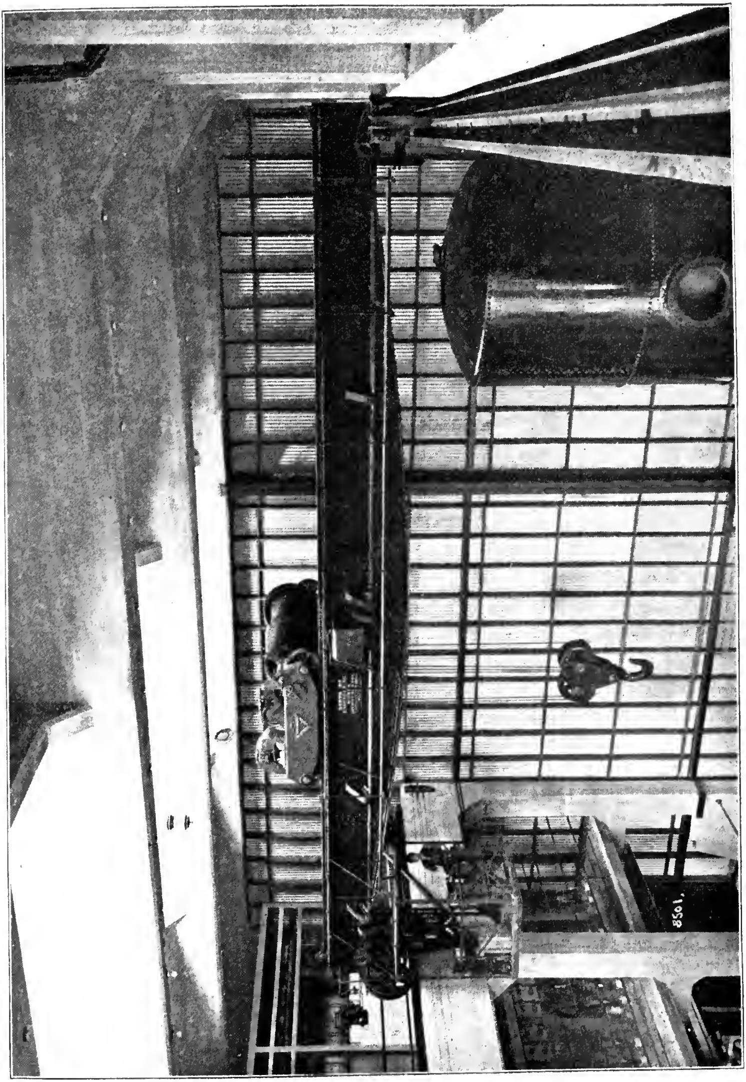


Fig. 107. Fifty-Ton Three-Motor Electric Traveling Crane.
Courtesy of Northern Engineering Works, Detroit, Mich.

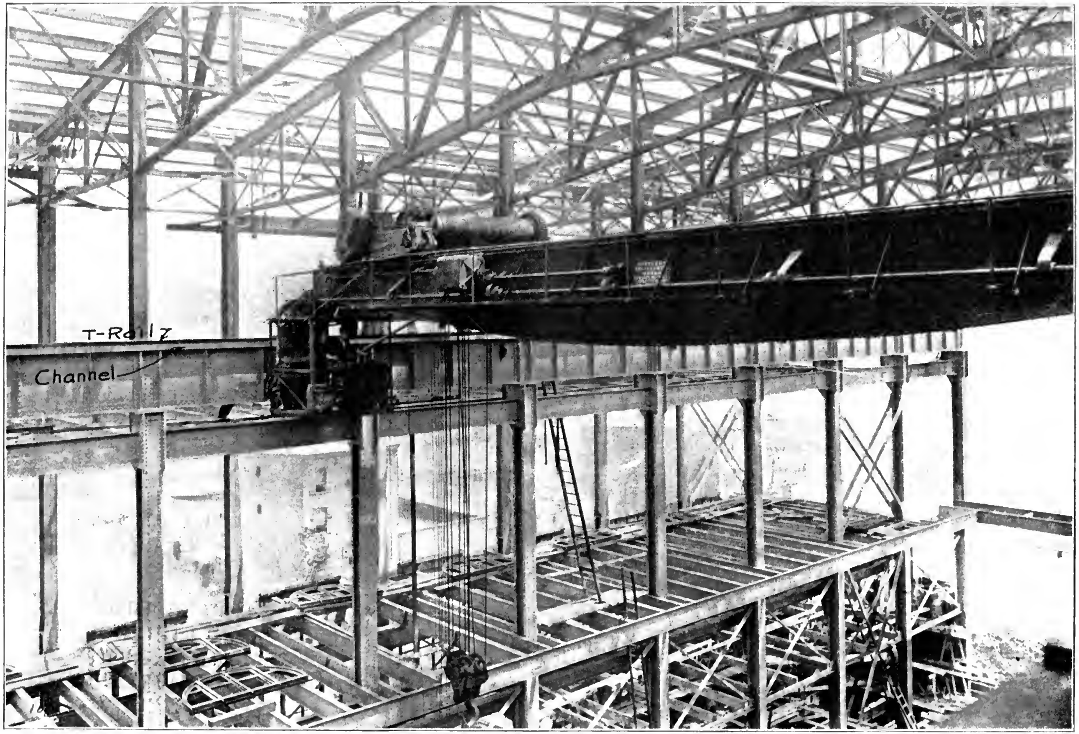


Fig. 108. Fifty-Ton Four-Motor Electric Traveling Crane.
Courtesy of Northern Engineering Works, Detroit, Mich.

will depend upon the capacity and span of the crane, and also upon the distance apart of the wheels at its ends. Where the bending moment is not too great, the runway girders may be composed of channels or I-beams (see Figs. 103, 104, and 106). In case the moment is too great to make the use of these possible, the runway girders are composed of plate-girders (see Figs. 105, 107 to 110).

Fig. 109. Wall Jib-Crane, Electrically Operated; Capacity, 10,000 Lbs.
Courtesy of Pawling & Harnischfeger, Milwaukee, Wisconsin.

Plate-girders consist of a flat plate called a *web plate*, which has riveted to it at its upper and lower edges two angles, or two angles and one plate, called the *cover-plate.* The angles are called *flange angles*; and the two angles together, and the cover-plate when used, are called the *flanges.* At certain distances along its length, equal to or less than its depth, vertical angles are riveted on opposite sides of the web plate. These are called *stiffeners,* their function being to stiffen the web under the action of the shear. See Fig. 111 for a general view of a plate-girder, together with the names of the various parts.

Fig. 110. Thirty-Ton Four-Motor Electric Traveling Crane in Power Station.

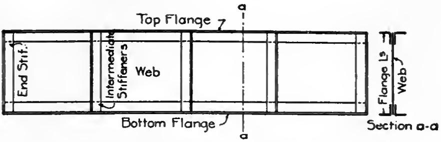


Fig. 111. Plate-Girder Notation.

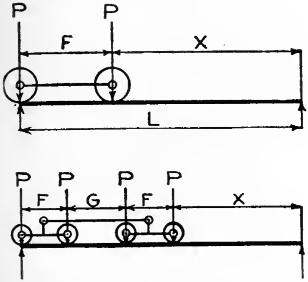


Fig. 112. Position of Crane Truck for Maximum End Shear of Runway Girder.

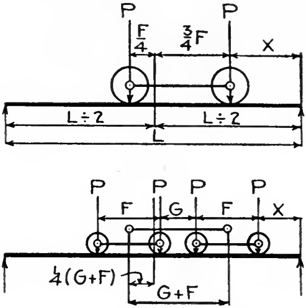


Fig. 113. Position of Crane Truck for Maximum Moment in Runway Girder.

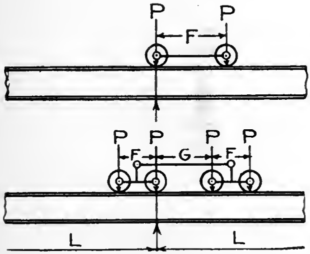


Fig. 114. Position of Crane Truck for Maximum Reaction on Column.

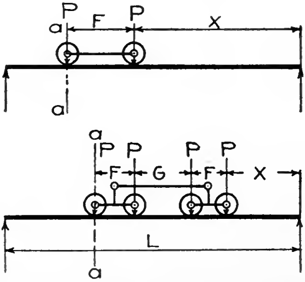
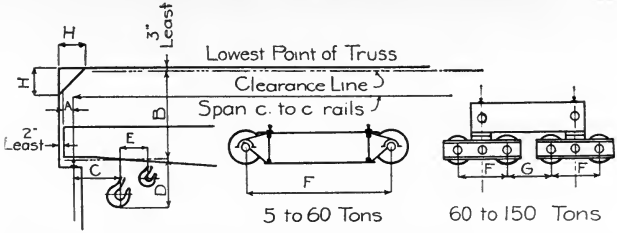


Fig. 115. Position of Crane Truck for Maximum Shear at any Section.

The maximum shear in the runway girder will occur when the crane wheels are in the position shown in Fig. 112; and the maximum moment will occur under the wheel nearest the middle of the span, when the wheels are in the position shown in Fig. 113. The maximum reaction of the runway girders on the column will occur when the wheels are in the position shown in Fig. 114. In order to

TABLE XIV

Maximum Crane Reaction



	Capacity (tons)	Span (feet)	A	B	C	D	E	F	G	Wheel Load (in lbs.)	Tram Rail Am. Std.	H
			in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.			ft. in.
SINGLE DRUM. TYPE C	5	40	7	4– 5½	1– 8 2– 0	7		7– 6½		10 000	3½–1⅞– 40	1– 5
		60	8	4– 7½	1–11 2– 1	5		9– 0		12 500		
		80	8	4– 8½	1–11 2– 2	4		9– 3½		15 500		
	10	40	8	5– 0½	1– 0 2– 4	9		8– 5½		16 500	3½–1⅞– 40	1– 0
		60	8	4–11¼	1–11½ 2– 4	10		9– 7¼		19 500		
		80	8	5– 0½	1–11½ 2– 4½	9		9– 9½		23 000		
	15	40	8	5– 4¼	2– 0 2– 9	1–3½	2– 0	9– 6		24 500	3⅞–2⅛– 50	1– 3
		60	8	5– 4¼	2– 0 2– 9	1–3½	2– 0	10– 7½		28 000		
		80	8	5– 5½	2– 0 2– 9	1–2¼	2– 0	10– 9½		31 500		
	20	40	8	5– 5½	2– 0 2– 9	1–6¼	2– 0	9– 6		30 000	3⅞–2⅛– 50	1– 3
		60	8	5– 5½	2– 0 2– 9	1–6¼	2– 0	10– 7½		34 000		
		80	9	5– 6½	2– 0⅛ 2– 9	1–5¼	2– 0	11– 1½		38 000		
DOUBLE DRUM. TYPE A	25	40	9	6– 0¼	2– 6	3–9¼	2– 7½	11– 0½		38 600	4¼–2⅜– 6^{0}	1– 3
		60	9	6– 0¼	2– 6	3–9¼	2– 7½	11– 3½		42 400		
		80	10	6– 2¼	2– 6	3–7¼	2– 7½	11– 8½		47 000		
	30	40	10	6– 3¾	2– 7	3–8½	2–10	11– 4½		45 600	4¼–2⅜– 60	1– 3
		60	10	6– 3¾	2– 7	3–8½	2–10	11– 6½		49 600		
		80	10	6– 3¾	2– 7	3–8½	2–10	12– 0		54 600		
	40	40	11	7– 4½	3– 1½	4–2½	3– 8½	12– 8		59 600	5 –2½– 80	1– 6
		60	11	7– 4½	3– 1½	4–2½	3– 8½	13– 0		64 000		
		80	11	7– 4½	3– 1½	4–2½	3– 8½	13– 5		70 000		
	50	40	13	7–11½	3– 6	4–0½	3– 9	13–10½		77 000	5¾–2¾–100	1– 6
		60	13	7–11½	3– 6	4–0½	3– 9	13–10½		84 600		
		80	13	7–11½	3– 6	4–0½	3– 9	14– 0		92 000		
	60	40	14	8– 7¼	4– 1	4–3¾	4– 4½	15– 2		88 000	5¾–2¾–100	1–11
		60	14	8– 7¼	4– 1	4–3¾	4– 4½	15– 2		94 000		
		80	14	8– 7¼	4– 1	4–3¾	4– 4½	15– 4		103 000		
	60	40	12½	10– 3¼	4– 0	2–7¾	4– 4½	3– 6	5–4	44 000	5¾–2¾–100	
		60	12½	10– 3¼	4– 0	2–7¾	4– 4½	3– 6	5–4	47 000	6 –4 –150	
		80	12½	10– 3¼	4– 0	2–7¾	4– 4½	3– 6	5–4	51 500		
	75	40	12½	11– 3	4– 6	3–8½	4– 0½	5– 0	6–0	55 000	5¾–2¾–100	2– 2
		60	12½	11– 3	4– 6	3–8½	4– 0½	5– 0	6–0	60 000	6 –4 –150	
		80	12½	11– 3	4– 6	3–8½	4– 0½	5– 0	6–0	64 000		
	00	40	16½	13– 2¼	4– 1	2–0	SPECIAL	5– 0	6–0	83 000	6 –4 –150	4– 7
		60	16½	13– 2¼	4– 1	2–0	"	5– 0	6–0	86 000		
		80	16½	13– 2¼	4– 1	2–0	"	5– 0	6–0	89 000		
	150	40	17	15– 6⅛	6– 0	3–2	"	6– 0	6–0	130 000	6 –4 –150	4– 7
		60	17	15– 6⅛	6– 0	3–2	"	6– 0	6–0	134 000		
		80	17	15– 6⅛	6– 0	3–2	"	6– 0	6–0	139 000		

TABLE XV
Typical Electric Cranes

CAPACITY (Tons)	SPAN (Ft.)	WHEEL BASE F	WHEEL LOAD P	$A+2$ in.	B	WEIGHT of RUNWAY RAIL For Plate-Girders	WEIGHT of RUNWAY RAIL I-Beams
5	40	8 ft. 6 in.	12 000	10 in.	7 ft.	40 lbs. per yd.	40 lbs.
	60	9 " 0 "	13 000	10 "	7 "	40 "	40 "
10	40	9 " 0 "	19 000	10 "	7 "	45 "	40 "
	60	9 " 6 "	21 000	10 "	7 "	45 "	40 "
15	40	9 " 6 "	26 000	10 "	7 "	50 "	50 "
	60	10 " 0 "	29 000	10 "	7 "	50 "	50 "
20	40	10 " 0 "	33 000	12 "	8 "	55 "	50 "
	60	10 " 6 "	36 000	12 "	8 "	55 "	50 "
25	40	10 " 0 "	40 000	12 "	8 "	60 "	50 "
	60	10 " 6 "	44 000	12 "	8 "	60 "	50 "
30	40	10 " 6 "	48 000	12 "	8 "	70 "	60 "
	60	11 " 0 "	52 000	12 "	8 "	70 "	60 "
40	40	11 " 0 "	64 000	14 "	9 "	80 "	60 "
	60	12 " 0 "	70 000	14 "	9 "	80 "	60 "
50	40	11 " 0 "	72 000	14 "	9 "	100 "	60 "
	60	12 " 0 "	80 000	14 "	9 "	100 "	60 "

obtain the maximum shear at any section, as *a–a*, the load should be placed as shown in Fig. 115; and the maximum shear will then be the left reaction, which is $R = 2P\ (x + \frac{F}{2}) \div l$, for two wheels; and $R = 4\,P\ (x + F + \frac{G}{2}) \div l$, for four wheels.

The values of P for traveling cranes of various capacities and spans may be obtained upon writing to the various crane manufacturing companies, whose addresses will be found in the advertising sections of the engineering periodicals. The distances between wheels may be obtained from their catalogues, which may be had upon application. The values of P, and the distances between wheels for cranes of various spans and capacities, are given in Table XIV, which is made from information furnished through the courtesy of Pawling & Harnischfeger, Milwaukee, Wisconsin.

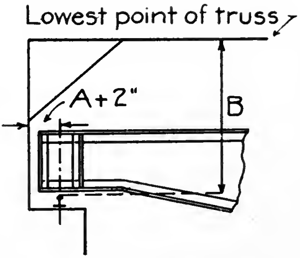


Fig. 116. Showing Notation used in Table XV.

The values in Table XV are taken from the "Transactions" of

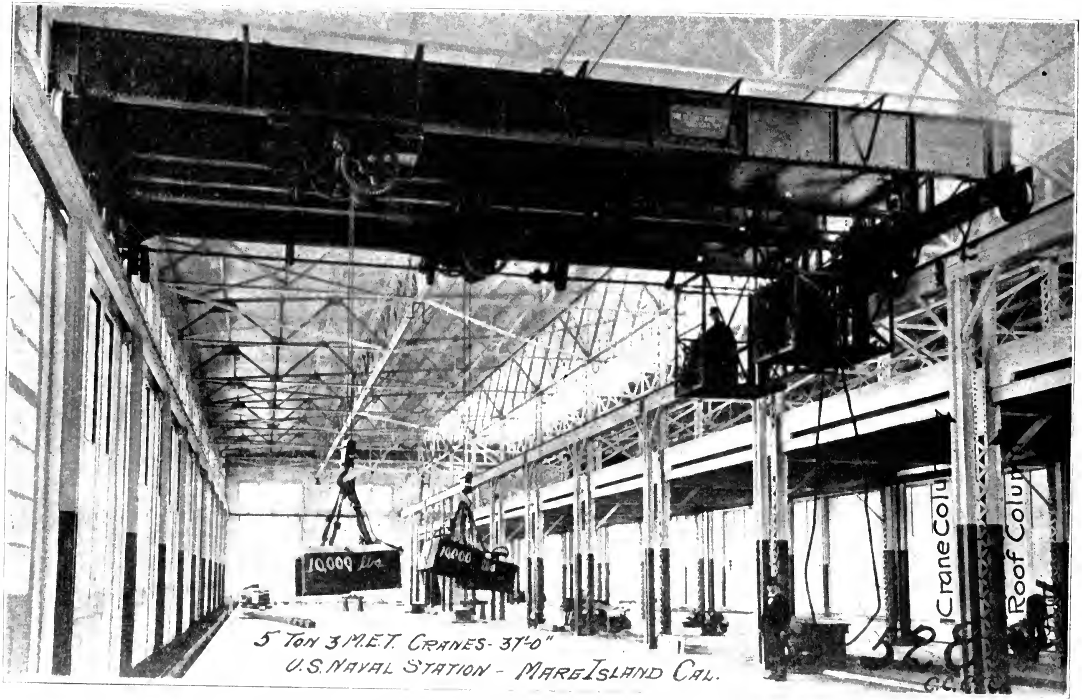


Fig. 117. Five-Ton Electric Traveling Cranes Installed at U. S. Naval Station, Mare Island, California.
Courtesy of Cleveland Crane & Car Company, Cleveland, Ohio.

the American Society of Civil Engineers, Vol. 54, p. 400, 1905. They are for typical traveling electric cranes, and are proposed by Mr. C. C. Schneider, one of the most distinguished of structural engineers.

The side clearance B from the center of the rail, and the vertical clearance of the beam from the top of the rail, are given in this table (see Fig. 116). These values for the cranes of different manufacturers may be obtained from their catalogues; and they must be known, in order that the crane shall not interfere with the columns or the roof trusses.

If the runway girder is composed of an I-beam, a channel is usually riveted to its top; and on this the rail on which the crane wheels move is fastened down at intervals (see Fig. 107) of about $2\frac{1}{2}$ or 3 feet. Figs. 106 and 117 show details of this kind of girder. Note that the rails are U-shaped (see Fig. 105). This rail is used extensively, although in many cases the common T-rail is used and is fastened down by means of clamps around the edge of the flange of the girder (see Fig. 110).

In case plate-girders are necessary for runway girders, they must be designed. The depth of these girders should be $\frac{1}{10}$ to $\frac{1}{6}$ of the distance between trusses or columns—that is, $\frac{1}{10}$ of their span; The depths must be in the even inch. For example, if the trusses were 16 feet apart, the depth of the girder would be $16 \div 10 = 1.6$ feet, which is equal to 19.2 inches. The depth of the girder must then be made 20 inches, since, if it were made 19 inches, it would be difficult to obtain a web plate 19 inches wide, for the mills do not as a rule have plates of odd-inch widths in stock.

The thickness of the web plate is given by the formula:

$$t = \frac{V_0}{S_s\, d};$$

but in no case shall it be less than $\frac{5}{16}$ inch. In this formula, V_0 is the maximum end reaction of the runway girder. It is equal to R as given by the formula on p. 87, when x is equal to $l - F$, and d is the depth of the girder, which is equal to the depth of the web plate, and S_s is the unit allowable shearing stress.

The flanges are composed of two angles, placed with the long legs horizontal in case unequal-legged angles are used. The required net area of *one flange* is given by the formula:

$$A = \frac{M_m}{S, (d-2)},$$

in which M_m is the moment obtained when the wheels are in the position shown in Fig. 113, S_t is the unit allowable tensile stress, and d is the width of the web plate. If the area A has been computed, two angles must be found from the tables in the Carnegie Handbook, such that when one $\frac{7}{8}$-inch or $\frac{3}{4}$-inch rivet-hole, as the case may be, is taken out, each angle will give a net area equal to or slightly in excess of the area A.

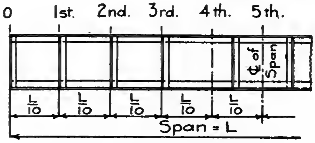


Fig. 118. Position of Tenth-Points.

These flange angles must be riveted to the web by rivets placed a certain distance apart. For convenience of manufacture, the girder is divided into ten equal parts, and the rivet spacing between any two of these divisions—or *tenth-points,* as they are called—is kept the same. These tenth-points are numbered (see Fig. 118). The rivet spacing in the first division is the same as that computed for the end of the girder, which is the zero tenth-point; the rivet spacing in the second division is the same as that computed for the 1st tenth-point; and so on. The rivet spacing at any point is given by the formula:

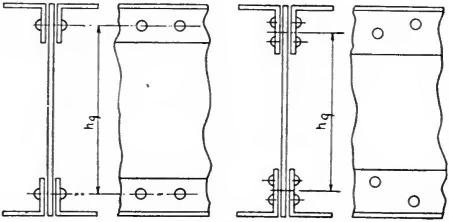


Fig. 119. Determination of Distance between Gauge Lines.

$$S = \frac{v}{\sqrt{\left(\frac{V_x}{h_g}\right)^2 + \left(\frac{P}{30}\right)^2}},$$

in which,

V_x = Maximum shear at the point;
v = Maximum allowable stress on one rivet; this will be the bearing value of the rivet in the web plate (see Table X, p. 47);
P = Maximum reaction of one crane wheel (see Table XIV or XV);
h_g = Distance between gauge lines of the angles.

In case there are two gauge lines on the angle, then the distance h_g is the distance between centers of these gauge lines (see Fig. 119).

Table IX, p. 46, gives the gauge lines for different lengths of angle legs. If S gives a value less than $2\frac{5}{8}$ inches, the leg of the angle against the web must be 5 inches or more, on account of practical limitations of manufacture.

26. *Examples.* In order to illustrate the preceding methods, two problems will be worked out.

1. Design a runway girder for a 5-ton crane of 40-foot span, the wheel loads and wheel base being as given in Table XV, p. 87, and the distance between trusses 20 feet.

In order to produce the maximum moment, the wheel must be placed as shown in Fig. 120. The left reaction is $12\,000\,(2.125 + 10.00 + 3.625) \div 20 = 9\,450$. The moment under wheel 1 is $9\,450 \times 7.875 \times 12 = 894\,000$ pound-inches, which requires a section modulus of $894\,000 \div 15\,000 = 59.60$. Looking in the Carnegie Handbook, pp. 97 and 98, it is seen that a 15-inch 42-pound I-beam with a section modulus of 58.9 will be sufficient, since the section modulus is less than $2\frac{1}{2}$ per cent under that required.

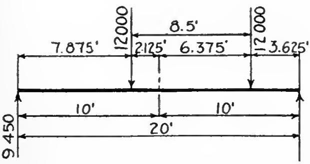


Fig. 120. Position for Maximum Moment for Problem 1 on Page 91.

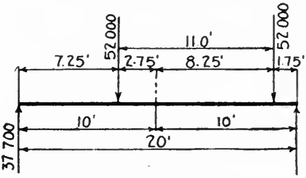


Fig. 121. Position for Maximum Moment for Problem 2 on Page 91.

2. Design a runway girder for a 30-ton crane of 60-foot span, the wheel loads and wheel base being as given in Table XV, and the distance between trusses 20 feet.

The wheels are placed in position as shown in Fig. 121. The left reaction is $\frac{52\,000\,(12.75 + 1.75)}{20} = 37\,700$ pounds; and the maximum moment, which occurs under wheel 1, is $37\,700 \times 7.25 \times 12 = 3\,285\,000$ pound-inches. The maximum shear occurs when the wheels are in position as shown in Fig. 112, p. 85, and is 75 400 pounds. The required thickness of the web is $\frac{75\,400}{10\,000 \times 24} = 0.314$ inch, the depth being $20 \div 10 = 2$ feet $= 24$ inches. The web will be made 24 inches wide and $\frac{3}{8}$ inch thick.

The required net flange area is $\frac{3\,285\,000}{15\,000 \times (24 - 2)} = 9.97$ square inches for two angles, or 4.99 square inches for one angle. An angle 6 by 6 by ½-inch gives a gross area of 5.75 square inches and a net area of $5.75 - 0.50 = 5.25$ square inches, one ⅞-inch rivet-hole being taken out of the section. Since this area coincides quite closely with the required area and is larger, it will be used. A 6 by 3½ by ⅜-inch angle would have been better in regard to area, but the rivet spacing is less than 2⅝ inches at the end, and this required a double gauge line and therefore a leg 5 inches or over.

The maximum shears at the tenth-points are now computed, and are tabulated as follows:

$V_0 = 75\,400$ pounds.
$V_1 = 65\,000$ "
$V_2 = 54\,600$ "
$V_3 = 44\,200$ "
$V_4 = 33\,800$ "
$V_5 = 26\,000$ "

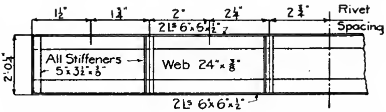


Fig. 122. Stress Sheet of Runway Girder of Problem 2 on Page 91.

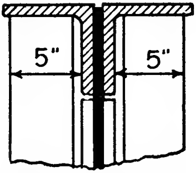


Fig. 123. Determination of Size of Stiffener.

The value of the shear to be used in any particular case is given above. In this case, $P = 52\,000$ pounds; $v = 6\,570$ pounds, ⅞-inch rivets being used; and h_g is $24\frac{1}{4} - 2\left(2\frac{1}{4} + \frac{2\frac{1}{2}}{2}\right) = 17.5$ inches. The rivet spacing for the first division or first two feet of the span is:

$$S = \frac{6\,570}{\sqrt{\left(\frac{75\,400}{17.5}\right)^2 + \left(\frac{52\,000}{30}\right)^2}} = 1.414, \text{ say } 1\tfrac{1}{2} \text{ inches.}$$

The rivet spacing for the other divisions may be computed by the student. It is given in Fig. 122. The web of the girder should be stiffened as shown in the figure, by angles placed as there indicated The thickness of the angles should not be less than $\frac{5}{16}$ inch, nor greater than ½ inch. The size of the angles should be such that the

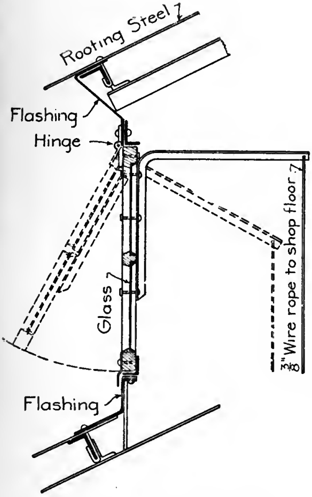


Fig. 124. Section of Glass Louvres in Monitor.

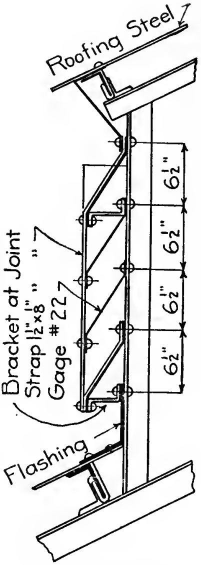


Fig. 125. Section of Metal Louvres in Monitor.

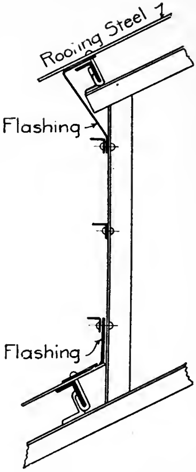


Fig. 126. Section of Open Monitor.

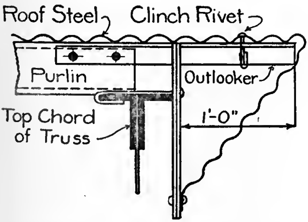


Fig. 127. Gable Details for Corrugated Steel.

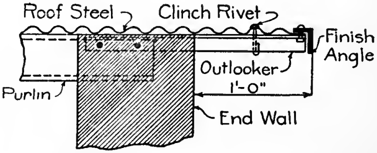


Fig. 128. Gable Details for Corrugated Steel.

outstanding leg does not reach beyond the leg of the flange angle (see Fig. 123). This makes their size as shown in Fig. 122. The crane rail may be connected directly to these and the flange angles; or a channel may be placed over the flange angles and riveted to them in a manner similar to that employed in the case of I-beams, the crane rail being fastened to that. If this latter detail is employed, the area of the channel is reckoned as forming part of the upper flange; and the net area of the angle must then be equal to the required net area, less the net area of the channel.

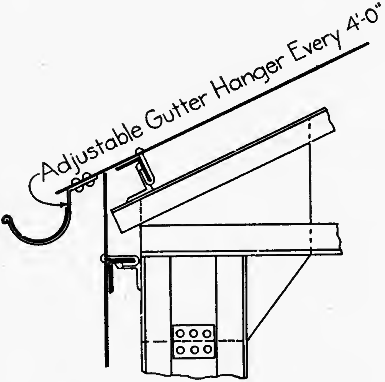


Fig. 129. Cornice Details for Steel Roof. See also Figs. 130 and 131.

27. **Ventilators.** Mill buildings may be ventilated by means of small circular ventilators such as shown in Fig. 69, p. 41, placed at certain intervals along the ridge or peak of the roof, or by means of monitors as shown in Fig. 71. The sides of these monitors may be fitted with swinging glass windows, with wooden or metal louvres, or, in case a large amount of ventilation is required, may be simply left open. Figs. 124, 125, and 126 give details of monitors, and show how they are connected to the trusses.

28. **Gable Details.** The gable is the end of the roof at that end of the building which is parallel to the roof trusses. Since this extends beyond the plane of the side cf the building, some method must be employed in connecting the outer edge with the wall of the building, in order to keep out the rain and wind. Figs. 127 and 128 give several details which are efficient and at the same time economical.

29. **Cornice Details.** The cornice is that edge of the roof which is perpendicular to the planes of the roof trusses. In addition to being necessarily so constructed as to keep out the wind and the elements, it must have in many cases some form of gutter connected to it, which takes the water off the roof. This gutter should be con-

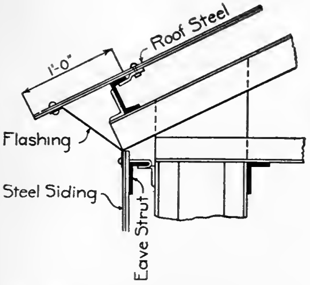


Fig. 130. Cornice Details for Steel Roof. See also Figs. 129 and 131.

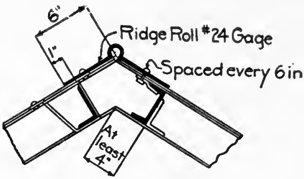


Fig. 133. Ridge Roll.

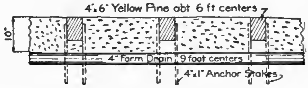


Fig. 134. Detail of Cinder Floor.

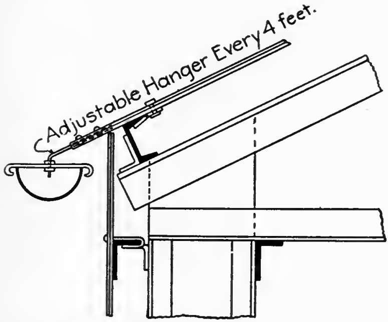


Fig. 131. Cornice Details for Steel Roof. See also Figs. 129 and 130.

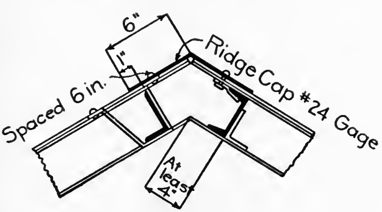


Fig. 132. Ridge Cap.

nected at intervals of every three bays—or, in case this exceeds 50 feet, every two bays—with a pipe or conductor to carry the water to the ground. Gutters, as a general thing, are semicircular or nearly so; and for ordinary spans they should not be less than 6 inches wide. Conductors should not be less than 5 inches in diameter. It is not to be supposed that the water entirely fills either the conductors or the gutters. The sizes are made so as to allow for any obstruction such as dirt or ice. Gutters should preferably have a pitch of one inch in every 10 feet. Figs. 129 to 131 give details of cornices with various forms of gutters attached.

The ridge, or peak of the roof, is usually covered with a plain sheet of metal, in which case it is called the *ridge cap*; or with a metallic roll with flared sides, in which case it is called a *ridge roll.* Figs. 132 and 133 show cross-sections of a ridge cap and a ridge roll.

30. **Floors.** The floor of the shop depends very largely upon the purpose for which the building is intended. It may consist of earth, cinders, boards, concrete, or sheet steel. In cases where men are required to work standing, cinders or boards give the best results. Earth floors will wear into holes in places where the men stand, and concrete or steel makes them foot-weary on account of its inelasticity. Where heavy machinery is installed, and men are seldom present except for a short time at certain periods, concrete makes an ideal floor. Figs. 134, 135, and 136 show details of various kinds of floors. Fig. 137 gives a detail of the floor in the Steam Engineering Laboratory of the University of Illinois. This consists of channels imbedded in concrete. These channels, which are placed in pairs a small distance apart, run both lengthwise and crosswise of the shop. The advantage of this form of construction is that machinery can be placed anywhere on the shop floor and quickly bolted into place by means of T-bolts, a detail of which is shown in the figure.

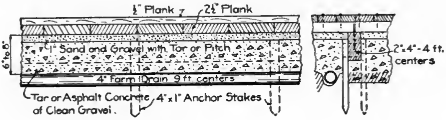


Fig. 135. Detail of Asphalt or Coal-Tar Concrete Floor.

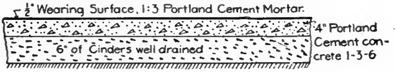
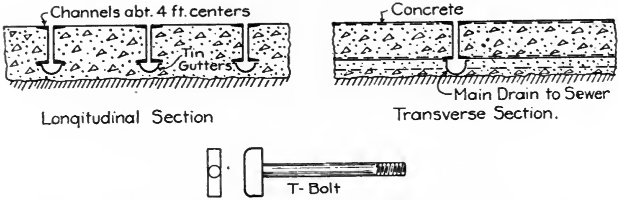


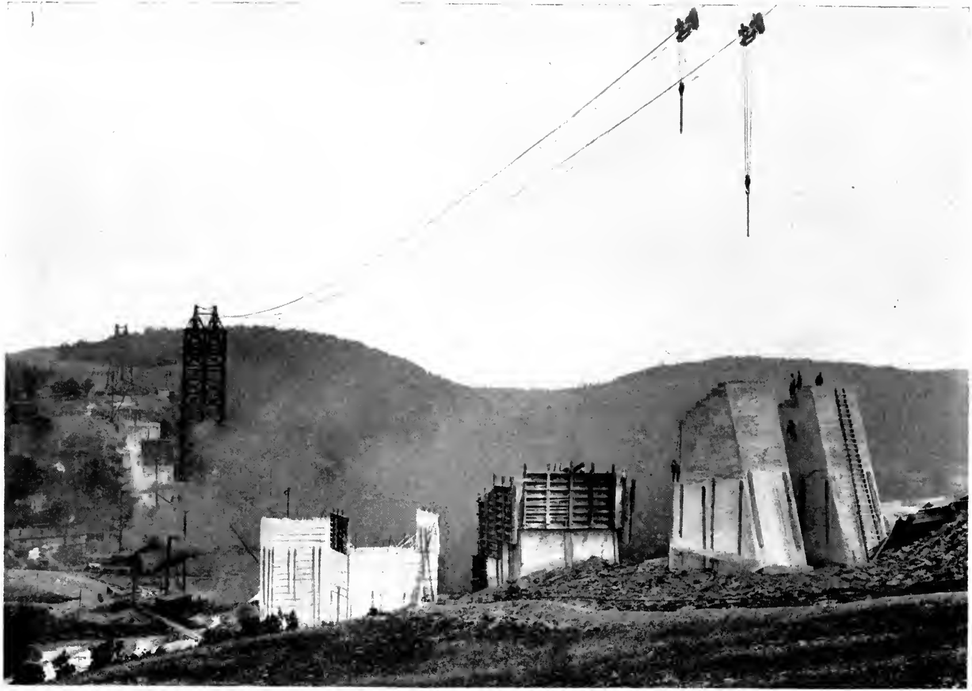
Fig. 136. Detail of Concrete Floor.



Longitudinal Section

Transverse Section.

Fig. 137. Detail of Floor of Steam Laboratory of the University of Illinois.



CONSTRUCTING REINFORCED CONCRETE PIERS FOR THE TUNKHANNOCK CREEK VIADUCT ON THE DELAWARE, LACKAWANNA, AND WESTERN RAILROAD

Note the immense towers and aerial tramway for carrying material used in the construction work.

Courtesy of Engineering Department, Delaware, Lackawanna, and Western Railroad

CIVIL ENGINEERING SPECIFICATIONS AND CONTRACTS

PART I

INTRODUCTION

In the preparation for letting a piece of work, the Engineer must, by drawing and written description or specification, set forth his ideas. He must also make estimates of the cost of the work under different methods of construction to determine the least expensive method of accomplishing the desired result and, if he wishes to let the work, he should make such public announcements as shall reach the greatest number of desirable contractors.

In order to insure an early execution of the construction, it is his duty to prepare the form of bid or proposal, with the instructions to bidders and, later, after attending to the opening of bids, he must adopt a form of articles of agreement and fix a bond, which, together with the specifications, drawings, and proposal, form the contract. These various steps will be treated in the following work, in the order of their importance in the contract from the Engineer's point of view.

GENERAL INSTRUCTIONS

Engineering. Engineering may be defined as the science or art of utilizing the forces and materials of Nature with the greatest amount of economy. It has been defined epigrammatically as ''the science or art of making a dollar go the farthest''. Engineering is divided into Civil Engineering, Mechanical Engineering, Electrical Engineering, Mining Engineering, Hydraulic Engineering, Gas Engineering, Chemical Engineering, Agricultural Engineering, etc. According to modern usage, *Civil Engineering* is confined strictly to fixed construction, such as railways, bridges, docks, tunnels, sewers, aqueducts, canals, lighthouses, dams, breakwaters, etc.

The Engineer. It is necessary that the two parties to a contract for the execution of any important construction work have some one in authority to decide all questions in dispute between them, and to see that the work is carried out in accordance with the requirements of the contract. This person is generally the Engineer who designs the work, although in some States, unless the Engineer's name is written in the articles of agreement, his decisions are not binding.

It is his duty to take a perfectly neutral position between the two parties, and to see that the work is carried out in strict accordance with the contract. He should work in harmony with the contractors, give all possible aid to accelerating the work, and take pains to secure work and material strictly up to the standard of requirements in the specifications. Although he is usually in the employ of the party for whom the work is being done, as the arbitrator his decisions must show perfect impartiality, so that both parties will admit their justice; but in order that there may be few questions at issue between the parties to the contract, the Engineer must be thoroughly familiar with the character of the work he is designing and the quality of the materials entering into it.

Contract. A contract is a written or verbal agreement between two or more parties specifying terms, conditions, etc., under which certain obligations are to be discharged. A contract for engineering work generally consists of the Advertisement, the Proposal (including the notice to bidders), the Drawings, the Specifications, the Articles of Agreement (generally spoken of as the contract), and the Bond, which is usually required to insure the carrying out of the contract.

It is the Engineer's duty to see that he obtains the greatest amount of the best work for the least expenditure of money. Experience has shown that to accomplish this end he should first determine the exact character of the structure which is to be built and, in addition to the drawings, which are generally necessary, he should prepare the following: (1) The form of Specification; (2) the Agreement; (3) the Proposal, or form of bid, including the notice to bidders; (4) the Advertisement. They are given above in the order of their importance to the Engineer and Contractor, and in that order they will be treated.

It is essential that all parts of the contract be prepared carefully in order to avoid misunderstanding. Many disputes are avoided by requiring contractors to make their bids on a regular form of proposal, furnished by the party for whom the work is to be done. In the case of small or unimportant work, the bond is often omitted. In some cases drawings are not necessary, and in many cases the work to be done is not advertised, as the work may not be of sufficient magnitude to warrant the expense, and as many corporations keep a list of the names of contractors who are regularly asked to bid on projected work. Of the above, the drawings and the specifications are the most important to the Engineer and the Contractor, as they are the guide for both in the execution of the work and are constantly in use during construction; hence, for convenience, the specifications and the drawings are often so prepared that they can be readily detached from the other components of the contract.

Drawings. Very few contracts for construction work are drawn without plans of some kind. They should be made accurately and on a scale large enough to show all details conveniently and clearly. All dimensions and distances should be written carefully upon the parts of the detail drawings to which they refer, and all dimensions should be checked by a second draftsman. The distance to be embraced by the figures should be indicated by dotted arrows. The drawings should be so accurate and so complete that there can be no question as to the intention of the designer even to the smallest detail. In preparing the specifications, the designer should keep a memorandum tablet on his table and jot down every thought that may be of service. The value of a drawing depends upon its accuracy.

The sheets should be uniform in size, carefully lettered or numbered for reference, and should be clearly and plainly titled. They should also show the scale, the date when completed, the initials of the draftsman, and the initials of the checking draftsman.

Maps should show a meridian and magnetic variation, if the latter be known.

The Government prohibits the letting of a contract without an accompanying plan; certain city ordinances and charters have the same prohibition. The requiring of plans to accompany the contract is to assure the competing Contractors that they are bidding on the same basis.

Contracts are frequently drawn for patented or special structures, without plans; in such cases, the Contractor furnishes a working drawing, subject to the approval of the Engineer, after the contract is executed. The specifications for such work are usually confined to a general description of the work required and a guarantee of results to be obtained by the Contractor, without setting forth the detail of construction or method. Sometimes plans are tendered by the bidders—thus allowing the Engineer to make comparison and choice of the different ideas submitted. This method of letting contracts is not recommended, but as the various branches of Engineering become more specialized and as most of the leading contracting firms have competent engineers who are specialists in their particular line of construction, it becomes necessary for the busy Engineer, with a general practice, to make use of the specialist in order to keep pace with modern construction methods.

Specifications. The specifications define the exact relations between the parties to the contract; they are supplementary to the drawings and should be embodied in the contract. They are a written description of the work to be performed and should show specifically whatever features are not shown on the drawings. They should define the quality and quantity of materials; the methods of construction; the nature of the workmanship; the manner of conducting the work; and the general conditions and stipulations.

The specifications must be most carefully drawn, leaving nothing to the imagination, as they are the guide to both Engineer and Contractor throughout the execution of the work. Great care must be taken that no important special and general clauses be omitted. They should set forth clearly and with great exactness what is to be done.

The Contractor is supposed to be experienced in the special class of construction to be undertaken, and should not be dictated to as to methods—except in very special cases—and he should be held strictly responsible for results. In some cases the Engineer may desire a specially manufactured article or material, or a special method to be used in accomplishing a certain result; in which case it is necessary to incorporate the specifically-mentioned article and the method of doing the work in the specification. If the specified article is inherently unsuitable for the purpose intended, or the method required does not accomplish the desired result, the Contractor must not be held for the results, as he is not free to act according to his own ideas and cannot be responsible for the mistakes of the Engineer. Either leave the methods and means entirely to the Contractor who is held responsible for results, or let the Engineer assume entire charge of methods and means and state that the Contractor will not be held responsible for results. To attempt to follow both courses at the same time is inequitable and will be so found if carried into the courts of law. In plain words, the specifications should point rather to the finished structure than to the method of accomplishing the work.

General and Specific Clauses or Provisions. Specifications are usually divided into general and special clauses or provisions. The general clauses are those that are applicable with slight variations to almost any important piece of construction work, while the special clauses refer to the character of the material, the details of construction, the special features and ideas to be incorporated, and no details should be spared that would add to the clearness of description in every step of the proposed work. All clauses should be numbered and properly headed, preferably by a marginal note, for convenience of reference. The general clauses should be segregated from those of a specific nature, thereby avoiding errors of omission.

General clauses or provisions describe the general relation of the parties involved, the time for beginning and completing the contract, payment for the work, the Contractor's liability, the special duties of the Contractor, inspection, change of plans, interpretation of plans, measurements, conduct of the work, maintenance of completed work, etc. It is advisable for the Engineer to have a list of the general conditions which are applicable to most contracts before him and, upon completion of the rough copy, to check over the clauses to see that all the conditions have been included. The writer has a list of over one hundred headings that he endeavors to embody in every specification drawn; although it is not necessary to have a special clause for each heading, he has found that this is the surest method to prevent omissions of necessary clauses.

Great care must be taken that clauses do not contradict each other; that they be not at variance with the plans; and that ambiguous description is not introduced.

Clearness of Statement. The wise and careful Contractor will note every detailed provision of a specification, and will bid accordingly, expecting to do no more than is required in the contract. Hence it is necessary that the Engineer set forth every detail fully, clearly, and concisely. Work should be so designed and described as to require no alteration in the course of construction.

The specification requiring the Contractor to ask the Engineer for an explanation of its meaning is not clearly drawn. The Engineer must not suppose that the Contractor will take anything for granted; he must draw his specification in such a manner as to cover the work, in general and in particular, in every detail.

It is of the greatest importance that there be no ambiguity and no omission of words. The clauses should be couched in the simplest language and the sentences should be short and to the point. Bad English, careless punctuation, and verbosity are to be carefully avoided. The incorrect placing of a comma has caused the loss of many thousands of dollars. Write so clearly that there will be no occasion to take the specification to court to decide what is the "spirit" of the contract; that is, what was intended by the writer of the contract and what the parties to it should understand by it. Repeat words or sentences, if it is found that the meaning is thereby made clearer.

Precision. While it is not always possible to prescribe exact quantities, the word "about" is to be avoided in specification writing. Be precise in all descriptions; ask for nothing that you do not know to be practicable, and be definite and specific in every detail. The units of measurement to be employed should always be clearly stated.

Knowledge Required of Engineer. The Engineer must have a thorough knowledge of every detail of the work before he attempts to describe what the Contractor is to accomplish under the specification; even when understood perfectly by the Engineer, it is often very difficult to describe exact requirements.

Avoidance of Unusual Conditions. Specifications should be so drawn that the best class of material and workmanship consistent with the amount of money to be expended on the undertaking be obtained. Avoid conditions which are unusual and beyond the ordinary requirements of good practice, and which are not absolutely necessary to the results desired. The Contractor will generally bid a figure out of all reasonable proportion, to insure himself against loss on work of a character with which he is entirely unfamiliar. Remember that Engineering has been defined as ''the science or art of making a dollar go the farthest''. Many young engineers are prone to introduce into their work some new idea of their own, of doubtful utility, for the sake of novelty and self-advertisement, where a more conservative man will follow the beaten road of approved practice.

Materials Employed. The materials of construction should, to as great an extent as possible, be those readily found in the local markets and in the neighborhood of the work. This does not mean, however, that any inferior or unsuitable material may be allowed to enter into the work; on the contrary, the most approved practice should be required both as to materials and workmanship. The Engineer may be sure that he will not get a better quality of material than that specified, and will often get a poorer one. Be careful in regard to specifying materials of special manufacture, as the Engineer must be above the suspicion of favoring any particular make or brand. It is wise to set as a standard the best brand on the market and then require it, or its equal. It is generally best to set forth the requirements or tests that a material must fulfill, in preference to naming the special manufacture.

Extra and Additional Work. What constitutes *extra* and *additional* work is the most frequent cause of controversy between the Engineer and the Contractor; therefore, the greatest care should be used in specifying what should constitute each. Extra work may be defined as work entirely unforeseen at the time of the drawing of the contract; while additional work is work of the same quality and workmanship as that described in the specification, which can be foreseen but not accurately calculated. The proposal should include unit prices for the various items of materials and workmanship, which it is thought may be required to complete the construction, over and above the work described in the specifications, in order that there be no cause for controversy over the items of additional work. But where there have been omissions in the requirements of the specifications; when alterations, changes, and additions become necessary; where errors have been made in lines or grades; where new methods or materials are experimented with by the Engineer; where damaged work is replaced; or where the work has to be extended to secure greater strength, durability, or stability, there is frequently more or less controversy as to just what shall constitute extra work under the contract. This trouble can be avoided by defining clearly just what work is to be done by the Contractor, and by requiring nothing of him beyond the lines of the work so defined.

Dividing Line between Contracts. The dividing line between contracts should be very carefully described and, where there are several contractors on one piece of work, the exact limits of the work to be performed by each one must be set forth most carefully.

The work for each of the several contractors should be described under separate headings, care being taken that each contractor agree to leave his work in such condition as to work no hardship on the one following him.

Verbal Information to Contractor. A clause in the specification should state that any information, whether verbal or otherwise, secured by the Contractor from the Engineer or his assistants prior to the signing of the contract is not binding, and that only the information as shown on the plans, or set forth in the specifications, has bearing on the contract. The specification is, and should be stated therein to be, a part of the contract. The plans and specifications should give as full information as possible as to conditions and difficulties that may be met with, such as soundings, borings, character of material, amount of water to be encountered, etc.; and any special difficulties known to the Engineer should be noted in the specification, and no information of use to the Contractor in making up his bid should be omitted.

Mistakes in Plans and Specifications. Finally, every precaution must be taken to prevent mistakes in the plans, and omissions or conflicting clauses in the specifications. Every possible check against errors should be made use of. When errors are discovered in the course of the work, no time should be lost in admitting them and setting about to rectify them. The principal object is to produce a finished piece of work, constructed according to the best approved practice, that will be a credit to the Engineer, as well as to every one who has had a hand in its construction.

GENERAL PROVISIONS

DETAILS PRIOR TO BEGINNING WORK

Grouping Provisions. There is a great difference of opinion as to the proper location of certain general provisions in contracts. Some place them in the articles of agreement, while others place the same clauses in the specification. The writer advises keeping the general clauses together as much as possible, grouping them so as to indicate their character and placing them almost entirely in the specification, making the contract as short and concise as possible. The proper grouping is very difficult, as many of the clauses might be placed in any of several groups.

In drawing up specifications it is a good practice for the Engineer to keep before him a list of general provisions covering all cases and, while all the provisions will not apply to any one contract, this will be a great aid in preventing omissions. Some of the following apply to one class of work only and have been grouped under the various headings, all being written as though one of the parties to the contract was the "Company", the other the "Contractor". Of course, the wording would be modified in case the work were being done for a municipality or an individual.

Careful Statement of Definitions. To prevent disputes, the principal parties to the contract and their representatives should be clearly defined; hence the necessity of a clause of the following character in most specifications:

Definitions. The following words and expressions used in this contract shall be defined and construed as follows:

City: The City of..

Director: The Director of the Department of Public Works of the City of..

Chief Engineer: The person holding the position or acting in the capacity of the Chief Engineer of the.................................... Company.

Engineer: The Chief Engineer of the....................................Company, or, in his absence, his regularly appointed and authorized Assistant Engineer, and Inspectors representing him, limited to the special duties intrusted to them and to no other employe of the....................................Company.

Contractor: The individual, parties, firm, or corporation with whom or with which the contract is made, or an authorized agent thereof.

Other words often have to be defined, such as Owner, Purchaser, Trustee, Board, Directors, President, Treasurer, each of which should be clearly defined so that there can be no possible question as to its precise use.

DRAWINGS, PLANS, ETC.

The following group of clauses relate to drawings, or plans, and notes on them:

Construing Specifications and Plans. To avoid disputes and litigation, it must be distinctly understood by the Contractor that the Engineer of the Company shall construe the specifications and approved plans; and explain any obscurity therein; and shall have the right to correct any errors or omissions in either and decide as to their purpose and intent; and his decision upon any doubtful or disputed point shall be final, conclusive, and binding upon the Company and the Contractor. The action of such correction shall be in force from the time the Engineer gives due notice thereof in writing.

Plans and Specifications of Equal Force. The approved plans and the specifications shall be of equal force and effect and, in case of discrepancy between the plans and the specifications, or between the plans and the details, or any lack of agreement in measurements upon different plans, or different figures upon the same plan, they must be submitted to the Engineer for interpretation before beginning construction of the work. Dimensions shown in figures on the plans shall have preference over the scale.

General Drawings. The Company will furnish to bidders drawings giving all general dimensions and sizes, and such partially detailed drawings as may be required to cover special features. After assigning the contract, such other drawings as may, in the judgment of the Engineer, be required, will be furnished by the Company. The Contractor shall prepare drawings for shop work, which shall include all details required to supplement and complete the general and partially detailed drawings furnished by the Company; and he shall submit 3 blueprints of each sheet for the approval of the Engineer. After approval, if required, additional prints shall be furnished. The approval of the Engineer shall in no way relieve the Contractor from responsibility for the correctness of all detail drawings before going to the shop, nor for the accurate and complete execution of the work.

Work in Accordance with Plans. The work and all its appurtenances shall be built of material, size, and dimensions, on the lines, to the depths, and in the manner shown on the plans filed in the office of the Company. No deviation from them will be allowed unless by permission in writing from the Engineer.

Record Drawings. The Contractor, upon completion of the work, shall furnish 3 complete sets of blueprints on linaura, of detail drawings of the machinery and all appurtenances; each set shall be neatly bound in cloth for record drawings of the work embraced under the contract as a whole.

Plans and Specifications. The approved plans and a copy of the specifications are to be kept constantly at the work by the Contractor or his authorized foreman.

Necessary to Render the Work Complete. If any workmanship or materials be required, which are obviously necessary to carry out the full intent and meaning of the plans, details, diagrams, and specifications, although the same may not be either directly or indirectly so specifically noted by drawings or specifications, the Contractor is hereby bound to consider and provide for the same in his proposal for the work, as fully as if they were so specifically denoted, and shall execute the same without charge or claim therefor.

Notes upon Drawings. Contractors proposing for any of the work under these specifications will be expected to examine all the notes upon the plans, which are intended to form a part of the specification. No consideration will be given to any claim that these notes have been overlooked.

Verbal Agreements. This contract shall in no wise be affected by verbal agreements or inferences from conversations previous to or subsequent to its execution.

MEASUREMENTS, LINES, AND GRADES

The following paragraphs may be grouped under Measurements, Lines, and Grades:

Lines and Grades by Engineer. The work shall be laid out on the ground by the Engineer, who shall direct the lines and grades that are to be observed, and all marks given by him shall be carefully preserved by the Contractor, who shall provide such stakes, forms, and assistance in doing the work as may be demanded of him by the Engineer.

Marks and Stakes to be Preserved. Contractors must carefully preserve bench marks and stakes and, in case of willful or careless neglect, they shall be charged whatever the Engineer shall consider an equitable amount to cover damages arising from such negligence, the same to be deducted from the amount due upon the completion of the work.

Work to Conform to Lines, etc. All construction work shall conform to the lines and stakes set out by the Engineer, and any increase of labor or material required, due to the neglect of these lines and stakes, shall not be estimated or paid for.

Standard of Measure. All measurements are given on the plans and shall be measured in United States standard feet. Where vertical dimensions are preceded by the sign + or —, they refer respectively to above or below an established horizontal plane called datum, which is................feet above (or below) mean high water and................feet above (or below) the mean low water in the..............................at..............................

Measurements. All quantities shall be determined by measurements in United States standard feet, made to the prescribed lines. No work outside these lines shall be paid for. No constructive conventional measurement will be allowed, any rule or custom in the section of the country through which the road passes, to the contrary notwithstanding.

Quantity Estimates. It is distinctly understood by both parties to a contract, that the quantities of material of all kinds shown on the plans or in the specifications are merely approximate, and will not in any manner affect the final settlement because of the fact that at the time of drawing up the specifications it was impossible to determine them accurately.

The Company reserves the right to require the use of whatever materials may be necessary for the safe and efficient temporary and permanent construction of the work; also the right to increase or diminish the quantities to the extent found necessary by the Engineer.

FULFILLING THE CONTRACT

EXECUTION OF WORK

The following clauses are generally grouped under Execution of the Work:

Prosecution of Work. The Contractor shall commence, prosecute, and complete the work in all its parts in the most energetic and workmanlike manner, and shall prosecute the work at and from as many different points, at such times, in such parts, and with such force of workmen, as the Engineer during the progress of the work may determine.

Should the necessary land or right of way not be procured at any place when the Contractor desires to work thereon, he shall distribute his forces to such other points as may be designated by the Engineer, without any claim for damages for failure to procure such land or right of way.

Delay in Procuring Right of Way or Land. The Company shall procure the necessary right of way and lands needed for the work to be done under this contract; but it is agreed and understood that, until the said Company shall have procured all the right of way or land required for this contract, the Contractor shall commence work, or make arrangements for commencing work, entirely on such ground as the Engineer may designate. The Contractor shall not have any claim for damage or detention by reason of delay in procuring titles to lands, but he shall be entitled to an extension of time on each part of the work on which he was prepared to commence, equal to the time lost from and after the day when he was so prepared, provided such detention shall exceed 10 days. In all such cases, however, the Contractor shall notify the Engineer in writing when and where he desires to commence work.

Duties of Contractors. Contractors will be required to give their personal attention and supervision to the work and will not be allowed to sublet the whole or any part of the same without the consent of the Company having been given thereto in writing.

Contractors must satisfy themselves by a careful personal examination of the nature and location of the work for which they bid, of the general form of the surface of the ground, and all other matters which can in any way influence their contracts; and no information upon such matters derived from maps, plans, profiles, drawings, or specifications, or from the Engineer or his Assistants, shall in any way relieve the Contractor from any risk, or from fulfilling any of the terms of this agreement.

Borings. The Company does not guarantee the correctness of the borings nor the nature of the materials shown upon the plans. The Contractor must assume all risks resulting from any differences from the borings found to exist when the construction is under way.

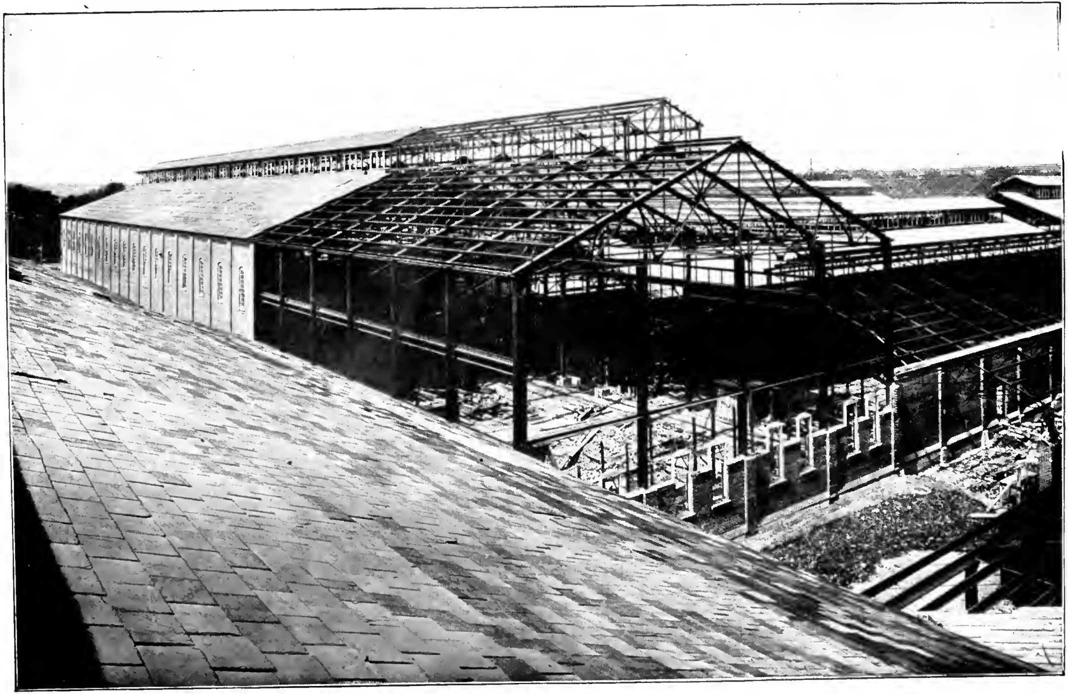
All loss or damage arising from any unforeseen obstructions or difficulties encountered in the prosecution of the work shall be sustained by the Contractor. The soundings and borings, and the profiles based thereon, are to be taken merely as guides for the Contractor in bidding, and must not be construed to relieve him from responsibility in determining for himself the nature of the materials which will be encountered.

Care of Materials. The Contractor shall receive, care for, and be responsible for all materials purchased by the Company and delivered to the said Contractor at the point herein designated. In case of loss by fire, flood, breakage, theft, carelessness, etc., the Contractor shall make good any loss.

NOTE.—This clause is necessary when the Company is supplying part or all of the materials of construction, such as spikes, bolts, etc., in track-laying contracts; lumber or iron in bridge work, when the contract is for the erection of the material only, and parallel cases.

Materials to be Furnished. The Contractor shall furnish all materials required, which shall be in full accordance with these specifications and the general and detail drawings, as they may be approved by the Engineer, and shall also furnish all labor, tools, and machinery necessary and all must be of the kind best adapted to the efficient, prompt, and safe execution of the work.

Right of the Company to Employ Additional Men. If at any time, in the judgment of the Engineer, the Contractor shall neglect to prosecute the work with a force sufficient for its completion within the time specified, the Company may employ such number of working laborers and foremen as, in its opinion, may be necessary to insure the completion of the work within the



BUILDINGS FOR THE PITTSBURG PLATE GLASS COMPANY, CRYSTAL CITY, MISSOURI

Grinder and Polisher building, 408 ft. by 532 ft.; Laying Yard building, 100 ft. by 578 ft.; Lehr building, 68 ft. by 475 ft. and 114 ft. by 171 ft.; Stripper building, 90 ft. by 408 ft.; Warehouse, 153 ft. by 304 ft. and 90 ft. by 173 ft. Total weight of steel work, 6,280,000 lbs.

Courtesy of American Bridge Company.

time specified in the contract, at such wages as it may find necessary or expedient; and may pay all persons so employed, and charge all amounts so paid as so much money paid to the Contractor under this contract.

Extension of Time. If the Contractor shall not complete the work within the time specified in the contract, and the Company shall, notwithstanding such failure, permit the Contractor to proceed with or complete the work as if such time had not elapsed, such permission shall not be deemed a waiver in any respect by the Contractor of any forfeiture or liability for damages or expense thereby incurred, arising from such noncompletion of the work within the time specified and covered by the "Liquidated Damages" clause of this contract; but such forfeiture or liability shall still continue in full force against the Contractor as if such permission had not been granted.

NOTE.—Where no time for completion of the work is given, the work must be completed within a reasonable time.

Twelve o'clock midnight of the day named in the contract as the date of completion is the limit of time unless a certain hour has been specifically named. Time clauses should state whether Sundays and holidays are excluded from the specified period.

What Prices are to Include. The prices specified in the accepted proposal and contract shall include the supply and erection, in a good, sound, substantial and workmanlike manner, of all dams, flumes, pilings, shorings, sheathing, shafts, forms, centering, false works, tramways, machinery, and scaffolding; also pumping, labor, workmanship, tools, fuel, and materials necessary for both permanent and temporary works, including all the items herein mentioned (unless specifically stated otherwise) for the prompt completion of the whole work proposed for, shown on the drawings, and described in these specifications. All materials and workmanship shall be of the best quality and description, and the work perfect and complete in all its parts.

NOTE.—This provision will change, as to the different items included, depending on the character of the work; for while the clause is applicable to a sewer, or pipe-laying contract, it would not cover the requirements for track laying.

INSPECTION OF WORK

The following four clauses are grouped under Inspection:

Inspection During Construction. The Contractor shall at all times afford every facility for inspecting materials and workmanship. Any materials or workmanship not in accordance with the plans and specifications shall be replaced with approved material or workmanship, or both, within the time fixed by the Engineer; and all rejected materials shall be immediately and entirely removed from the site of the work. If, after written notice to the Contractor, the rejected materials are not removed or the condemned work built anew within the time fixed, the Company shall be at liberty to remove the rejected materials and supply new materials, or build anew any unapproved work, at the expense of the Contractor, and the cost thereof shall be deducted from any money which may be due him.

Nothing in this contract shall be construed as vesting in the Contractor any right of property in the materials used, after they have been attached or affixed to the work on the soil; but all such materials shall, upon being so attached or affixed, become the property of the Company.

Materials and workmanship may be inspected at any time. All structural steel shall bear the Inspector's mark of acceptance. The Contractor shall execute the work in the presence of an Inspector at all times; work in absence of same shall be subject to rejection.

Final Inspection. The final inspection and acceptance of the work will take place after construction; and any inspection and acceptance of materials and workmanship at the site of the work, foundries, shops, etc., to facilitate the progress of the work, shall not prevent rejection of such materials and workmanship thereafter, if the same be found unsuitable or imperfect.

Cost of Engineering and Inspection. The cost of engineering and inspection, after the expiration of the time agreed upon in the contract for the completion of the work, shall be at the expense of the Contractor, and such cost shall be deducted from the amount due the Contractor at the time for final payment.

Labor Furnished to Inspector. If required, the Contractor shall furnish such labor as the Engineer shall deem necessary to assist in the inspection of materials to be embodied in the construction under this contract and to assist in giving lines and grades on the work, all free of cost to the Company.

NOTE.—This provision is unusual and is used or enforced only in comparatively small contracts, or when it would be unjust to expect the Company to keep a corps of engineers and inspectors on work indefinitely to accommodate a Contractor who is in default with his work. On small contracts, requiring little or only occasional staking out, or where the work is in remote sections, it is customary to get the assistance of some of the Contractor's laborers to drive the stakes, cut brush, etc., to avoid the expense of maintaining a large corps constantly on the work.

PROTECTIVE AND LABOR CLAUSES

Builders' Insurance. The Contractor will be required to take out from time to time, in an approved company, a Builders' Insurance Policy covering the value of all materials liable to injury by fire, incorporated in or brought to the work, and shall assign same to the Company. The policy shall be approved as to form and amount by the Engineer.

Freezing Weather. The work shall be carried on in cold weather only at such times and in such manner as directed by the Engineer. When work is done during freezing weather, if required, the Contractor shall provide proper facilities for heating the materials entering into the work and shall thoroughly protect the new construction from damage caused by the elements, during and after building. Upon the suspension of work due to freezing weather, all new work shall be protected and the grounds left in good order.

Competent Men and Discharge for Cause. The Contractor shall employ only competent men; and he shall discharge any foreman or other employe who shall, in the judgment of the Engineer, be unfaithful, unskillful, or remiss in the performance of his work, or guilty of riotous, disrespectful, or otherwise improper conduct; and no person so discharged upon this work, or any other work done for the Company, shall be employed again by the Contractor upon the work to be done under this contract without the written consent of the Engineer. The work under this specification shall be subject to all federal, state, and (or) municipal laws, or regulations, in regard to the employment of laborers, workmen, and mechanics and also those laws regulating the hours of employment of such employes; and further, before receiving each payment, the Contractor, if required by the Engineer, shall furnish an affidavit that such laws have been faithfully fulfilled.

Employment of Labor. The Contractor, in the construction of the work, shall give preference in employment to citizens of the commonwealth; and in the employment of mechanics and laborers, where citizens of the commonwealth are not available, shall give preference to citizens of the United States who are not citizens of the commonwealth. Persons employed in the performance of manual labor under this contract shall not be required to work more than............................hours in each day, and............................hours shall constitute a day's work.* The Contractor shall neither directly nor indirectly require as a con-

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* An 8-, 9-, or 10-hour day should be specified, according to local laws and circumstances.

dition of the employment of any person that the employe shall lodge, board, or trade at a particular place or with a particular person, but every employe shall lodge, board, and trade where and with whom he elects.

Foreign Corporations. The Contractor, if a foreign corporation, shall file with the Company, if so requested, duly authenticated copies of its charter or certificate of incorporation.

Note.—It is of the greatest importance that a corporation, attempting to do business in a State other than that under whose laws it was incorporated, secure a license and certificate to do business in said State as, in many States, without such license, the corporation cannot enforce its claims in the courts. As the laws differ in every State, it is advisable that the Engineer secure the advice of a local attorney at law, of good standing, to advise in regard to the legal provisions of the contract.

MISCELLANEOUS OBLIGATIONS OF CONTRACTOR

Orders and Instructions. The Contractor must strictly follow, without delay, all orders and instructions of the Engineer or his authorized assistant, in the prosecution and completion of the work, and every part thereof.

Personal Attention. The Contractor is required to give his personal attention to the faithful prosecution of the work, and not to sublet or assign the same, without the written consent of the Company, but to keep it under his own control; and, in case of his absence, to have a competent representative or foreman on the work, who shall receive orders and directions from the Engineer and Inspector and have the same carried out without delay, and who shall have full authority to supply men, material, and labor immediately.

Time of Commencement and Completion. The Contractor shall begin work within..............................days from the date of the notice given to that effect by the Engineer, and he shall complete all the work under this contract in the time specified, which will be reckoned from the date of said notice.

Delays. No charge shall be made by the Contractor for hindrance or delay from any cause during the progress of any portion of the work embraced in this contract; but such hindrance or delay may entitle him to an extension of time allowed for completing the work, sufficient to compensate for the detention, to be determined by the Engineer, provided the Contractor shall give the Engineer immediate notice, in writing, of the cause of the detention.

A contractor on any one or more of several sections, into which the work may be divided, will not be allowed any claim for delay on account of any act of a contractor or contractors on a neighboring section or sections.

Use of Coal under Boilers. The Contractor shall in all cases, where steam power is employed in streets, use anthracite coal under the boilers for generating steam and, where ordered by the Engineer, shall provide electric power for operating all power-driven machinery.

Filling-In of Old Drains. All sewers, culverts, drains, or basins met with and rendered unnecessary, or becoming disused by the construction of the work herein contemplated, must be filled in, and the street or ground over their site must be restored, without extra charge.

Location of Underground Structures. Where existing sewers, water or gas mains, electric and other conduits, met with during the progress of the work, are shown upon the plans, the locations of the structures are intended to be approximate only. The Company will not be responsible for any omission upon the plans as to the location of such sewers, pipes, or conduits met with in excavation, nor for any errors in locations due to incomplete or faulty records.

Buildings for Engineer and Inspector. The Contractor shall provide at least 120 square feet of floor space in a suitably heated, satisfactory building with doors, windows, locks, etc., near the work, for the use, when required, of the Engineer and Inspectors in charge of the work. Telephone service shall be furnished by the Contractor for the use of the Engineer and Inspectors in charge.

NOTE.—While unnecessary in some cases, it is always advisable to have a private room for the Engineer or Inspector where plans and instruments may be safely kept.

Work Day and Night. The work shall be carried on day and night, if necessary, to complete within the time specified.

Pipes and Electric Wires. The Contractor shall take care of all pipes and electric wires encountered on the work, see that they are properly protected, that they are raised and lowered when necessary, and that they are not injured in any way; all damage done to such property shall be paid for by the Contractor. He shall maintain the flow of drainage, whether on the surface or underground. The cost of all such work shall be included in the price bid.

Property of Contractor. Generally, all waste materials excavated, or removed from within the required limits of the excavation, shall be considered the property of the Contractor;

excepting private property, bridges, or parts thereof, water and gas pipes, which, in case they are not required to be replaced, shall be removed to such locality as may be directed by the Engineer. The materials excavated shall be reserved for better construction, support, and protection of the work when required.

When the work under this specification extends through private property, all excavated material not required for the proper construction of the work, and all standing timber, if claimed by the owner of the property, shall not be removed from the ground. If not claimed by the property owner, the material shall be removed and the ground left clean, as required by these specifications.

Examination of Finished Work. The Contractor shall furnish—if deemed advisable by the Engineer—all necessary facilities for making an examination of any work already completed. If the work is found defective in any respect, the Contractor shall defray all expense of such examination and of satisfactory reconstruction. If the work is found satisfactory, such expense will be allowed for.

Material Specified. Where materials are called for specifically by name of the manufacturer, this specification is intended for a standard of style and quality only; but no deviation from or substitution for this material will be permitted without written permission from the Engineer.

Risks from Floods, etc. The Contractor shall assume all risks from floods and casualties of every description; all damage to grading, bridges, trestlework, sewers, masonry, and all other kinds of work not herein specified, from high water, rains, fire, or from any cause whatsoever; and the work so damaged shall be replaced at the expense of the Contractor. In case of any such accident he shall give immediate notice to the proper authorities.

Sanitary Regulations. Necessary sanitary conveniences for the use of laborers on the work, properly secluded from public observation, shall be constructed and maintained by the Contractor in such a manner and at such points as shall be approved by the Engineer, and their use shall be strictly enforced.

Shanties. The building of shanties or other structures for housing the men will be permitted only at such places as the Engineer shall approve, and the sanitary condition of the ground in or about such shanties or other structures must, at all times, be maintained in a manner satisfactory to the Engineer.

No Spirituous Liquors. The Contractor shall neither permit nor suffer the introduction or use of spirituous liquors upon or about the works embraced in this contract, or upon any grounds occupied by him.

Roads to be Opened. The Contractor shall, immediately after signing the contract for the work under this specification, proceed to open and maintain such good and safe roads and paths for foot and horse travel, along the whole line of the work herein described, as the Engineer may direct; and on portions of the work where there are no highways convenient for the wagoning of supplies, he shall open and maintain such wagon roads as may be directed by the Engineer, who also shall decide what extra amount, if any, he shall be entitled to for this work.

NOTE.—This clause is applicable only to such classes of work as railroads, canals, extensive sewer and pipe-line contracts, and reclamation work.

Contractor Responsible for Violation of Laws. In all operations connected with the work embraced in this contract, the Contractor shall be held responsible for any failure to respect, adhere to, and comply with all local ordinances, and all state and national laws controlling or limiting in any way the actions of those engaged upon the work, or affecting the transportation or disposition of the materials. He shall place sufficient lights on or near the work, and keep them burning from twilight to sunrise; he shall observe such rules relative to signals and safeguards as the laws, regulations, or ordinances require; and shall also provide watchmen on the work for the protection of the public.

Liability of Contractor. The Contractor shall assume all liability for, and indemnify the company against, all loss, cost, or damages for or by reason of any liens, claims, or demands for materials; all loss from laborers, mechanics, and others; from any damages arising from injuries sustained by mechanics, laborers, or other persons, by reason of accidents or otherwise; and from damages sustained by depositing materials to public injury, or to the injury of any person or corporation (including costs and expenses of defense), provided that he be duly notified of the bringing of suits in such cases, and be permitted to defend the same by his own counsel, if he should so elect.

Other Work on the Company's Land. The Company reserves the right to carry on its construction and other work, outside that enumerated in this specification, at the same time that the Contractor is prosecuting the work under these specifications; and its Engineer shall at all times be authorized to permit others to pass over or haul any materials over the Company's land, and perform work thereon, having at all times due regard to the fact that such authority given to him shall not seriously interfere with or impede the work of the Contractor.

Cleaning up Débris. The Contractor shall remove all falsework, piling, and other unsightly material and obstructions, all débris and surplus materials from the site of the work, the right of way, adjacent properties, highways, and thoroughfares as each piece of work is completed. Channels of streams, public and private roads, and streets must be left in as good order as previous to the commencement of the work, and in a condition satisfactory to the Engineer and proper authorities.

INTERFERENCE WITH TRAVEL, ETC.

Obstruction to Travel. The Contractor shall conduct his work in such manner as neither to obstruct traffic on any railroad, highway, or thoroughfare, on land or water, nor interfere with, nor obstruct the use of private property, or wagon entrances, or the work of other contractors employed at the site of the work. In case of accident or claim for damages, due to the Contractor's neglect in these respects, he will be held strictly responsible for any such claim therefor.

Interference with Traffic. When work is to be done upon or adjacent to a railroad, the Contractor shall so prosecute his work as to interfere as little as possible with the traffic of such railroad; and all work that may affect the safety of the traffic of the same shall be subject to the direction of the superintendent of the railroad company upon which, or adjacent to which, the work is being carried out.

Where the work under this contract is crossed by public or private roads, the Contractor shall provide and maintain a safe road for traffic, and the work shall be carried on in such a manner as not to obstruct or block travel. Where directed by the Engineer, temporary crossings shall also be provided. All material excavated or delivered shall be so placed as not to interfere with traffic.

Watchmen and River Signals. The Contractor shall provide at his own expense the necessary watchmen, signals, and lights, and must observe the local laws of the district in protecting the public against all injury and damage. He shall conform to all the rules and laws governing navigation in the waters crossed by structures specified in this contract, and shall notify the proper authorities of the location of, or change in position of, proposed structures and plant in said waters, and shall establish and maintain the necessary lights, fog signals, etc., upon structures in course of construction, and upon his plant. In case of any damage resulting from neglect to keep and maintain suitable lights and signals, or from mistake in signals, it must be promptly repaired at the expense of the Contractor.

Railroad Crossings. Where the work is to be constructed under the tracks of a steam railroad, the Contractor will be required to make satisfactory arrangements with the railroad company for the support of its tracks.

Water and Gas Pipes—Drainage. The Contractor is required to sling, shore up, and secure in their places all water and gas pipes and electrical conduits, or other underground structures encountered, without injury; and to provide for and maintain the flow of water, gas, electricity, drainage, and watercourses, whether on the surface or underground, which may be intercepted or interrupted during and by the progress of the work. Where the location of such pipes, drains, etc., has to be changed on account of the new construction or its appurtenances, the Contractor shall bear all expenses attending such changes.

Restoring Street and Road Surfaces. All road surfaces, sidewalks, and paving, disturbed by the work herein described, shall be restored to their original condition upon the completion of the work.

DAMAGES, CLAIMS, ALTERATIONS, ETC.

Damage to Persons and Property, Patents, etc. The Contractor shall be responsible for all damage to persons and to public and private property; for trespassing, or for any other offense committed by his workmen or others in his employ; for damage by explosives, fires, or any other causes incident to the conduct of the work. Any damage resulting from neglect of precautionary provisions by the Contractor or his employes, shall be paid for by the Contractor and, if necessary, the payments may be withheld, at the option of the Engineer, until such damage is satisfactorily settled. The intention of the contract is that the Company shall not be held responsible for any claims or losses incurred through the construction of the work herein described.

Suits, Claims, Patents. The Contractor shall indemnify the Company from all suits and actions of every nature and description brought against the said Company for, and on account of, the use of any patents or infringements of patents in connection with this contract, or for any damages or injuries received and sustained by any party or parties in the performance of the work under this agreement.

Forfeiture for Overtime—Liquidated Damages. It is expressly agreed that time is of the essence of this contract, and the Contractor agrees that the Engineer is authorized to deduct and retain permanently out of the moneys which may be due or become due the said Contractor under this contract, the sum of..dollars per day as *liquidated damages*, and not as a penalty, for each and every day that the work herein described remains uncompleted beyond the time stipulated.

Note.—This claim is seldom enforced as the Company may have to prove that it has been damaged to the amount specified and that such damage is entirely due to the delay of the Contractor in completing his work. Of course, the sympathy of the Engineer is often with the Contractor who is behind with his work, through no fault of his, and the sympathy of the jury is generally with the Contractor and workingman, as against the party with money, be it an individual or a corporation.

Note.—When the *penalty* for the noncompletion of work on time is provided in the contract, the amount of same may be recovered from the Contractor by legal process; but if the Contractor is delayed by the Company at any time during the progress of the work, the penalty cannot be enforced by the Company.

Should the Company order extra or additional work, for which extra time is allowed, it does not excuse the Contractor from completing the work on time nor from making the payment for delay.

Extra Work. The Contractor shall do any extra work, not herein otherwise provided for, when and as ordered in writing by the Engineer; and shall, when requested by the Engineer so to do, furnish itemized statements of cost of the work ordered; and give the Engineer access to accounts, bills, and vouchers relating thereto; nor shall any claims be allowed for extra work unless the same shall be done in pursuance of a written order from the Engineer, and the claim made at the first settlement after the work is executed; unless the Engineer, at his discretion, shall direct the claim, or such part of it as he may deem just and equitable, to be allowed; and it is expressly understood that the Contractor agrees to accept such allowances and estimates in full satisfaction of such extra work, loss, or damage, the decision of the Engineer as to the amount of such extra work, loss, and damage being as final, conclusive, and as binding on both parties as though the said extra work were a part of the work specifically described in this contract.

Note.—It is customary for the Engineer to allow from 10 to 15 per cent for profit over and above the actual cost of the work, which should include the cost of superintendence and repair of tools.

Alterations. The Engineer may from time to time, by an instrument in writing signed by him, order the Contractor to make changes in the work. In case the changes so ordered make the work less expensive to the Contractor, a proper deduction shall be made from the contract price, and the Contractor shall have no claim, on this account, for damages or for anticipated profit on the work that is dispensed with; in case such changes make the work more expensive, a proper addition shall be made to the contract price; such deduction or addition shall be determined by the Engineer. In case of any change ordered as aforesaid, or in case any other changes in the work are made by the mutual consent of the parties hereto, whether affecting the contract price or not, or the time of completion or not, all and each of the other provisions of this specification shall remain in force and apply to the contract as thus altered. Changes so made shall not make void any bonds that may have been given by the Contractor.

Change of Line and Grade. The line of the work or the gradients or elevations may be changed, if the Engineer shall consider such change necessary or expedient, and for any considerable alteration the injury or advantage to the Contractor will be estimated, and such allowance or deduction made in the price as the Engineer may deem just and equitable; but no claim for an increase in prices on the part of the Contractor will be allowed or considered unless presented in writing to the Engineer before the work on that part of the section where the alteration is to be made shall have been commenced.

NOTE.—This provision is, of course, applicable to railroads, pipe lines, canals, sewers, etc., and hence is not, strictly speaking, a general provision; but, as it applies to many kinds of work, it has been introduced here.

NOTE.—The changing of plans and specifications is always to be avoided, if possible, but it is almost impossible to write a faultless contract and to foresee all conditions that will arise. After the beginning of construction, changes must sometimes be made. The right of the Engineer to make changes during the progress of the construction, while customary, should generally be limited to details and to the character of the materials. Of course, the more perfect the plans and specifications, the fewer alterations will be required, and, consequently, the fewer demands for extra compensation for unforeseen work. Remember that changes made in the specification, plans, or contract after execution are not binding unless they are known and agreed to by both parties to the contract, in which case all should be noted in writing on the instrument and signed by both parties setting forth the date of the change. All changes on drawings should be made in a conspicuous color and be carefully dated.

PAYMENT, LIENS, ESTIMATE, BOND, ETC.

Spirit of Specification. The "spirit" of these specifications is to furnish all material and workmanship necessary for the construction herein described, complete in every respect, for the purpose for which it is designed; and the Contractor is hereby bound to consider and provide for any workmanship or materials, which are obviously necessary in order to carry out the full intent and meaning of the plans, details, diagrams, and specifications, although the same may not be either directly or indirectly noted by drawings or specifications. He shall provide, in his proposal, for the said omissions, as fully as though they were specifically denoted, and shall execute the same without charge or claim therefor.

Payment. Monthly estimates of the amount of work done and material delivered under this contract shall be made by the Engineer on or about the first day of the month; and from the estimates so made, the value of the work done and of the material delivered on the site of the work shall be determined. Upon the Contractor's furnishing a complete release of liens for all labor and material furnished to the time of the taking of the said estimate, within..............................days the Company shall pay the Contractor..............................per cent of the amount due, as determined by the Engineer, and this method of payment shall continue until the work under this contract is completed.

The balance or amount remaining unpaid and due the Contractor shall be paid within..............................days after the final completion and acceptance of the work by the Engineer.

NOTE.—*Amount of Retained Percentage.* To insure completion, it is customary to retain from 10 to 20 per cent of the monthly estimate until the work is finished. In very large contracts, as certain sections are completed and turned over to the Company, the retained percentage is surrendered to the Contractor. The time required in making up estimates, forwarding same to headquarters, auditing, and forwarding check, takes from 10 to 30 days, depending on circumstances; 15 days is usually ample time to allow for these transactions.

NOTE.—*No Claim for Payment until Work is Turned Over.* The Contractor can make no claim for payment until the materials or the work accomplished have been put into the possession of the Company. Should the Company decline to accept the materials or work after same has been turned over to it, the Contractor may then bring suit to compel payment.

NOTE.—*No Payment until Certain Amount Complete.* Payment may be made by installments based on a certain amount accomplished. Under such an arrangement the Contractor can make no claim for payment until such an amount has been accomplished. Should the Contractor abandon the work before such an amount of work be done, he could not recover.

NOTE.—*Accidents.* When the work is to be finished before payment is made, the Contractor must stand the risk of fire, flood, or other accident; but if there is no written contract or custom requiring the entire construction to be completed before payment is made, the Contractor may recover for what he has accomplished, in case of accident, fire, or flood, provided it can be proved that he used all proper precautions.

Some contracts require the Contractor to procure and present certificates of the proper fulfillment of contract from the Engineer, Inspector, etc., before claim is made for payment.

Release of Liens. Before the final payment the Contractor shall give the Company a complete release of liens and claims chargeable to said Contractor; and if at any time any liens or claims are filed, making the Company, or the work, or construction liable, the Company has the right to retain out of any and all payments due, or to become due to said Contractor, amounts sufficient completely to indemnify the Company, work, or buildings, against such liens and claims; and in the event of any liens, or claims, being established after all payments have been made and the security surrendered to the Contractor, the Contractor is to pay back to the said Company all money or moneys that the Company may have been compelled to pay in consequence of such liens or claims.

NOTE.—It is of the greatest importance that the Company be protected against liens of every character. In cases of unsuccessful contractors, it will be found that laborers, mechanics, and material men will make use of liens to protect themselves.

Liens. The Contractor shall file no liens for any labor or material furnished under this contract; such waiver of liens, however, shall in no way be considered as a waiver of action by law for the recovery of the amount due the Contractor as approved or awarded by the Engineer; it is further agreed that no subcontractor for work or material and no laborer, mechanic, or any person whatsoever shall have the right to file any lien of any kind for any sum which may be due or become due to him under this contract, or for work and material furnished thereunder, or for any other purpose, and his right to file such liens is expressly waived.

Monthly Estimate Subject to Variation. Every monthly estimate shall, for the time being, be conclusive upon both parties thereto, but being made (except as herein provided as to extra work) merely as a basis for payment on account, though with a great desire and effort for accuracy, may be only approximately correct, and therefore shall (except as herein provided as to extra work) be subject to correction by the Engineer in any subsequent monthly estimate, or in any final estimate. No such monthly estimate or certificate for unfinished work shall be considered or taken as an acceptance of the work; or as a release of the Contractor from responsibility therefor; or as controlling the Engineer in the final certificate, which alone shall operate as an acceptance of the work or as a release of the Contractor.

Contractor's Bills in Arrears. If at any time it shall be found that the Contractor's bills for material or labor are not being paid within a reasonable time, the Company may withhold from the Contractor's monthly estimate a sufficient amount to cover the said bills, and the Company shall apply the amount so withheld to the payment of said debts.

Abandonment or Violation of Contract. Should the Contractor neglect or abandon the work, or should the Engineer at any time be convinced that the work is unreasonably delayed, or that the conditions of the contract are being wilfully violated, or executed carelessly, or in bad faith, he may notify the Contractor in writing and, if his notification be without effect within 24 hours after the delivery thereof, then and in that case the Contractor shall discontinue all work under the contract, and the Engineer shall have full authority and power immediately to enter upon and take possession of the work, plant, tools, and materials; and to purchase and hire materials, tools, labor, animals, and machinery for the completion of the contract at the expense of the Contractor, or his sureties, or both; or the said Engineer may declare the contract null and void, in which case the security bond, the retained percentage, the materials built into the work, and the materials delivered shall then become the property of the Company.

In case either of the above methods is resorted to, the Company shall have the right to use the plant, animals, and materials until the completion of the work; and should the amount retained on the previous estimates be insufficient to pay all bills in connection with the work, the Company shall have the right to sell as much of the Contractor's plant and tools as shall be sufficient to make good the deficit. Upon the completion of the work the plant and tools, or those that may remain in case it is necessary to make such sale, shall be turned over to the Contractor.

Right to Suspend Work. The Engineer reserves the right to suspend or terminate the work embraced in these specifications for reasons not herein specified, and the Contractor shall discontinue all work within 10 days after receiving notice of such suspension or termination; in which case, the Contractor shall be entitled to payment in full for all materials actually handled or supplied, at a valuation to be fixed by the Engineer, but shall make no claim for consequential damages or anticipated profits upon work not actually performed, or damage of any kind resulting from such suspension or termination.

Agreement. The successful bidder, upon notice from the Company, shall at once furnish it with the names of the sureties to be offered, and shall execute the agreement and furnish the executed bond within.......................days from the date of mailing of notice to the said bidder that the contract is ready for signature; and in case of failure or neglect to do so, he will be considered to have abandoned the contract, and the check accompanying the proposal shall be forfeited to the Company.

Bond. The Contractor will be required to give an approved surety company bond to the Company in the sum of........................ ....dollars for the faithful execution of the work under this specification; for keeping in perfect repair and good order all of the new work constructed hereunder; for all breakage or other damage that may occur to any works that may be within the lines of the work herein described, for............ ....years after date of final payment; for the prompt payment for labor and materials used in the work; and for the protection of the Company from all claims on patents, or damages to persons or property caused by the negligence of the Contractor or his employes in connection with the work herein described; and it is understood that such surety shall not in anywise be released by any modification or alteration in this contract agreed upon between the parties, the said bond being expressly subject to said modifications or alterations. Said bond shall be surrendered...................................months after the date of completion and acceptance of the work executed hereunder.

NOTE.—Avoid personal bonds; good trust company bonds are secured readily by good contractors and are much more satisfactory to the Company.

TYPICAL ILLUSTRATIVE SPECIFICATIONS

The various groups of clauses which have just been given under the head of General Provisions are, as the heading indicates, intended to cover the general features of any well-drawn set of specifications. The typical specifications which follow give a clear idea of the nature of the provisions required for special kinds of work, the selections being sufficiently varied in character to cover the usual types of contract.

RAILROAD GRADING

Tools, Materials, and Labor. The Contractor shall, at his own expense, cost, and charge, find and provide a full and ample supply of the best and most suitable tools and appliances required to be used in the performance of the work to be executed under this contract; he shall provide the best materials of every kind that may be needed for the thorough and expeditious execution of said work; and he shall furnish and provide in sufficient numbers all mechanics, laborers, and other workmen, and also all things that may be requisite and necessary for constructing and completing, within the time herein stipulated, the whole of the work herein agreed to be done.

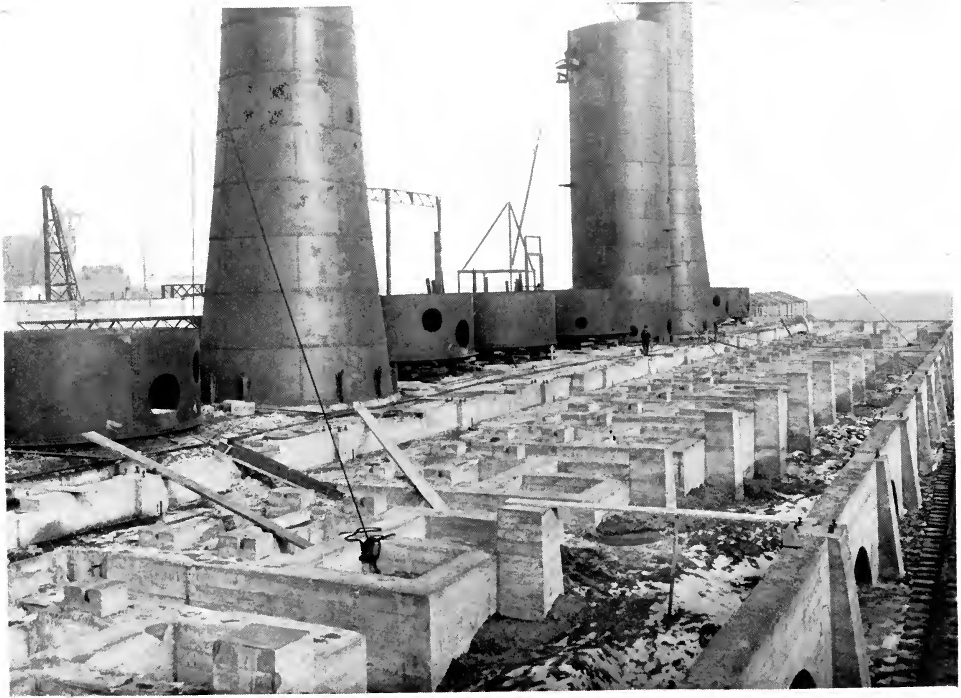
Location of Work. The work covered by this specification is on the line of the..Railroad which is located between..............................in..............................County and ....in..............................County, all lying in the State of............................... The section extends from Station.................. ....to Station.............................. and involves principally clearing, grubbing, grading, trestling, masonry, pipe, masonry or timber culverts.

GRADING SPECIFICATIONS

Under this head shall be included all the clearing and grubbing, all excavation and embankment required for the formation of the roadbed ready for the track; cutting of ditches or drains about or contiguous to the road; widening or changing channels for streams or watercourses; the construction of farm crossings; the foundation of culverts and bridge masonry, walls or bridges; reconstruction of mill races, highways, and roads where they are interfered with or destroyed in the formation of the roadway; also the furnishing and erecting of all masonry, trestling, planking, piling, pumping, bailing, and all the excavation and embankment in any way connected with or incident to the construction of said railroad.

The road shall be graded in conformity with such directions as the Chief Engineer may give concerning breadths, depths, and slopes of excavation and embankment.

Clearing. The lands of the railroad company shall be cleared to the full extent of the right of way of all trees, logs, bushes, and other perishable matter, which shall be destroyed by burning, or deposited in heaps, as the Engineer may direct. Large trees must be cut not more than 1 foot from the ground and, under embankments less than 4 feet high, they shall be cut even with the surface of the ground. The top of stumps shall not be less than 3 feet below subgrade under embankments. All small trees and bushes shall be cut even with the ground. The burning of brush must be done in such a manner as not to endanger adjacent timber land or property. Clearing shall be paid for by the acre



FOUNDATION WORK OF BLAST FURNACES FOR THE IROQUOIS IRON COMPANY

18,000 concrete piles are driven and 35,000 cubic yards of concrete are placed in ten months.

Courtesy of Great Lakes Dredge and Dock Company, Chicago or fraction thereof, to the extent indicated by the Engineer by stakes or by marks on the ground or timber. All trees which the Engineer may reserve shall be stripped of their tops and branches, cut to such lengths, and be neatly piled at such places, on the right of way, as the Engineer may direct.

Grubbing. All stumps, roots, muck, and perishable material shall be grubbed out and removed from all places where embankments occur less than 2 feet in height. All stumps grubbed out shall be burned. Until the Contractor is notified that the work done on the surface to be grubbed is satisfactory to the Engineer, no embankment shall be made on such surface. Grubbing is to be paid for by the acre or fraction thereof actually grubbed.

Excavation. All material shall be measured in the excavations, and estimated by the cubic yard, and shall be classified under the following heads, viz: solid rock, loose rock, earth, foundation excavation in water, and ditching in earth.

Solid Rock. Solid rock shall include all rock which will ring under the hammer, which is found in ledges and detached masses exceeding 1 cubic yard each; and which, in the judgment of the Engineer, may be best removed by blasting.

Loose Rock. Loose rock shall include all kinds of hard shale, slate, soapstone, detached stones of less than 1 cubic yard and more than 3 cubic feet, and all rock which, in the judgment of the Engineer, cannot be plowed and which can be removed with pick and bar, and is soft and loose enough to be removed without blasting, although blasting may be resorted to in order to facilitate the work.

Earth. Earth shall include clay, sand, loam, gravel, and all other matter of an earthy nature, of whatsoever name or character, not unquestionably rock as above defined. Boulders or detached stones containing less than 3 cubic feet shall be classified as earth.

Excavation in Water for Bridge or Culvert Foundation. Foundation excavation in water shall apply to material below the natural water surface and only in cases where (through no fault or delay of the Contractor) constant unavoidable pumping or bailing is a necessity, and where draining by a ditch would be too expensive or impossible; the material shall be classified as excavation, and the price shall include the necessary cofferdams, caissons, sheeting, shoring, draining, bailing, and pumping of water, and the benching and dressing of the rock for base of masonry. Where unnecessary delay occurs in finishing a foundation promptly in dry weather, it will be at the Contractor's risk, as regards the excavation, in case water is met.

Embankments. Embankments shall generally be made in horizontal layers, crowned in the middle, in accordance with the instructions of the Engineer, and shall consist of materials which, in his judgment, are suitable; they shall be built of such width and carried to such height above grade as the Engineer may deem necessary to provide for shrinkage, compression, washing, drainage, and settlement, and must be maintained to their proper height, width, and shape until accepted by the Engineer. No large stone will be allowed within a depth of at least 2 feet below grade; the best materials must in all cases be reserved for finishing and dressing the surfaces. Whenever the embankment is made from the side ditches, such ditching and the crest of the slopes thereof shall in no case approach within 6 feet of the foot of the embankment slopes, and the slopes of such ditching next to the embankment shall not be steeper than the slope of the embankment. Whenever new watercourses or channels are required to be formed, they shall be put at such distances from the foot of the slopes as the Engineer may direct.

No perishable materials will be allowed in embankments. All proper materials taken from the excavation on the line of the railroad shall be placed in the embankment, and all surplus materials shall be used in widening embankments in such manner as the Engineer may direct.

The subgrade must be compact and finished to agree with the standard roadbed section, and no depression that would hold water shall be left.

Embankments about Culverts. Embankments about masonry and pipe culverts and bridges shall be built at such times, and in such manner, and of such material as the Engineer may direct. Embankments shall be carried forward in the usual way to within 10 feet of any bridge or culvert, finished or in progress, from which point the earth shall be carefully rammed to such width, depth, slopes, and in such manner as the Engineer may direct. No additional prices shall be allowed for this work.

Borrow Pits and Spoil Banks. In all cases where the excavations are insufficient to make the embankments, the deficiency shall be supplied by widening the excavations, or it shall be supplied from borrow pits, as the Engineer may direct, and all such excavations and borrow pits shall be located, drained, and sloped as the Engineer may direct. No borrow pit shall be opened until same has been staked out on the ground by the Engineer in charge. All excavations and borrow pits shall be left in such shape that they can be readily measured.

Any surplus material taken from the excavation and not required for embankments, or other purposes, shall be deposited evenly on either side of the embankment, as the Engineer may direct, and shall in no case be raised above the grade of the road.

Ditches. In cuts, ditches shall be dug along the foot of the slopes, of such dimensions as the Engineer may direct. To protect the cuts from washing, intercepting ditches shall be dug above the cutting, upon ground sloping toward the cuts, and connected with the embankment ditches, when directed by the Engineer; and if the material from such ditches is wasted, it shall be deposited between the ditch and the cut. Such excavation shall be paid for as part of the ordinary excavation of the section.

Ditches for changing the flow of streams and for draining marshes, ponds, etc., shall be cut of such dimensions and the materials shall be so deposited as the Engineer shall direct; the same to be paid for at the price named in the proposal for "Ditching in Earth".

Valuable Material and Timber. All materials taken from the excavations, which, in the judgment of the Engineer, may be of greater value to the railroad company for other purposes than embankments, and also all timber, removed from the line of the railroad, shall be considered the property of the Railroad Company, and shall be deposited in convenient positions, under the direction of the Engineer.

Slips and Falls. All slips and falls of slopes attributable, in the opinion of the Engineer, to excessive use of powder, negligence, or carelessness of the Contractor shall be removed by the Contractor at his own cost; but if not so attributable, an allowance, to be fixed by the Engineer, shall be made for such removal as "Earth Excavation".

Measurements. Clearing shall be paid for by the acre or fraction thereof. The clearing of scattered trees shall be paid for by the approximate area of the surface of ground covered by their branches before being felled. Grubbing shall be paid for by the acre or fraction thereof, of surface actually grubbed. The Contractor shall give the Engineer at least 48 hours' notice previous to beginning the making of embankments on surface grubbed, and the same shall not be paid for unless it shall have been measured by the Engineer, and the Contractor shall have been given a written order to proceed with the embankment on the surface in question.

Materials in excavations shall be measured whenever possible, and the term "excavation" shall include all cuttings, borrow pits, roadways, changes of watercourses, ditches, foundations, and trestle pits, and, in fact, every kind of excavation required at any time in the course of the work.

Excavation, in all the several classes thereof, shall be of such dimensions and slope as the Engineer may direct, and shall be estimated and paid for by the cubic yard, and no allowance whatever shall be made for overhaul. The price for excavation shall include all the necessary sheeting, shoring, pumping, and bailing. For the material to be excavated (under the..Railroad from........................Station to..Station) for the roadbed and for abutment walls, a special price will be paid, as named in the proposal, which price for excavation shall cover the sheathing of excavation and supporting of tracks in a manner satisfactory to the Chief Engineer of the........................Railroad Company.

GENERAL CONDITIONS AND PROVISIONS

Duties of Contractor. Contractors shall satisfy themselves by a careful personal examination of the nature and location of the work they bid for, of the general form of the surface of the ground, and all other matters which can in any way influence their contract; and no information upon such matters derived from the maps, plans, profiles, drawings, or specifications; or from the Engineer or his assistants, shall in any way relieve the Contractor from any risk, or from fulfilling any of the terms of this agreement.

Interference with Traffic. When work is to be done upon or adjacent to a public or private road, or to a line of railway in use, the Contractor shall so prosecute his work as to interfere as little as possible with the traffic of the railway, or the traffic of such public or private road. And all work that may affect the safety of the railway traffic shall be subject to the direction of the Division Superintendent of the railway company. When it is necessary to support the tracks of the railway, the railway company will furnish and place all of the necessary timbers for this work, but the Contractor shall do all the excavating therefor.

Property on Right of Way. Fences, buildings, timber, and wood on the right of way along the line of the road are the property of either the landowner, or the party of the .... part; and if not removed by the landowner within a reasonable time, shall be cleared off by the Contractor, and shall be piled up, and preserved for the use of the party of the .... part, without charge.

Damages. In case one portion of the work, contracted to be done in accordance with these specifications, is delayed through the negligence or incompetence of a contractor for some other portion of the work, whatever damage may result, or whatever expense may be incurred by the Contractor so delayed, because of such negligence or incompetence, the amount of damage or expense shall be charged to the contractor at fault, and the Engineer shall decide the amount so to be charged; and the party of the second part shall in no wise be responsible therefor, or for the payment therefor by the other contractor.

Roads to be Opened. Contractors having work awarded to them shall, immediately after signing their contracts, proceed to open and maintain such good and safe roads and paths for foot or horse travel along the whole line of their sections, as may be directed by the Engineer; and on portions of the line where there are no highways convenient for the wagoning of supplies, they must open and maintain such roads, and the Engineer shall decide what extra amount, if any, they will be entitled to for this work.

Any person having permission from the Engineer shall be allowed to pass along or haul any materials required for the road over any section, provided such persons do not interfere with or impede the work of the Contractor.

Marks and Stakes to be Preserved. Contractors shall carefully preserve bench marks and stakes and, in case of willful or careless neglect of these, they shall be charged whatever the Engineer shall consider an equitable amount to cover damages arising from such negligence.

All excavations and embankments shall conform to the line and stakes set out by the Engineer, and any excess of excavation or waste of material required for embankment at the mouth of cuts, due to neglect of these lines and stakes, shall not be estimated or paid for.

Contractors shall clear away the surplus stone and wreckage from masonry sites after the jobs are done; and, before the completion of each section, remove from adjacent properties, bermes, and highways the blasted rock and all other débris accumulated during construction.

Grade. The word ''grade'' whenever herein used refers to the surface of the roadbed as completed and prepared for the reception of the ballast.

Acknowledgment. These specifications are hereby acknowledged, accepted, and made part of this agreement.

Claims for Labor or Material. It is hereby agreed that no lien nor claim shall be filed by anyone for the work or labor to be done or the materials to be furnished, under or in pursuance of this contract.

FOUNDATIONS

General Specifications. Foundations for masonry shall be excavated to such depths as may be necessary to secure a bearing which is satisfactory to the Engineer. In case of foundations in rock, the rock shall be excavated to such depths and in such form as may be required by the Engineer, and shall be dressed approximately level to receive the foundation course. Materials excavated shall be paid for as provided for under ''Excavation''.

Special Foundations. Should the bottom as found be not satisfactory, special foundations shall be constructed of concrete, reinforced concrete, or of timber piling or platforms, as directed, and in accordance with plans to be furnished. If work of special character be required, the Contractor shall be paid for it at the special prices named in the proposal, and said prices shall include all materials and all labor necessary for placing it in the work.

Piles. Piles shall be of white oak, long-leaf yellow pine, or spruce pine, as directed; sound, of straight growth, not less than 8 inches in diameter at the small end, and not less than 12 inches at the butt end when sawed off. They shall be trimmed close, barked if required, pointed or shod as directed, and hooped to prevent splitting. They shall each be of one piece without splicing or doweling. They shall be driven with a hammer weighing at least 2500 pounds, to refusal, or to the point directed, in straight rows, and shall be sawed off truly level. If any piles are raised by the subsequent driving of others, they shall be redriven. If any piles be driven too low to be cut off or fitted at the required elevation, proper piles shall be substituted. Piles split or otherwise injured shall be replaced or repaired as directed.

The piles in place shall be paid for at the price per lineal foot given in the proposal. No part of the pile shall be paid for except that which remains in the work.

Pile Shoes. Pile shoes, when required, shall be paid for as additional steel. They shall be chilled points, 4 inches square at the point of the pile, with 4 straps of approved size, fastened with 8 three-eighths-inch by 4-inch spikes to the pile, which shall be properly fitted to give a square and even bearing on the shoe.

MASONRY

GENERAL CLAUSES

Stone, General. Stone masonry shall be built of the kinds of stone specially designated, with such arrangement of courses and bonds as is directed or shown on the plans. The stone shall be hard and durable, as large as practicable for the work, of approved quality and shape, and in no case having less bed than rise.

Laying. Stone masonry shall be laid with the stones on their broadest beds, well bonded and solidly bedded.

All walls shall be laid up in cement mortar, cement grout being used to fill all vertical joints which cannot be thoroughly filled with mortar, and the stone shall be thoroughly wetted when it is laid. All walls shall be made as water-tight as possible. The face and back of the walls shall be carried up together. No hammering on the wall shall be allowed after the stone is set; if any inequalities occur, they shall be carefully pointed off.

Clean Walls. The showing face of all walls shall be left thoroughly clean upon the completion of the work.

Setting. Dressed stone shall be set with a lewis if required; and where dressed stone is bedded in mortar it shall be settled on the bed with a wooden maul.

Concrete Coping. Concrete coping shall be composed of 1-3-6 concrete as specified, built to the dimensions shown on the plans. The top and sides shall be treated as specified under the paragraphs relating to exposed surfaces of concrete. If made as a monolith on top of the wall, the coping shall be cut into such lengths as may be directed. Payment shall be made at the price per cubic yard for "Concrete Coping" in the proposal, which price shall include the cost of all forms, etc.

Concrete coping may be made as an artificial stone. If so made, the length of the blocks and all details shall be approved by the Engineer.

Back Walls. Where stone is used for back walls, it shall be laid as stretchers and extend through the wall without being backed with other masonry; the faces shall be rough-pointed. Back walls shall be capped with a regular course, peen-hammered on top. Generally, they shall not be built until the superstructure has been placed in position.

Bridge Seats and Pedestal Blocks. Where bridge seats and pedestal blocks are of stone, approved granite shall be used. The top surfaces under the bearings of trusses, main girders, columns, or other principal metal bearings shall be bushhammered and the remainder of the upper surfaces shall be peen-hammered. The showing edges of bridge seats, pedestals, and caps shall be rough-pointed. Bushhammers shall have 5 cuts per inch.

Concrete Bridge Seats and Pedestal Blocks. Where bridge seats and pedestal blocks are of concrete, they shall be composed of 1-2-4 concrete, made with three-fourths-inch stone, as specified, and built to the dimensions shown on the plans, with a hard trowel finish on all showing faces. Payment shall be made at the special price per cubic yard named in the proposal, which price shall include the cost of all forms, etc.

Finish of Walls not Coped. The top of the masonry when not covered by a coping shall be finished with large stones selected for the purpose, which will give an approximately flat surface.

Pointing. The joints on faces of masonry above the foundation shall be cleaned out to a depth of 1 inch, wetted, and pointed with Portland cement mortar well and securely pressed into the joints; the whole work shall have a neat and clean finish. Cut-stone work shall be hollow-pointed; all other masonry shall be cut-pointed.

New Masonry on Old. When new masonry is laid on old masonry, the latter shall be cleaned, wetted, and thoroughly grouted before laying new work. All new work shall bond with the old. The new face stones shall match the old.

Dressing before Setting. All cutting and dressing necessary shall be done before the stones are set, and by skilled workmen. Under no circumstances shall the hammering or dressing of stone upon the walls be allowed. The stones shall be placed in position so as not to disturb those previously laid.

Dressing. In all classes of work, the faces of the stone shall have uniform projections, not exceeding 3 inches beyond the neat lines. All projecting angles and arrises shall have hammer-dressed beds and joints and shall be run with a neat chisel draft of 1½ inches on each face.

Mortar Joints. Mortar joints in the face of the wall, in first-class and second-class work, shall not exceed one-half inch in thickness. The vertical joints of the face shall be in contact at least 1 foot in first-class and 9 inches in second-class work, measured in from the face, and as much more as the stone will admit.

Dashing Backs of Walls. The joints on the back of all masonry walls shall be carefully and thoroughly dashed with cement mortar so as to make the walls as nearly water-tight as possible.

When the back of a wall adjoins rock, it shall be built tight against the rock and the joint shall be thoroughly grouted.

Dry Stone Packing. Dry stone packing shall consist of stone laid without mortar, and the stone used shall generally be from three-fourths of a cubic foot to 2 cubic feet in volume.

Measurement. All masonry shall be built according to the plans and instructions furnished by the Engineer, and the several classes thereof shall be estimated and paid for by the cubic yard, computing only the actual solidity thereof required by the plans.

No constructive or conventional measurement shall be allowed, any rule or custom to the contrary notwithstanding.

Freezing Weather. All work in stone and brick masonry and concrete shall be suspended during freezing weather except on structures in which delay would affect the general progress of the work and under such regulations and conditions as the Engineer may prescribe. Whenever required by the Engineer, the sand and water shall be heated before being used in the work. No masonry laid in freezing weather shall be pointed until spring.

Inspection. All material shall be subject to inspection and any that has been condemned shall immediately be removed from the site of the work. All masonry shall be subject to the supervision of an Inspector whose duties shall be to see that the requirements of these specifications are conformed to, but his presence is in no way to be presumed to lessen in any degree the responsibility of the Contractor or his obligations.

No masonry of any kind shall be covered up before it has been inspected and passed upon.

Price to Include. The price per cubic yard paid for stone, brick, or concrete masonry shall include the furnishing of all material, all scaffolding, forms, and centering, and all other expenses necessary to the construction and completion of the masonry and the maintenance of same until the work is accepted.

CLASSIFICATION OF MASONRY

Masonry shall be classified under the following heads: First Class; Second Class; Third Class; First-Class Arch; Brick; and Concrete.

First-Class Masonry

First-class masonry shall consist of range rock work of the best description. The face stones shall be accurately squared, pointed, and bedded, and laid in regular and horizontal courses of not less than 12 inches in thickness and not greater than 30 inches, decreasing in thickness regularly from the bottom to the top of the walls. The stones of each course shall be so arranged as to form a proper bond with the stones of the underlying courses, and a bond of less than 1 foot shall in no case be allowed.

Stretchers. Stretchers shall not be less than 4 feet in length. They shall have 18 inches width of bed for all courses under 18 inches; and for all courses above 18 inches they shall have as much bed as face. They shall not break joint on headers.

Headers. Headers shall not be less than 4 feet in length. They shall occupy one-fifth of the face of the wall and no header shall have less than 18 inches width of face; where the course exceeds 18 inches in height, the width of face shall not be less than the height of the course.

When the walls do not exceed 4 feet in thickness, the headers shall run entirely through, and in all cases they shall be long enough to form a proper bond with the backing.

When the stone used in any work is in very large blocks, exceeding the requirements given above, then a stone that runs into the wall to a distance at least as great as the average length of the stretchers shall be considered a header.

Backing. The backings shall be of third-class masonry or 1-3-6 concrete, as shall be directed by the Engineer, well bonded with the facework and itself.

Foundation Courses. All work below the neat line shall be 1-3-6 concrete, laid as specified, and paid for at the price for ''1-3-6 concrete masonry in foundation''.

Laying. The masonry shall be laid up as specified under ''Laying''.

Bridge Piers. Bridge piers built in streams subject to ice floes shall be built of *first-class masonry* facing with *concrete masonry* backing, in the heart of the wall.

The stones forming the cutwater of piers which act as ice breakers shall be neatly and smoothly dressed on their faces, and fastened together with iron cramps and to the interior of the piers. The surfaces of the other face stones shall, with the exception of the draft, be left as they come from the quarry unless the projection above the draft exceeds 3 inches, in which case they shall be roughly scabbled down to that projection.

Second-Class Masonry

Second-class masonry shall consist of broken or random range rock work of the best description, and shall conform in every other respect to first-class masonry.

Third-Class Masonry

Third-class masonry shall be formed of approved quarry stone of good shape and good flat beds. No stones shall be used in the face of the walls less than 6 inches thick, or less than 12 inches in their least horizontal dimensions.

Headers and Face Stones. Headers shall generally form at least one-fifth of the faces and backs of the walls, with a similar proportion throughout the mass when they do not interlock, and the face stones shall be well scabbled or otherwise worked so that they may be set close, and chinking with small stones be avoided.

Size of Stones, etc. In walls 5 feet thick or less, the stones used shall average from 6 to 8 cubic feet in volume, and the length of the headers shall be equal to two-thirds of the thickness of the wall; in walls over 5 feet in thickness, the stones used shall average 12 cubic feet in volume, and the headers shall not be less than 4 feet long. Generally no stones shall be used having a less volume than 4 cubic feet, except for filling the interstices between the larger stones.

Limit of Height and Bond. In no case shall stones be used having a greater height or build than 30 inches, and these stones must bond the joints above and below at least 18 inches; in all other cases the smaller stones used must bond the joints above and below at least 10 inches.

Foundation Stones. The stones in the foundation generally shall be not less than 10 inches in thickness and contain not less than 10 square feet of surface.

The foundation shall consist of 1-3-6 concrete, if so directed by the Engineer.

Laying. The masonry shall be laid up as specified under "Laying".

First-Class Arch Masonry

First-class arch masonry shall be laid in cement mortar, and shall be built in accordance with the specifications for first-class masonry, when and to the extent that the Engineer may direct. The ring stones shall be dressed to such size and shape as the Engineer may determine.

Ring Stones and Arch-Sheeting Stones. The ring stones and arch-sheeting stones shall not be of less thickness than 10 inches on the intrados of the arch, and shall be dressed with $\frac{3}{8}$-inch radial joints, and shall be of the full depth specified by plans, or otherwise, for the thickness of the arch. The joints shall be made on true radial lines, and the ends of the sheeting stones and the ring stones shall be dressed to make close joints. The ring stones and the arch-sheeting stones shall break joints not less than 1 foot apart.

Parapets. The parapets shall be finished with a coping course of the full width of the top of the parapet, with such projection as may be directed by the Engineer. The stones shall be not less than 10 inches in thickness.

Brick Masonry

Brick masonry shall be laid with the best quality of hard burned brick, well tempered and molded to standard size.

Quality of Bricks. No bats, except necessarily as closers for properly dimensioning the several courses, nor cracked, crooked, or salmon bricks, shall, under any circumstances, be allowed in the work. The bricks shall be thoroughly wetted and shall be laid, end and side at one operation, in full close joints of mortar. The style of bond shall be prescribed by the Engineer. The best-shaped and best-colored brick shall be reserved for facework, which shall be finished with a neatly drawn joint and pointed where required.

Mortar and Grouting. *Proportions.* All mortar to be used in the building of stone or brick masonry shall be composed of 1 part of cement to 3 parts of sand. All mortar for pointing and bedding copings, bridge seats, and pedestal blocks shall be composed of 1 part of cement to 2 parts of sand.

Grout shall be composed of 1 part of Portland cement to 3 parts of sand, except where the foundations are wet, when the quantity of sand shall be diminished, making the proportions 1 part of cement to 2 parts of sand, and this shall be used in the foundation masonry up to the neat lines, if required.

All the above mixtures shall be proportioned by measurement. It is assumed that 376 pounds of cement shall have a volume of 3.6 cubic feet. The sand and cement shall first be mixed dry in suitable tight boxes, after which the proper amount of water shall be gradually added. Only such quantities of mortar or grouting shall be mixed as are needed for immediate use; if allowed to set, it shall not be retempered and used in masonry construction.

Tensile Strength. Mortar taken from the mixing box and molded into briquettes, 1 square inch in cross section, shall develop the following ultimate tensile strengths:

	Per Square Inch
7 days (1 day in air, 6 days in water), 1 part of cement to 3 parts of sand.........	125 lbs.
28 days (1 day in air, 27 days in water), 1 part of cement to 3 parts sand.......	175 lbs.

Sand. Sand for grouting shall be tide-washed, sharp, siliceous, dry-screened bar or approved bank sand, containing not more than 5 per cent of loam, clay, dirt, or other impurities. Sand for mortar shall be composed of grains graded from coarse to fine, thoroughly screened to reject all particles exceeding one-eighth inch in diameter, and shall be clean and sharp, containing not more than 5 per cent by weight of clay, loam, dirt and other impurities, and equal in quality to the best New Jersey bank sand.

Water. Water shall be fresh, and free from dirt, oil, or grease. Salt water may be used, as directed by the Engineer, when necessary to construct masonry in freezing weather.

Cement

Kind. All cement shall be Portland, of the best quality, dry and free from lumps. By Portland cement is meant the finely-pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials to which no addition greater than 3 per cent has been made subsequent to calcination.

Packages. Cement shall be packed in strong cloth or canvas bags, or in sound barrels lined with paper, which shall be plainly marked with the brand and name of the manufacturer. Bags shall contain 94 pounds net and barrels shall contain 376 pounds net.

Inspection. All cement shall be inspected. The Contractor shall submit the cement, and afford every facility for inspection and testing, at least 12 days before desiring to use it. The Engineer shall be notified at once upon receipt of each shipment. No cement shall be inspected or allowed to be used unless delivered in suitable packages, properly branded.

Protection. The cement shall be protected in a suitable building having a wooden floor or platform raised from the ground, and may be reinspected at any time.

Storage. The cement shall be stored in a manner that will enable each carload lot to be kept separate and be tagged with car number and date of receipt. One carload shall not be placed immediately upon another.

Failure of Brand. The failure of a shipment of cement on any work to meet the requirements given below may prohibit further use of the same brand on that work. Rejected cement shall immediately be removed from the work.

Quality. The acceptance or rejection of a cement to be used shall rest with the Engineer, and shall be based on the following requirements:

Specific Gravity: not less than 3.1.

Ultimate Tensile Strength per square inch:

7 days (1 day in air, 6 days in water).....	500 lbs.
28 days (1 day in air, 27 days in water)..	600 lbs.
7 days (1 day in air, 6 days in water), 1 part of cement to 3 parts standard quartz sand........................	200 lbs.

28 days (1 day in air, 27 days in water), 1 part of cement to 3 parts standard quartz sand .... 275 lbs.

Fineness: Residue on No. 100 sieve not over 8 per cent by weight. Residue on No. 200 sieve not over 25 per cent by weight.

Set. It shall require at least 30 minutes to develop initial set, and not less than 1 hour nor more than 10 hours to develop hard set. These requirements may be modified where the conditions of use make it desirable.

Constancy of Volume. Pats of cement 3 inches in diameter, one-half inch thick at center, and tapering to a thin edge, when immersed in water after 24 hours in moist air, shall show no signs of cracking, distortion, or disintegration. Similar pats in air shall also remain sound and hard. The cement shall pass such accelerated tests as the Engineer may determine.

The following test will be made in accordance with the rules adopted for Standard tests by the American Society for Testing Materials, August 16, 1909, with subsequent amendments.

Sulphuric anhydride (SO_3); not more than 1.75 per cent.

Magnesia (MgO); not more than 4 per cent.

Briquettes for testing shall be 1 square inch in area of cross section; sieves shall be of brass wire-cloth having approximately 9800 and 37,500 meshes per square inch, respectively, the diameter of the wire being 0.0045 and 0.0023 inches, respectively.

Concrete

Proportions. Concrete masonry shall consist of two grades. These shall be used wherever specified or directed by the Engineer. They shall be known as 1-2-4 and 1-3-6, respectively.

Parts by Volume

CEMENT	SAND	STONE
1	2	4
1	3	6

If required by the Engineer, the mixture shall be modified by changing the relative amounts of sand and stone, but keeping the aggregate of 6 parts of sand and stone for the 1-2-4 concrete, and 9 parts of sand and stone for the 1-3-6 concrete.

The proportions of all materials shall be determined by measurement. The volume of a barrel of cement, 376 pounds, shall be assumed to be 3.6 cubic feet. The sand and stone shall not be packed more closely than by throwing in the usual way into a barrel or box at the time of measurement.

Cement. Portland cement shall be used, of the quality specified under "Cement".

Stone. The stone shall be clean hard crushed stone or pebbles, to be approved by the Engineer, composing the whole run of the crusher, in size from one-fourth inch to three-fourths inch, when used for bedding on metal decks, bridge seats, etc.; and from one-fourth inch to 1½ inches for other purposes, screened of dust and particles less than one-fourth inch.

Sand. Sand shall be clean and sharp and shall be composed of grains graded from fine to coarse, screened if required, to reject all particles of a greater diameter than one-fourth inch. It shall not contain more than a 5 per cent weight of clay, loam, dirt, or other impurities, and shall be equal in quality to the best New Jersey bank sand.

Care of Sand and Stone. Sand and stone when delivered on the work shall be dumped on platforms and not upon the ground.

Machine Mixing. All mixing shall preferably be done by machine, but hand mixing shall be allowed in special cases.

When mixed by machine, cubical box mixers, or those which allow of dry mixing of the materials before the water is added, shall be preferred. The proportions shall be accurately determined before being placed in the mixer and means shall be provided for accurately measuring the water.

(See water specifications, page 43.)

Measuring boxes or other approved apparatus shall be used, so that the proportions can be exactly determined. The ingredients shall be thoroughly mixed before the water is added, and the mixing shall be continued until every particle of stone is covered with mortar. No retempering shall be allowed under any conditions.

Hand Mixing. When mixed by hand, the cement and sand shall be first mixed dry and then made into a mortar. The stone shall be spread upon a suitable floor to a depth of about 6 inches and thoroughly wetted (see water specifications, page 43), and the mortar evenly spread over it, care being taken that the stone of each batch is mixed as to size. The whole mass shall then be turned over 4 times and raked to secure complete and uniform mixture. If the Contractor desires to use some other method, he shall submit it for approval. Should the mixture be permitted to set before placing or tamping, it shall be removed and not used. Hand-mixed batches shall not be larger than 1 cubic yard in volume.

Depositing. All concrete shall be deposited in sections and in layers of such thickness—not exceeding 9 inches—as the Engineer shall direct. It shall be of such consistency that when dumped in place it will not require much tamping, but shall not be wet enough to cause the mortar to separate from the stone; it shall be spaded down and tamped sufficiently to level off and will then quake freely like jelly. Where concrete is marked on the face into courses, each requiring two or more layers, the layers shall follow each other in close succession before setting, so as to avoid visible joints on the face of a course.

Surface of Concrete Exposed to the Street. Surfaces of concrete exposed to the street shall be composed of 1 part cement, 2 parts coarse sand or gravel, and 2 parts granolithic grit, made into a stiff mortar. Granolithic grit shall be granite or trap rock crushed to pass a one-fourth-inch sieve and screened of dust. For vertical surfaces the mixture shall be deposited to a minimum thickness of 1 inch against the face forms by skilled workmen. This shall be done as the placing of the concrete proceeds, and thus form a part of the body of the work. Care shall be taken to prevent the occurrence of air spaces or voids in the surface. The face forms shall be removed as soon as the concrete has sufficiently hardened and any voids that may appear shall be filled up with the mixture.

The surface shall then be washed immediately with water until the grit is exposed; it shall then be rinsed clean, protected from the sun, and kept moist for 3 days. For horizontal surfaces, the granolithic mixture shall be deposited on the concrete to a minimum thickness of 1½ inches, immediately after the concrete has been tamped and before it has set, and shall be troweled to an even surface; after it has set sufficiently hard, it shall be washed until the grit is exposed.

All concrete surfaces exposed to the street shall be marked off into courses in such detailed manner as may be directed by the Engineer.

Other Showing Surfaces. All other showing surfaces shall be prepared by keeping the stone well back from the face as the concrete is placed; this is done by bringing the mortar against the forms by "spading".

Horizontal exposed surfaces shall be finished with a layer of cement mortar, 1 part cement to 2 parts sand, 1 inch thick, and troweled to a smooth surface.

After the forms are removed the surfaces shall be pointed

REINFORCED CONCRETE PILES IN PLACE AS SUB-STRUCTURE FOR ORE DOCK

A 50-ton test load of pig iron has been mounted on one pile to show whether any appreciable settling resulted.

Courtesy of Great Lakes Dredge and Dock Company, Chicago

where necessary and washed with neat cement applied with a brush.

Plastering the face after removing the forms shall not be permitted.

Protection of Exposed Surfaces. Provision shall be made to protect exposed surfaces from the action of the elements, until the concrete has set.

Forms. Suitable forms shall be constructed, the cost of which shall be included in the price per cubic yard for the concrete.

The dimensions shall be such that the finished concrete shall be of the form and dimensions shown on the plans or as ordered by the Engineer. All forms shall be set true to the lines designated and shall be built so as to remain firm and secure until the concrete has firmly set. They shall be satisfactory to the Engineer and shall remain in place as long as he deems it necessary. The interior surfaces of the forms which come in contact with the exposed surfaces of the concrete shall be of dressed lumber having close joints, and shall be so constructed as to leave all exposed surfaces of the concrete smooth, even, and presentable. Face forms shall have triangular beads secured to the planks to mark the face of the concrete into courses by imprint.

All top edges of copings, pedestal blocks, and bridge seats, the vertical angles of abutments, piers, and retaining walls, and the bottom edges of the rings of all arches shall be formed by placing fillets inside the forms as shown on the plans.

Cleaning Joints. In work above ground, the top surface of each course shall be scraped within 24 hours, to remove the "laitance" or scum, and insure the adhesion of the next layer.

Contraction Joints. Contraction joints shall be placed wherever directed by the Engineer. The sections of wall shall generally be about 50 feet in length, shall be made with tongue and grooved joints as directed, and corrugated asbestos boards shall be used on the faces of the joints. Payment shall be made for the corrugated asbestos boards at the price given in the proposal, but all other expenses attendant upon making the joint shall be included in the price per cubic yard of concrete.

Steel in Reinforcement. Rods for reinforcing concrete shall be of steel of some approved shape specially formed for that purpose and designed to secure an interlocking bond between the concrete and the steel. If the rods are twisted, the twists shall be made cold and shall be sufficient to give one complete turn in a length equal to 6 times the least diameter of the bar.

Imbedded Stone. If the Contractor shall so elect, approved hard stone not exceeding 6 to 8 feet may be imbedded in the foundation concrete; similar stone, but not larger than 2 cubic feet each, may be imbedded in the neat work. The stones shall be thoroughly cleaned and placed so as to be entirely surrounded by concrete, and shall not be closer than 6 inches to any face of the work. In the neat work, the stones shall be imbedded so as to form dowels bonding each day's work.

Concrete Deposited under Water. In case it is found necessary to lay concrete under water, approved appliances shall be used to insure its being deposited with as little injury as possible.

Waterproofing

Percolation of Water to be Prevented. It is the very essence of these specifications to secure an underground structure which shall be entirely free from the percolation of ground water or outside water, to which end construction shall be carried out as follows:

Preparation of Foundations. After the soil has been excavated to the required depth and dressed off to a true grade as directed by the Engineer, there shall be laid a bed of concrete of the proportions herein described, and of such thickness as (in the judgment of the Engineer) the local conditions demand. On such bed, which shall be made as level and smooth as possible on the top surface, there shall be spread a layer of hot asphalt, and on such asphalt there shall be immediately laid sheets or rolls of felt, all of the quality hereinafter described; another layer of hot asphalt shall be spread over the felt; another layer of felt laid, and so on until not less than 2 such layers of felt nor more than 6 be laid, with asphalt between each layer, and asphalt beneath and on top of the whole. On top of the upper surface of asphalt, the remainder of the concrete as called for by the contract drawings shall be put in place. In dry open soil the felt in the floor concrete may be omitted, the base course of concrete being covered with one good layer of asphalt. In rock excavation, where the same is dry and above water level, both the felt and the asphalt in the floor may be omitted.

Side-Wall Construction. When the I-beam columns of the side walls are set and secured permanently in place, the concrete composing the side walls shall be rammed in place in such manner that the back or outer face is flush with the outer flanges of the columns. On such outer face hot asphalt shall be brushed and felt spread in alternate layers, in the same manner as described for the foundations, and the backing of concrete shall then be added, as shown by the plans. Instead of constructing the side walls with the waterproofing as described above, the Contractor may build in dry open soils, if permitted by the Engineer and if no additional width of excavation is required for sewers or other purposes, a 4-inch brick wall supported at the back by the trench sheathing, laid in cement mortar or hot asphalt, and at a distance of at least 2 inches in the clear from the line of the exterior faces of the side-wall beams; and then he may attach to it the layers of waterproofing material as described above, and ram around the beams and against the waterproofing surface the concrete composing the side walls. Under similar conditions in dry rock excavation, the rock may be excavated so that no projecting point comes within 3 inches of the line of the exterior face of the side-wall beams; then the rough surface shall be made smooth with a plaster of concrete, and on such smooth surface the waterproofing material shall be spread; and then the concrete of the side walls may be rammed against the same in the manner described above.

Roof Construction. The roof of the structure shall be treated in a similar manner by finishing the jack arches to such height as may be directed by the Engineer, spreading the asphalt and felt in alternate layers, and then adding a cover of concrete, completing the roof as called for by the Contract Drawings.

Continuous Waterproof Envelope. By the arrangement above described there will be a continuous sheet of asphalt and felt imbedded within the concrete of the bottom, top, and both sides, and completely enveloping the structure.

Quality of Asphalt. The asphalt used shall be the best grade of Bermudez, Alcatraz, or lake asphalt of equal quality, and shall comply with the following requirements:

> The asphalt shall be a natural asphalt or a mixture of natural asphalts, containing in its refined state not less than 95 per cent of natural bitumen soluble in rectified carbon bisulphide or in chloroform. The remaining ingredients shall be such as not to exert an injurious effect on the work. Not less than two-thirds of the total bitumen shall be soluble in petroleum naphtha of 70° Baumé or in acetone. The asphalt shall not lose more than 4 per cent of its weight when maintained for 10 hours at a temperature of 300° Fahrenheit.

Coal Tar Prohibited. The use of coal tar, so-called artificial asphalts, or other products susceptible to injury from the action of water, will not be permitted on any portion of the work, or in any mixtures to be used.

Quality of Felt. The felt used in waterproofing such part of the structure as is below ground water level shall be composed of asbestos or other equally nonperishable material dipped in asphalt and weighing not less than 10 pounds to the square of 100 feet. The felt used in other parts of the structure shall be the same as the above, or of the best quality of coal tar felt weighing not less than 15 pounds to the square of 100 feet; except that, if the latter be used, one layer more of it will be required than of the former. All felt shall be subject to the approval of the Engineer.

Surfaces to be Smooth. The surfaces to be waterproofed shall be smooth, without projecting stones, or made smooth where necessary by a coating of mortar made of one portion Natural cement to one portion sand, and should be dry before the asphalt is applied.

Artificial Drying. Means for artificially drying the surface of concrete may be taken by the Contractor by blowing warm air over it, or as otherwise permitted by the Engineer, but not until the concrete has had at least 48 hours in which to set.

No Cracks or Blowholes. Each layer of asphalt fluxed as directed by the Engineer must completely and entirely cover the surface on which it is spread, without cracks or blowholes.

Felt to be Carefully Laid. The felt must be rolled out into the asphalt while the latter is still hot, and pressed against it so as to insure its being completely stuck to the asphalt over its entire surface. Great care should be taken that all joints in the felt are well broken; that the ends of the rolls of the bottom layer be carried up on the inside of the layers on the sides; and that those of the roof be carried down on the outside of the layers on the sides, so as to secure a full lap of at least 3 feet. Especial care must be taken with this detail.

Skilled Men. None but competent men, especially skilled in work of this kind, shall be employed to lay asphalt and felt.

Top Surface of Asphalt not to be Broken. When the finishing layer of concrete is laid over or next to the waterproofing material, care must be taken not to break, tear, or injure in any way the outer surface of the asphalt.

Number of Layers of Felt. The number of layers of felt on the sides and under the floor shall in no case be less than 2 in ground that is quite dry; and where there is a water pressure against the masonry equal to 12 feet, there shall not be less than 6 layers. Where the water pressure is less than 12 feet, or where the ground is damp, such number of layers between 3 and 6 shall be used as the Engineer may direct. The number of layers of felt on the roof shall be not less than 3 of asphalted asbestos or 4 of tarred felt.

Bricks Dipped in Asphalt. At any point where the Contract

Drawings and the Engineer permit, the Contractor may lay, instead of the asphalt and felt above described, one or more courses of bricks dipped in hot asphalt of the above described quality, and laid while the coating of asphalt is still hot.

Asphaltic Concrete. In foundations, the Contractor may lay, if he prefer, instead of the ordinary concrete with the layer of waterproofing material, as above described, a bed of asphaltic concrete, composed of broken stone of the qualities previously described for concrete, heated in a suitable heater to such proper temperature as the Engineer may direct and, when so heated, have added thereto the melted asphalt of the quality as described above, in such proportion as to insure a covering of each particle of stone with asphalt; the whole mass shall then be thoroughly mixed and incorporated in a suitable mixer. Such asphaltic concrete shall be spread in place and thoroughly rolled and compressed, so that it will present a smooth even surface that will be impervious to water. No asphalt shall be heated to exceed a temperature of 325° Fahrenheit.

Waterproofing—When Omitted. In masonry-lined structures where there is no steel work and the ground is dry, the regular waterproofing may be omitted, but in that case in arched-cut and cover work the extrados of the arch shall be coated with hot asphalt of the quality described, or the best grade of refined Trinidad asphalt.

Leaky Masonry to be Rebuilt. Any masonry that is found to leak at any time prior to the completion of this work shall be cut out and the leak stopped, if so ordered by the Engineer.

LUMBER

Specifications. All lumber shall be sound, straight grained, and free from excessive sap, loose or rotten knots, wind shakes, or any other defect that would impair its strength or durability. It shall be sawed or hewed perfectly straight to exact dimensions, with full corners and square edges.

All long-leaf yellow pine shall be first-class Southern long-leaf yellow pine, sawed true and out of wind, full size, free from wind shakes, large or loose knots, or other defects impairing its strength or durability, and equal in quality to the grade of .... *in "Interstate Rules of 1905, for Classification and Inspection of Yellow Pine Lumber".

All framing shall be done in a thoroughly workmanlike manner and both material and workmanship shall be subject to the

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* Insert here the class of inspection desired, that is, Standard, Merchantable, or Prime. See "Specifications for Classification and Inspection of Lumber".

inspection and approval of, or rejection by, the Engineer. Only the timber actually called for in the plans shall be estimated and paid for. No allowance shall be made for waste.

INTERSTATE RULES OF 1905 FOR THE CLASSIFICATION AND INSPECTION OF YELLOW PINE LUMBER

EFFECTIVE ON AND AFTER FEBRUARY 1, 1905

General Rules

All the lumber must be sound commercial long-leaf yellow pine (pine combining large coarse knots with coarse grain is excluded under these rules), well manufactured, full to size, saw-butted, and free from the following defects: Unsound, loose, and hollow knots, wormholes and knotholes, and through shakes or round shakes that show on the surface. It shall be square-edged, unless otherwise specified.

A through shake is hereby defined to be a fissure through, or fissures connected from side to side, edge to edge, or side to edge.

In the measurement of dressed lumber, the width and thickness of the lumber before dressing must be taken; less than 1 inch thick shall be measured as 1 inch.

The measurement of wane shall always apply to the lumber in the rough.

Where the terms ''one-half heart'' and ''two-thirds heart'' are used, they shall be construed as referring to the area of the face on which measured.

In the dressing of lumber, when not otherwise specified, one-eighth inch shall be taken off by each planer cut.

Classification

Flooring. Flooring shall embrace 4, 5, and 6 quarter inches in thickness by 3 to 6 inches in width, excluding 1½ × 6. For example: 1 × 3, 4, 5, and 6; 1¼ × 3, 4, 5, and 6; 1½ × 3, 4, and 5.

Boards. Boards shall embrace all thicknesses under 1½ inches by over 6 inches wide. For example: ¾, 1, 1¼, and 1⅜ inches thick by over 6 inches wide.

Plank. Plank shall embrace all sizes from 1½ to under 6 inches in thickness by 6 inches and over in width. For example: 1½, 2, 2½, 3, 3½, 4, 4½, 5, 5¼, 5¾ by 6 inches and over in width.

Scantling. Scantling shall embrace all sizes exceeding 1½ inches and under 6 inches in thickness, and from 2 to under 6 inches in width. For example: 2 × 2, 2 × 3, 2 × 4, 2 × 5, 3 × 3, 3 × 4, 3 × 5, 4 × 4, 4 × 5, and 5 × 5 inches.

Dimension. Dimension sizes shall embrace all sizes 6 inches and up in thickness by 6 inches and up in width. For example: 6 × 6, 6 × 7, 7 × 7, 7 × 8, 8 × 9, and up.

Stepping. Stepping shall embrace 1 to 2½ inches in thickness by 7 inches and up in width. For example: 1, 1¼, 1½, 2, and 2½ × 7, and up in width.

Rough Edge or Flitch. Rough edge or flitch shall embrace all sizes 1 inch and up in thickness by 8 inches and up in width, sawed on 2 sides only. For example: 1, 1½, 2, 3, 4, and up thick by 8 inches and up wide, sawed on 2 sides only.

Inspection

Standard. All lumber shall be sound. Sap is no objection and wane may be allowed one-eighth of the width of the piece measured across the face of the wane, extending one-fourth of the length on one corner, or its equivalent on two or more corners, provided that not over 10 per cent of the pieces of any one size shall show such wane.

Merchantable. All sizes under 9 inches shall show some heart the entire length on one side; sizes 9 inches and over shall show some heart the entire length on two opposite sides. Wane may be allowed one-eighth of the width of the piece measured across the face of the wane, and extending one-fourth of the length of the piece on one corner or its equivalent on two or more corners, provided that not over 10 per cent of the pieces of any one size shall show such wane.

Prime. *Flooring.* Flooring shall show one heart face, free from through or round shakes or knots exceeding 1 inch in diameter, or more than 4 in a board on the face side.

Boards. Boards 7 inches and under in width shall show one heart face; over 7 inches in width, they shall show two-thirds heart on both sides, all free from round or through shakes, large or unsound knots.

Plank. Plank 7 inches and under in width shall show one heart face; over 7 inches in width, they shall show two-thirds heart on both sides, all free from round or through shakes, large or unsound knots.

Scantling. Scantling shall show three corners heart, free from through or round shakes or unsound knots.

Dimension Sizes. All square lumber shall show two-thirds heart on two sides, and not less than one-half heart on two other sides. Other sizes shall show two-thirds heart on face and show heart two-thirds of length on edges, excepting when the width exceeds the thickness by 3 inches or over; then it shall show heart on the edge for one-half the length.

Stepping. Stepping shall show 3 corners heart, free from shakes and all knots exceeding one-half inch in diameter and not more than 6 in a board.

Rough Edge or Flitch. Rough edge or flitch shall be sawed from good heart timber and shall be measured in the middle, on the narrow face, free from injurious shakes or unsound knots.

Wane shall be allowed on not over 5 per cent of the pieces in any one size, as on merchantable quality.

TERRA COTTA DRAIN PIPE FOR CULVERTS

The Contractor shall furnish and lay vitrified terra cotta pipe, according to place, size, and length, as shown on the plans and profiles, or as ordered by the Engineer.

Quality. The terra cotta pipe shall be of standard lengths and quality, double strength, made of the best material, thoroughly and perfectly burned, of homogeneous texture, without imperfections, and well glazed, so that its surfaces shall be smooth, hard, and even. The pipe shall be straight, not varying more than one-eighth inch from a straight line per foot of length; true to form; of full diameter throughout; of a thickness at least equal to that of double strength standard sewer pipe and of the same diameter; and it may have either socket or sleeve joints. The bells shall be of standard depth, and large enough to receive to their full depth all spigot ends without clipping and to leave a space of not less than $\frac{1}{4}$ of an inch all around for cement.

Laying. All pipe shall be laid true to line and grade given by the Engineer, and on good bottom. Unless timber and concrete foundations are indicated on the profile, an excavation of at least 6 inches in depth to receive the pipe shall be made to conform to the shape of the pipe. The pipe shall be laid in such length as to extend at least 1 foot beyond the foot of the slopes of the finished embankment unless otherwise ordered by the Engineer.

Joints. The space between the pipe and the socket shall be as uniform as possible, and shall be made water-tight by first using a small jute gasket, thoroughly saturated with neat cement, carefully coiled and calked in the bell of the pipe. The joints shall then be thoroughly filled with cement mortar, made of equal parts of cement and clean sharp sand, thoroughly mixed dry, water enough being afterwards added to give it the proper consistency, and the mortar shall be used as soon as made; after this the joint shall be carefully wiped inside and out, and pointed.

Interior of Pipe. The interior of the pipe shall be carefully cleaned of all dirt, cement, or superfluous materials of every description.

The Contractor shall make good all defects and remove any foreign matter which may have been left in or otherwise introduced into the pipe, before the final acceptance of the work.

Payment. Drain pipe shall be estimated and paid for by the linear foot in place, the price to include the pipe, the hauling, and placing as specified. Where shown on the profile, end walls for the drain pipe shall be constructed of masonry in accordance with the standard plans for end walls for pipe culverts, the concrete for same to be paid for at the price given in the proposal for No. 2 concrete.

CAST-IRON PIPE CULVERTS

The Contractor shall furnish and lay cast-iron water pipe according to place, size, and length as shown on the plans and profiles.

Quality. All cast-iron pipe shall be free from such defects and imperfections as shall, in the opinion of the Engineer, make it unacceptable for use as pipe culverts, and it shall be of standard thickness and length. Where it is necessary to use cut pipe, the cutting shall be done in such a manner as to leave a smooth end at right angles to the axis of the pipe.

Laying. All pipe shall be laid true to line and grade, and in such lengths that the ends of the pipe shall extend not less than 1 foot beyond the foot of the slopes of the finished embankments, unless otherwise ordered by the Engineer.

Blocking. Each length of pipe shall be laid upon blocking set at 3 different places along its length. It shall be of sound 3- by 10-inch planking and shall have a length equal at least to the diameter of the pipe. Wedges shall be placed on the blocking to hold the pipe in position. The blocks shall be bedded firmly and evenly across the line of pipe and, when any block has been sunk too deep, additional blocking shall be placed to bring the pipe to the required grade.

Joints. The space between the pipe and the socket or collar shall be as uniform as possible, and shall be made water-tight by being thoroughly filled with Portland cement mortar, made of equal parts of an approved cement and clean sharp sand.

Interior of Pipe. The interior of the pipe shall be carefully cleaned of all dirt, mortar, or superfluous materials of every description. The Contractor shall make good all defects and remove any foreign matter which may have been left in or otherwise introduced into the pipe, before the final acceptance of the work.

Payment. Cast-iron pipe shall be estimated and paid for by the linear foot in place, the price to include the pipe, the hauling, and the placing as specified. Where shown on the profile, end walls for the pipe shall be constructed of masonry in accordance with the standard plans for end walls for pipe culverts.

STRUCTURAL STEEL FOR BUILDINGS*

Steel. All steel may be made by either the Bessemer or the open-hearth process, except rivet steel and steel for plates or angles over $\frac{3}{4}$ inch in thickness which are to be punched, and these will be made by the open-hearth process. The finished products shall be straight and free from flaws and shall have clean smooth surfaces.

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* See specification for steel under Bridges, p. 65, as another example.

Schedule of Requirements. The requirements are as follows:

Chemical and Physical Properties	Structural	Rivet
Phosphorous maximum, Bessemer........	0.10 per cent	....
Phosphorous maximum, open-hearth......	0.06 per cent	0.06 per cent
Sulphur	....	0.045 per cent Desired
Tensile strength, lbs. per sq. in.........	55,000–65,000	48,000–58,000
Elastic limit, minimum per sq. in.......	½ tens. str.	½ tens. str.
Elongation—minimum per cent in 8 in....	$\left\{\frac{1,400,000}{\text{tens. str.}}\right.$	$\left\{\frac{1,400,000}{\text{tens. str.}}\right.$
Elongation in 2 in. minimum per cent.....	22	....
Character of fracture..................	silky	silky

Bend Tests. The test specimens for plates, shapes, and bars shall bend cold through 180 degrees without cracking on the outside of the bent portion, as follows: For material ¾ inch to and including 1¼ inches in thickness, around a pin the diameter of which is equal to the thickness of the specimen; and for material over 1¼ inches in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen. For pins and rollers the test specimen shall bend cold through 180 degrees around a 1-inch pin, without cracking on the outside of the bent portion. For rivet steel the test specimen shall bend cold through 180 degrees, flat on itself, without cracking on the outside of the bent portion.

Annealing Tests. Material which is to be used without annealing or further treatment shall be tested in the condition in which it comes from the rolls. When material is to be annealed or otherwise treated before use, the specimen representing such material shall be similarly treated before testing.

Test Pieces. For each melt there shall be furnished by the Contractor, properly prepared, free of charge to the railway company, at least 1 tensile and 1 bending test.

Stock Material. No material shall be taken from stock without the consent of the Inspector. Such material shall be stamped with the original melt number and shall not have more than surface rust. In any case in which the rust has eaten into the material, the piece shall not be accepted.

Shop Work. All workmanship shall be first class in every particular and all parts shall be neatly finished.

STEEL BRIDGE SPECIFICATIONS

When specifications are contained in letter of invitation, or shown on accompanying plan, they shall supersede those herein which conflict therewith.

Should any question arise as to the interpretation of these specifications, the decision of the Chief Engineer of the.......................... Company shall determine the matter.

RAILROAD BRIDGES

General Clauses

Material. All bridges shall be constructed of rolled steel; but cast iron or cast steel may be used in the machinery of drawbridges, and wrought iron for laterals and unimportant members.

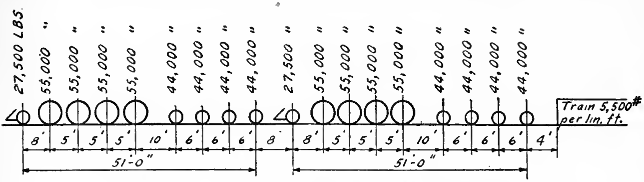

Fig. 1. Live Load Diagram for Railway Bridges.

Live Load. All structures shall be designed to carry, in addition to their own weight, the moving load shown in Fig. 1 or Fig. 2, moving simultaneously on each truck in the same direction.

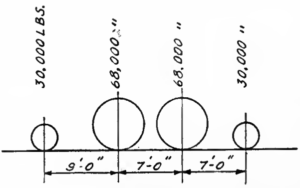

Fig. 2. Live Load Diagram for Railway Bridges.

For transverse trough or buckled plate floors, the live load shall be taken at 16,000 pounds per foot of track.

Dead Load. The dead load shall consist of the weight of the metal in the structure and an assumed weight of 500 pounds per lineal foot of single track for the ordinary wooden floor, the rails, etc. For ballast floors the following weights shall be assumed:

Ballast	120 lbs. per cubic foot
Concrete	140 lbs. per cubic foot
Asphalt	90 lbs. per cubic foot
Lumber	54 lbs. per cubic foot

Wind Pressure. For girder bridges the wind pressure against each chord of the bridge shall be taken at 200 pounds per lineal foot. In addition to this, on the chord which carries the track, a wind pressure of 400 pounds per lineal foot, with its point of application 7½ feet above the rail, shall be taken as a moving load.

For viaducts and trestle towers, on the unloaded structure, the wind pressure shall be taken at 50 pounds per square foot of the projected surface of two trusses and two sides of towers on the vertical plane through the axis of the structure; on the loaded structure, the pressure shall be taken at 30 pounds per square foot of this same surface and, in addition, the moving wind load specified for girder bridges.

For determining the requisite anchorage for the loaded structure, the train shall be assumed to weigh 600 pounds per foot.

Momentum of Train. The horizontal force developed by suddenly stopping a train shall be taken at one-fifth of the moving load.

Centrifugal Force. The centrifugal force shall be taken at 2 per cent of the moving load for each degree of curvature of the track—all the tracks being loaded. Centrifugal force shall be considered live load.

Spans. The spans assumed for calculation shall be as follows: For pin bridges, the distance between centers of end pins; for riveted bridges, the distance between centers of end bearings; for floor beams, the distance between centers of trusses; for stringers, the distance between centers of floor beams.

Depth. The depths assumed for calculation shall be as follows: For pin bridges, the distance between centers of chord pins; for riveted bridges, the distance between centers of gravity of flanges.

Stress Sheets and Plans. All parts shall be so designed that the stresses coming upon them can be accurately calculated.

Bidders shall submit with their bids a general plan and complete stress sheet, showing the loads used and the separate stress produced on each member by each of the foregoing loads and forces, and the sizes and arrangement of parts in sufficient detail for comparison with other plans.

Upon award of contract the Contractor shall furnish in duplicate to the Chief Engineer of the railway company blueprints of complete shop and erection plans showing all details, which shall be subject to the approval of the said Chief Engineer. Upon completion of the work all tracings shall be delivered to the Chief Engineer of the railway company. Tracings shall be of uniform size, and not larger than 30 inches by 42 inches.

Clearance. The gage of the track is 4 feet 8½ inches, and the distance between the tracks, center to center, is 13 feet.

The vertical clearance for through bridges shall be 22 feet above the top of the rails.

For single-track through bridges, on tangent with rails at the same level, the lateral clear width at the top of rails shall not be less than 10 feet 6 inches; from a height of 2 feet to a height of 17½ feet, it shall not be less than 14 feet; and at a height of 22 feet, it shall not be less than 6 feet (see Fig. 3).

For double-track bridges and for curves and elevation of outside rail, the lateral clear widths shall be increased accordingly.

Wood Floor. The wood floor shall be shown as a standard bridge floor, plan dated................

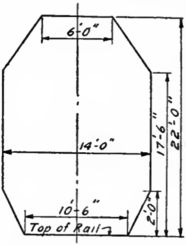

Fig. 3. Vertical Section of Clearance Dimensions on Bridges.

The wood floor shall be continued over all piers and back walls.

Unit Stresses and Sections

To provide for impact and vibrations the stresses produced by the live load shall be increased by the formula

$$I = S \frac{300}{L + 300}$$

where I = amount to be added to the live load stress
S = calculated live load stress
L = length in feet of the loading which produces the maximum stress in the member

The unit stresses produced by the foregoing loads and forces, including impact, shall not exceed the following values:

tension, net section, 15,000 pounds per square inch

compression, $$\frac{15{,}000 \text{ pounds per square inch}}{1 + \dfrac{l^2}{13{,}500 r^2}}$$

where l = length of member, center to center of connections, in inches
r = least radius of gyration in inches

No compression member shall have a length exceeding 100 times its least radius of gyration, except that wind bracing may have a length equal to 120 times its least radius of gyration.

Alternate Stress. Members subject to alternate tension and compression shall have a net sectional area equal to the sum of the areas required for the separate stresses.

Counters. When in any panel the shear from the live load, including impact, exceeds seven-tenths of the opposite shear from the dead load, the oblique equivalent of this excess shall be provided for. No counter rod, however, shall have a smaller section than 1 square inch.

Transverse Loading. In deck truss bridges, when the cross-ties rest on the chord, the sum of the direct thrust per square inch and three-fourths of the fiber stress per square inch produced by the maximum load on the chord panel considered as a supported beam—the pins being in the neutral axis of the section—shall not exceed the allowable compressive stress, the proper amount of impact being added to each kind of loading.

Should the pins be out of the neutral axis, the additional stress thus produced shall be provided for.

The sum of the direct stress per square inch on any member, and the fiber stress per square inch produced by its own weight, shall not exceed the allowed direct stress per square inch by more than 10 per cent.

Shop Rivets and Pins. The shearing stress shall not exceed 11,000 pounds per square inch of section; the pressure on the bearing surface (diameter × thickness of bearing) shall not exceed 22,000 pounds per square inch; the fiber stress due to bending, considering the centers of the bearings at the points of application of the stresses, shall not exceed 22,000 pounds per square inch.

For field-driven rivets a deduction of 20 per cent from the above values shall be made.

The size of the rivets before driving shall be considered their effective size for calculation.

Plate Girders. The bending moment shall be considered as resisted solely by the flanges, with no portion of the web assisting.

The shear in webs of plate girders shall not exceed 10,000 pounds per square inch. But no web shall be less than three-eighths of an inch thick. The entire end shear shall be considered as transferred into the flange angles in a distance equal to the depth of web. The pitch of rivets connecting the web to a top flange supporting the track shall not exceed 3 inches.

When the thickness of web plate is less than one-thirtieth of the unsupported distance between flange angles, stiffeners shall be riveted on both sides of the web, with fillers as thick as the chord angles, and with close bearings against both flanges. For girders 30 feet long and less, the stiffeners shall be $3\frac{1}{2}$ inches by 3 inches by $\frac{3}{8}$-inch angles; for girders 90 feet long, they shall be 5 inches by $3\frac{1}{2}$ inches by $\frac{3}{8}$-inch angles; and for intermediate lengths, intermediate sized angles.

Generally, the stiffeners shall be placed at intervals equal to the depth of the web, with a maximum limit of 5 feet.

Generally, there shall be two pairs of stiffeners over each bed plate, their combined sectional area in square inches being equal to the total end shear in pounds, including impact, divided by 15,000.

Net Section. To obtain the net section of the bottom flange of plate girders or other members, all the rivet holes in any section, taken $\frac{1}{8}$ inch larger in diameter than the rivet to be used, shall be deducted.

The top and bottom flanges shall have the same gross sectional area.

Cover plates shall be at least 12 inches longer than the net calculated length. When over 14 inches wide there shall be at least 4 lines of rivets, with pitch not exceeding 9 inches in any of the lines.

Sway Bracing. Efficient sway bracing and lateral bracing on top and bottom flanges shall be provided. Generally this bracing shall be of the same sized angles as the intermediate stiffeners. The unsupported length of flange shall not exceed 12 times its width, except as noted for track stringers.

Track Stringers and Floor Beams. Track stringers of double track through bridges and deck plate girders shall generally be spaced 6 feet, center to center, under each track. For single track through truss bridges the stringers shall be 8 feet, center to center.

Track stringers shall be riveted into the floor beams and shall bear upon the bottom flange of floor beams, or upon brackets which bear upon the bottom flange of floor beams; but the value of this bearing shall not be considered in computing the number of rivets required in the stringer connections.

Floor beams with riveted end connections shall bear on the bottom flange of the main girder, or on a bracket, in all cases where such bearing can be provided; but the value of this bearing shall not be considered in computing the number of rivets required in the connection. In case such bearing cannot be provided, then the number of rivets in the connection shall be 25 per cent more than the computed number.

In the connection angles between the stringers and floor beams, and other similar angles or plates, the shear shall not exceed 7000 pounds per square inch; but no connection angle shall be less than five-eighths of an inch thick.

When the length of stringer exceeds 20 times the width of flange, lateral bracing shall be provided between the flanges.

The webs of floor beams shall be of the same thickness at center of beams as at the ends.

Minimum Thickness. The minimum thickness of metal used shall be three-eighths of an inch except for lattice bars or for fillers where a lesser thickness is required.

Combined Stresses. In case the sum of the stresses per square inch in the chords and end posts of truss bridges, or the posts of trestle towers—due to the live load including impact, the dead load, and the wind—shall exceed 19,000 pounds per square inch properly reduced for compression, the section shall be increased until this limit is not exceeded.

In the end posts of through bridges the sum of these stresses added to the maximum fiber bending stress per square inch, produced by the portal bracing, shall not exceed 20,000 pounds.

Should the stresses be reversed in any case, proper provision shall be made for such stresses.

Portals and Diagonal Bracing. All through spans with top lateral bracing shall have riveted portal bracing composed of angles, latticed as deep as the headroom will allow, rigidly connected to the end posts.

When the height of the truss exceeds 25 feet, an approved system of overhead diagonal bracing shall be provided at each panel point.

Deck bridges shall have diagonal bracing at each panel point proportioned to resist the unequal loading of the trusses; the position of the track, and the action of the wind and the centrifugal force being considered.

Pony trusses and through plate girders shall be stayed by knee braces or gussets at each floor beam or transverse strut, and at the ends.

No lateral or diagonal rod shall have a smaller area than 1 square inch.

Expansion Rollers, etc. All bridges exceeding 75 feet in length shall be anchored to the masonry at one end, and shall have at the other end nests of turned friction rollers, not less than 4 inches in diameter, running between planed surfaces. The pressure per lineal inch on these rollers shall not exceed $1200\sqrt{d}$ pounds—d being the diameter of the roller in inches.

For bridges less than 75 feet in length one end shall be free to move on planed surfaces.

GENERAL VIEW OF CAMP BIERD, CRISTOBAL
The view shows living accommodations for laborers on the Canal.
Courtesy of Panama Canal Commission, United States Government, Washington, D. C.

Variations in temperature of 150° F. shall be provided for.

Provision shall be made at movable ends against side motion.

Bed Plates. The pressure of bed plates on the masonry shall not exceed 400 pounds per square inch. When two spans rest on the same masonry, a continuous rolled plate $\frac{3}{4}$ inch thick shall extend under the adjacent bearings.

All bed plates shall have efficient stone bolts fastened with sulphur or cement.

Joints and Splices. All joints in riveted work, whether in tension or compression, shall be fully spliced.

Chord sections shall be connected at abutting ends by splices sufficient to hold them true to position, and to transmit the shearing stress at the joint.

Web plates of girders shall be spliced at all joints by a plate on each side, capable of transmitting the entire shear through the splice rivets.

Rivets. The pitch of rivets in the direction of the stress shall not exceed 6 inches, nor sixteen times the thickness of the thinnest outside plate connected, nor be less than three times the diameter of the rivet. At right angles to the stress, the pitch shall not exceed thirty times the thickness of the thinnest outside plate.

At the ends of compression members the pitch shall not exceed four diameters of the rivet for a length equal to twice the width of the member.

The distance from the edge of any piece to the center of rivet hole generally shall be not less than $1\frac{1}{2}$ inches, nor more than 5 inches, nor more than 8 times the thickness of the plate.

Tie Plates. All segments of compression members connected by latticing only shall have tie plates at each end, the rivets and net section of which shall be sufficient to transfer one-half the total maximum stress borne by the segment, and the thickness of which shall be not less than one-fiftieth of the distance between the rivets connecting them to the compression member. In no case, however, shall the length of the tie plate be less than its width across the segments.

Latticing. The open sides of compression members shall be stayed by tie plates at the ends, and by intermediate diagonal latticing.

Generally, the thickness of single lattice bars shall not be less than one-fiftieth, and the thickness of double bars, connected by a rivet at their intersection, shall not be less than one-sixtieth of the distance between rivets connecting them to a member. The inclination of lattice bars with long axis of members shall approximate 60 degrees for single lattice and 45 degrees for double lattice, and the distance between points of connection of the latticing along a segment shall not be more than 8 times the least width of the segment. The width of lattice shall be as follows:

Length of Lattice	Width
Under 10 inches	2 inches
Under 15 inches	2¼ inches
Under 20 inches	2½ inches

For the chords and end posts of truss bridges the lattice shall be generally 3 inches by seven-sixteenth inch.

Pins. The members bearing against any pin shall be so packed as to produce the least bending moment upon the pin, and all vacant spaces must be filled with filling rings.

All pins requiring driving shall be supplied with pilot nuts for use in erection.

Preference. Preference will be given to details which will be most accessible for inspection and painting. No closed sections will be allowed.

Stiff lateral bracing shall be preferred for use between the chords which carry the floor.

Preferably all sections shall be made symmetrical, and the pins placed in the neutral axis. Bending moments at connections shall be avoided as much as possible.

Tension at the foot of trestle posts shall be avoided where practicable.

Camber. Truss bridges with parallel chords shall be given a camber by making the panel lengths of the top chord longer than those of the bottom chord in the proportion of one-eighth of an inch to every 10 feet.

In the wood floor one-half the camber shall be taken out unless otherwise directed.

Bolts. When members are connected by bolts which transmit shearing stress, the holes shall be reamed parallel and the bolts turned to a driving fit.

Screw Ends. In tension members with screw ends, the area at the base of the threads must be at least 15 per cent greater than that required in the body of the member.

Upsetting, etc. The heads of eyebars and the enlarged parts of rods with screw ends shall be made by upsetting, rolling, or forging into shape. Welds in steel bars will not be allowed. In iron bars they will only be allowed to form the loops of laterals, counters, or sway rods.

Quality of Material

Steel. All steel shall be made by the open-hearth process, and shall be uniform in quality. The finished products shall be straight, free from flaws, and have clean smooth surfaces.

Identification of Material. Copies of all bills of material, shipping lists, and complete chemical analyses showing the amount of phosphorus, carbon, sulphur, and manganese shall be furnished by the Contractor free of charge. All material shall be plainly stamped with the number of the melt. Rivet and lattice steel and other small parts may be bundled, with the above marks on an attached metal tag.

Schedule of Requirements. The requirements are as follows:

Chemical and Physical Properties	Structural Steel	Rivet Steel	Steel Castings
Phosphorous maximum... Acid	.08	.04	.08
Phosphorous maximum... Basic	.04	.04	.05
Ultimate Tensile Strength per square inch	Desired 60,000	Desired 50,000	Not less than 65,000
Elastic Limit not less than	½ Ten. Str.	½ Ten. Str.	.45 Ten. Str.
Elongation, minimum per cent in 8 inches	$\frac{1{,}500{,}000}{\text{Ult. Ten. Str.}}$	$\frac{1{,}500{,}000}{\text{Ult. Ten. Str.}}$	
Elongation, minimum per cent in 2 inches	....	....	18
Character of fracture	Silky	Silky	Silky or fine granular

Cold Bends. Samples of structural and rivet steel up to seven-eighths inch in thickness shall bend to close contact without fracture on the convex side. For greater thickness, sample shall bend 180 degrees to a curve of diameter equal to thickness of specimen, without fracture.

Samples of cast steel 1 inch by one-half inch shall bend 90 degrees around a diameter of 1 inch without fracture on outside.

Tensile Tests. Tensile tests of steel showing an ultimate tensile strength within 5000 pounds of that desired will be considered satisfactory, except that if the ultimate strength varies more than 4000 pounds from that desired, a retest shall be made on the same gage which, to be acceptable, shall be within 5000 pounds of the desired ultimate.

Chemical Analyses. Check chemical analyses shall be made from the finished material, if called for by the Chief Engineer, in which case an excess of 25 per cent above the required limits will be allowed.

Material which is to be used without annealing or further treatment shall be tested in the condition in which it comes from the rolls. When material is to be annealed or otherwise treated before use, the specimen representing such material shall be similarly treated before testing.

Drifting. Material punched as in ordinary practice, shall stand drifting until the diameter of the hole is increased 50 per cent without cracking in the periphery of the hole or in the external sheared or rolled edge.

Test Pieces. For each melt there shall be furnished by the Contractor, properly prepared, free of charge to the railway company, at least one tensile and one bending test. Drifting tests shall be furnished occasionally during the progress of the work.

In general, tests shall be selected to cover extreme gages. Material will not be accepted on tests cut from pieces of radically different size or section from that used in the work.

Every test specimen shall be at least one-half square inch in area, and shall be planed, sawed, or turned with sides parallel.

Plates. Plates up to 36 inches wide shall be rolled in a universal mill. Long plates shall not be more than one-half inch out of line in a length of 20 feet, nor three-fourths inch in a length of 40 feet.

Variation in Gage. All shapes shall be rolled to gage. All plates, both sheared and universal, shall be of specified gage on edges. Shapes or plates 3 per cent less than thickness specified shall be rejected, except that in the case of plates 80 inches wide or over a variation of 5 per cent will be allowed.

Stock Material. No material shall be taken from stock without the consent of the Inspector. Such material must be stamped with the original melt number, and must not have more than a surface rust. If any piece of material sent either from the mill or stockyard is rusted when needed in the shop, this rust must be scraped off before the piece is punched. In any case in which the rust has eaten into the material, the piece will not be accepted.

Full-Sized Eyebar Tests. Full-sized tests shall be ordered by the Engineer, and in general will be not more than 4 per cent of the total number of bars in the structure.

The bars shall show an ultimate strength of not less than 55,000 pounds per square inch; an elastic limit of not less than one-half the ultimate strength; and an elongation taken between the necks of the bars of not less than 12 per cent, for bars 20 feet and less between necks. For bars exceeding 20 feet, the elongation shall be not less than 10 per cent.

Fracture. In all full-sized tests, 75 per cent of the fractured area shall be silky, the remainder fine granular.

Retests. If one bar of a lot breaks in the head but fulfills the above requirements, the lot shall not be rejected on that account. If several bars break in the head but fulfill the above requirements, an additional bar for a retest shall be furnished by the Contractor free of cost to the railway company. If more than one-third of the total number of bars tested break in the head the entire lot of bars shall be rejected.

Full-sized members tested to destruction shall be paid for by the Company at cost, less their scrap value, if they fulfill the requirements specified. If they do not, they shall be paid for by the Contractor.

Cast Steel. All steel castings shall be practically free from blowholes and shall be thoroughly annealed.

Wrought Iron. All wrought iron shall be tough, ductile, fibrous, and of uniform quality. Finished bars shall be perfectly welded and have a smooth finish throughout, free from cinder spots, blisters, cracks, buckles, or imperfect edges.

Test specimens shall show an ultimate strength of 50,000 pounds per square inch, an elastic limit of at least 26,000 pounds per square inch, an elongation of at least 20 per cent in a length of 8 inches, and shall stand bending cold 180 degrees to a curve of diameter equal to twice the thickness of specimen, without sign of fracture.

Cast Iron. Unless otherwise specified, all castings shall be tough gray iron, free from cracks, cinders, blowholes, or other imperfections, and of workmanlike finish.

Sample pieces 1 inch square, cast from the same heat of metal in sand molds, shall be capable of sustaining, on a clear span of 4 feet 6 inches, a central load of 500 pounds when tested in the rough bar.

Timber. Unless otherwise specified, the timber shall be first-class Southern long-leaf yellow pine, sawed true and out of wind; full size; free from wind shakes, large or loose knots, or other defects impairing its strength or durability; and equal in quality to grade of "Prime", in Interstate Rules of 1905 for classification of yellow pine lumber. (See page 52.)

Shop Work

Workmanship. All workmanship shall be first class in every particular and all parts neatly finished.

Straightening. All material shall be thoroughly straightened in the shop, before being laid off, by methods that will not injure it and, if bent by punching, shall be again straightened before bolting up.

Punching. In all punched work the diameter of the die shall be not more than one-sixteenth inch greater than the diameter of the punch.

All holes shall be perpendicular to the surface of the punched piece, and be clean-cut, without torn or ragged edges.

Rivet holes shall be so accurately spaced and punched that, when the parts of a member are assembled, a rivet one-sixteenth inch less in diameter than the hole can be entered hot into the holes. Occasional variations shall be corrected by reaming.

Reaming. Steel up to and including a thickness of five-eighths inch may be punched without subsequent reaming. Steel of greater thickness than five-eighths inch shall be drilled or punched one-eighth less than the diameter of the rivet and reamed to a diameter of one-sixteenth inch greater than the diameter of the rivet. The reaming of the rivet holes may be done after the various pieces have been punched and assembled, but every hole after reaming shall show that the reamer has everywhere touched the metal. Sheared edges and ends in all metal over five-eighths inch in thickness shall be planed at least one-eighth inch.

Riveting. The rivet when driven shall completely fill the holes, have full round heads concentric with the rivet, of a height not less than three-fifths the diameter of the rivet (unless otherwise shown on the plans), and in full contact with the surface, or be countersunk when so required.

Rivets shall be machine driven wherever possible, by machines capable of retaining the applied pressure after the upsetting is completed. Pneumatic hammers shall be used in preference to hand driving.

Tightening rivets by calking or re-cupping will not be allowed.

Finished Members. Built members, when finished, shall be true and free from twist, kinks, buckles, or open joints between the component pieces.

Eyebars. Before boring, each eyebar shall be properly annealed and carefully straightened. They shall be free from flaws; of full thickness in the neck; the thickness of the heads shall not be more than one-sixteenth inch greater than the thickness of the bar; and the hole shall be in the center of the head and on the center line of the bar. No forge work shall be done on bars after they are bored.

No variation from the calculated length between pinholes of more than one-sixty-fourth of an inch for each 25 feet will be allowed. Whenever bars are to be packed more than one-eighth of an inch to the foot of their length out of parallel with the axis of the structure, they shall be bent with a gentle curve until the head stands at right angles to the pin in their intended position before being bored. All bars belonging to the same panel shall be placed in a pile and shall allow the pins to pass through both ends at the same time without forcing.

Pins and Pinholes. Pins shall be turned straight and smooth, and shall fit the pinholes within one-fiftieth of an inch for pins 4 inches or less in diameter, and within one-thirty-second of an inch for larger pins.

Pinholes shall be bored clean and smooth, to a true parallel with one another, within one-thirty-second of an inch of the specified distance apart, center to center, and at right angles to the axis of the member, unless otherwise shown on drawings.

Facings. Eyes of laterals, stirrups, sway rods, and counters shall be bored.

All abutting surfaces in compression members shall be truly faced to even bearings.

The ends of track stringers and floor beams shall be faced true and square.

Reaming. All holes for field rivets except those for lateral and sway bracing connections shall be drilled to an iron template or reamed while the parts are temporarily put together.

Shop Erection. Adjoining chord sections shall be fitted together in the shop and all parts match marked; and when so fitted their abutting ends must be in full contact and the two sections in perfect alignment.

Other parts of the structure shall be erected in the shop when so required by the Inspector.

Rivets. In riveted steel work all rivets shall be of steel.

General Annealing. All members or parts of members which have been partly heated or worked at blue temperatures shall be properly annealed.

Painting

Painting in Shop. Before leaving the shop all work shall be thoroughly cleaned from all loose scale and rust, and given one good coat of pure linseed oil, well worked into joints and open spaces.

In rivet work, the surface to come in contact shall be painted before riveting together.

Parts which are not accessible for painting after erection shall have, in addition to the coat of oil, two coats of paint before erection.

Painting After Erection. After erection, the entire structure, except the wood floor, shall be thoroughly and evenly painted with two coats of paint, by practical painters. The two coats shall be different in color.

When work is delivered f. o. b., ready to be dropped into place, it shall be given only the above coat of oil before loading.

Materials. The materials for the field paint will be furnished by the railway company to the Contractors at the freight station nearest the bridge at the following prices: For the paste, — (—) cents per pound; for the Japan, — dollar and — cents ($—) per gallon, and for the linseed oil, — (—) cents per gallon.

No material shall be painted or oiled when it is wet.

Pins, pinholes, screw threads, and other machine-finished bearing surfaces shall be coated with white lead and tallow before leaving the shop.

Inspection

Inspection Facilities Furnished by Contractor. Due notice that material is ready for inspection shall always be given.

All facilities for inspection of material and workmanship shall be furnished by the Contractor, and free access to any works in which any portion of the material is made shall be allowed.

The Contractor shall furnish, free of cost, the use of an efficient testing machine at all mills where any of the material may be manufactured.

Such specimens (prepared) as may be required for testing shall be promptly furnished, without charge, by the Contractor.

No shop work shall be done on any material until it has been inspected and accepted.

Copies of all shipping invoices from mills or shops shall be promptly furnished the Inspector.

No material shall be loaded for shipment until it has been accepted by the Inspector.

The acceptance by an Inspector of any material or workmanship shall not prevent the rejection of the same, if it is afterwards discovered to be defective.

Erection

Previous to and during erection all material shall be kept clean, and shall be carefully handled, so as not to injure any of the parts.

Replacing Bridge. In case of replacing a bridge, the Contractor shall carefully take down the old structure and neatly pile the material at some point near the bridge convenient for loading on cars. If the old bridge is to be erected again, special care shall be taken not to injure any of the parts, and the different pieces shall be plainly marked at connections by the Contractor, in order to facilitate re-erection. All material in the old structure shall remain the property of the railway company.

Staging and False Work. The Contractor shall furnish all staging and false work, and provide for carrying traffic during erection, and so prosecute his work as to interfere as little as possible with the traffic over the bridge, or under the bridge, if there should be any such.

Any work affecting the safety of the track shall be subject to the direction of the Division Superintendent of the .... Railway Company.

Main Work. The Contractor shall furnish, erect, and adjust the entire structure, including the wooden floor, complete, ready for the rails. He shall also remove all false work after the erection is completed, and repair any damage produced by his operations.

Watchmen. The Contractor shall provide watchmen and other safeguards during erection, and shall be responsible for any accident or damage to person or property arising from his negligence or default; and he shall comply with all laws, ordinances, and regulations of properly constituted authorities, should there be any such affecting the work.

The Contractor shall be responsible for the work until it is finally completed and accepted by the Chief Engineer of the .... Railway Company.

HIGHWAY BRIDGES

Loads. Highway bridges shall be proportioned to carry the following moving loads in addition to their own weight:

On the floor system for all spans	100 pounds per square foot of floors
Or a concentrated load of 8 tons on two pairs of wheels, 8 feet centers	
On the trusses, for spans of 60 feet or less	100 pounds per square foot of floors
On the trusses, for spans 60 feet to 125 feet	80 pounds per square foot of floors
On the trusses, for spans over 125 feet	60 pounds per square foot of floors

Impact. Allowance for impact shall be one-half as great as for railroad bridges.

Unit Stresses. The allowed unit stresses shall be the same as for railroad bridges.

On yellow pine floor joists the allowed fiber stress shall be 1600 pounds per square inch.

Requirements. The requirements as to quantity of material, workmanship, painting, erection, etc., shall be the same as hereinbefore specified for railroad bridges.

PRICE

Bidders shall name in their bids a lump sum for furnishing and transporting all labor and materials of every kind necessary to complete the superstructure in place, ready for the rails in railroad bridges; or ready for the traffic in highway bridges, in strict accordance with these specifications. Bidders shall state in their tenders, that for the price named they will complete the superstructure at or before a specified time; and if it is not completed at the specified time, the price shall be .... dollars less than the sum named, for every day after the specified time that the structure remains unfinished; provided that no reduction in price shall be made for delay caused by the masonry not being ready to receive the superstructure.

TUNNELS

Approach Cuts. The approach cut shall be excavated to such widths and slopes as the said Chief Engineer may direct, and all the materials from the cuts and the ends of the tunnels shall be placed in embankments on the line of the railroad, on roads adjacent, or wasted, as the said Chief Engineer may direct, and they shall be classified and paid for according to the excavation classification of these specifications.

Dimensions. Tunnels shall be of such width and height as the said Chief Engineer may direct, and shall be excavated in conformity with the cross section to be furnished by him. If the tunnel requires support, and timber is adopted, the area of its cross section shall be enlarged and measured 3 inches outside the lagging; or, if masonry is adopted, 6 inches outside the exterior lines of the side walls and arching.

Classification and Price of Excavations. Materials from tunnel excavation shall be paid for by the cubic yard, or by the lineal foot, completed, in case such bid is accepted. The price paid shall cover all materials contained between the two portals, and strictly in all cases within the lines of the normal or enlarged cross section furnished from time to time by the said Chief Engineer, and shall include the cost of all temporary supports, such as props, scaffolding, strutting, etc., that may be necessary to secure a safe prosecution of the work in advance of the introduction of permanent supports of timbering or masonry, which temporary supports shall in all cases be removed by the said Contractor at his own expense after or concurrently with the completion of the permanent supports.

Bottoms. The bottom shall be picked to a uniform surface, and no rocky protuberances shall be allowed inside the general line of the sections.

Drainage Ditches. The drainage ditch through the center of the tunnel shown on the drawing of the normal cross section shall be carefully excavated to its full dimensions, and in it shall be laid broken stone in such manner and of such size and form as the said Chief Engineer may direct.

Shafts. The said Chief Engineer shall determine the number and location of shafts, the dimensions of which shall be such as he may direct. The excavation price paid for them shall be by the cubic yard, and shall cover all materials contained between the surface of the ground and soffit of the tunnel, and within the area of the cross section furnished by the said Chief Engineer. In case the shaft is sunk alongside the tunnel, the price paid shall cover the cost of such curbing or other supports as the sides of the shaft may require; also whatever materials or labor may be required for ventilation and keeping the tunnel and shafts free from water; and shall also cover all hoisting and pumping machinery.

Sumps. The excavation of all necessary wells or sumps shall be paid for at the same price per cubic yard as shaft excavation.

Niches. Niches or openings shall be left in the walls when and at such points as the Chief Engineer may direct.

Falls. Drilling and blasting shall be conducted with all possible care, so as not to shatter the roof and the sides outside the section lines. Any falls that, in the judgment of the said Chief Engineer, are attributable to the carelessness or want of proper skill or attention on the part of said Contractor, shall be removed and disposed of at his own expense; but if by unavoidable accident or natural causes not thus attributable, any outside rock shall become loose or shattered, it shall be removed by the said Contractor, and a just and equitable allowance shall be made by the said Chief Engineer to compensate and remunerate him for such removal, provided a claim for such removal be made by the said Contractor during the month in which a fall so occasioned shall occur.

Permanent Supports. Should it be determined by the said Chief Engineer during the progress of the work that any tunnel or any portion of a tunnel requires permanent supports, or that the shafts require lining, timber or masonry of brick or stone may be used for such supports and lining, as the said Chief Engineer may direct.

Timber. If timber is used, the said Chief Engineer shall determine its description and quality and shall prescribe the general plan of the support, and it shall be paid for by the 1000 feet, board measure, framed, and placed in the work.

Iron Work. All wrought- and cast-iron work ordered by the said Chief Engineer and used in the work shall be paid for by the pound, in place.

Masonry. When lining or arching of brick or stone masonry shall be ordered, it shall be laid in the most skillful and workmanlike manner, and strictly in accordance with the plans and directions prescribed by the said Chief Engineer from time to time, to suit the necessities of each case as it occurs.

Should it be determined to erect masonry façades at the portals of the tunnels, or to finish out above the surface any or all of the shafts with ventilators, such work shall be executed by the said Contractor in accordance with such plans and directions as may be prescribed by the said Chief Engineer for the same.

All masonry used in and about tunnels shall be classified and paid for under the masonry classification of these specifications.

Timbering Must Follow Excavation. The commencement, extent, and termination of all permanent timbering and masonry shall be determined by the said Chief Engineer and, when so determined, such timbering or masonry must progress right along with the excavation; and, if necessary, the excavation shall be secured and protected by temporary supports before the introduction of permanent ones.

Packing. The vacancies behind the permanent timber, lagging, or masonry walls, and above the arching, shall be filled with concrete and dry packing, as the said Chief Engineer may from time to time direct, which packing shall be classified and paid for under the masonry classification of these specifications. Dry packing shall consist of hard durable stone, approved by the said Chief Engineer, broken to the required size to pack well, and shall be well rammed in.

Work Required Before Acceptance. Before tunnels are accepted their whole length shall be entirely cleared of débris, rubbish, and surplus materials of every kind, and the bottom dressed off true to the grade line, and the drains cleaned out, as directed by the Chief Engineer.

Night Work if Required. All work incident to the construction of tunnels shall be carried on by 2 shifts of 10 hours each, or 3 shifts of 8 hours each, as the said Chief Engineer shall direct.

BORINGS FOR A SUBAQUEOUS TUNNEL

General Specifications. The work to be done under this contract is to determine carefully by borings the character of materials that will be encountered during the construction of two tunnels under the .... River and under streets of both the Cities of .... and .... The borings shall be made at regular intervals 100 feet apart on the lines as shown on the plan attached hereto.

The borings on land will approximate 3000 lineal feet, while those taken in the river, measured from the bottom of same, will aggregate about 2400 lineal feet. The dotted line on the profiles indicates the depth to which it is proposed to take the borings. No payment will be made for borings made to a greater depth than that thus indicated, without a written order from the Engineer.

Quantities Approximate. It will of course be understood that the approximate quantities given above are not to be used in making payment, but that payments will be made upon quantities determined by the Engineer.

Boreholes Cased. All holes bored shall be cased with 4-inch pipe; and the character of all material passed through from the surface of the ground or bottom of the river must be carefully determined, and the depth of all changes in the stratification from the surface of the ground or low water mark shall be noted.

Preservation of Samples. Samples of the various materials encountered shall be preserved and placed in glass jars, bottles, or tubes, as the Engineer may direct, the same to be carefully labeled, giving the number of boring and the depths between which the material is found. Upon the completion of the work all samples shall be delivered at the office of the Company.

Borings to Rock. If directed by the Engineer, the borings shall be carried to rock formation and into same, to hard rock. Should rock be encountered above the dotted line shown in the drawing (profile drawing should always be submitted with regular specifications), borings shall be carried down only to hard rock.

Repaving. Upon the completion of a boring, the casing pipe shall be withdrawn and, wherever street paving shall have been disturbed by the work, it shall be restored to its original condition upon the completion of each boring, in a manner satisfactory to the proper city officials, without cost to the Company.

Ground Water. A record shall be kept at each borehole on land, of the depth of ground water below the surface of the ground.

Price to Include. Payment will be made for all borings at the price per vertical foot of hole bored, no allowance being made for the depth of the water where the boring is made; said price to include the removal of all material excavated within the casing and all pipe, pumping (with the proper appliances and appurtenances), transportation, glass jars or tubes for samples, materials, floats, scows, tools, and labor necessary for the completion of the above described work in the best, most rapid, and most approved manner.

Violation of Laws. The Contractor shall assume all blame or loss by reason of neglect or violation of the United States Government or municipal laws, regulations, or ordinances. The Contractor shall place sufficient light on or near the work, keep the light burning from twilight to sunrise, and observe such rules relative to signals and safeguards as the laws, regulations, or ordinances require.

Watchmen and River Signals. The Contractor shall provide at his own expense the necessary watchmen, signals, and lights, and must observe the local laws of the district in protecting the public against all injury and damage. He shall conform to all the rules and laws relating to navigation in the waters crossed by structures covered by this contract, and shall notify the proper authorities of the location of or change in position of proposed structures and plant in said waters, and shall establish and maintain the necessary lights, fog signals, etc., upon structures in course of construction, and upon his plant. In case of any damage resulting from neglect to keep and maintain suitable lights and signals, or from mistake in signals, it must be promptly repaired at the expense of the Contractor.

Inspection. The Contractor shall execute the work under this contract in the presence of an Inspector at all times; work done in absence of same shall be subject to rejection.

PILE TRESTLE FOR AN ELECTRIC RAILROAD ACROSS AN OCEAN INLET

General Specifications. The trestle shall consist of a single track structure extending out from either shore and across the various channels, as shown on the plans.

The piles which are not exposed to salt water shall be of white oak, while the other piling in the trestle, fenders, guard, and rest piers, exposed to salt water, shall be treated with creosote oil as herein specified, the timber in same being of quality as specified under ''Piling''.

The piles, both vertical and battered, shall be jetted and driven to the depth shown on the plan. They shall be driven in the bents of the trestle, in the guard piers, and in the foundation for piers, for the watchmen's houses, and for the refuge bays.

The quality of lumber and the workmanship on all structures shall be as specified under "Timber and Framing". Creosoted timber and galvanized iron shall be used where shown.

The trolley poles on the trestle shall be of Southern long-leaf yellow pine, 35 feet long, sawed to octagonal shape, measuring not less than 8 inches between parallel faces at the top and not less than 14 inches between faces at the base. They shall be attached to the trestle as shown, securely, and in a workmanlike manner, and shall be erected accurately to line and grade.

The price bid for the work shall include the furnishing and erection of all lumber, piles, and hardware in place, complete with all appurtenances.

TIMBER AND FRAMING

Quality. All timber must be sound, straight grained, and free from excessive sap, loose or rotten knots, wind shakes, wormholes, or any other defects which would impair its strength or durability. It must be sawed or hewn perfectly straight to exact dimensions, with full corners and square edges. All timber shall be long-leaf yellow pine or white oak. All yellow pine shall be long-leaf Southern yellow pine, and must satisfy the requirements under "Merchantable Inspection" in the Interstate Rules of 1905 for the classification and inspection of yellow pine lumber.

Workmanship. Material and workmanship shall both be subject to inspection, and approval or rejection, by the Engineer. The fenders, rest, and guard piers, pile trestle, and refuge bays shall be built according to the plans and directions given by the Engineer, and of materials as specified under timber, framing, and iron work.

Framing. All framing must be done in a thorough and workmanlike manner. No open joints, blocking, or shims will be allowed; the bearing of caps and stringers must all be sized, and perfect bearings must be secured throughout. The side with most sap shall be placed downward. All timber shall be squared off with the saw. The holes for the bolts shall be bored with an auger of the exact diameter of the bolts. The nuts on all bolts shall be screwed up tight so that the washers shall draw hard upon the timber and bring all parts of the structure close together.

Surfacing Ties. All bridge ties will be furnished and placed in the bridges by the Contractor, surfaced and brought to a true plane under the rails, so that they will have a full bearing on the four stringers, and so that the rails will have an even bearing on every tie.

Surfacing Stringers. All track stringers shall have their upper surfaces brought to a true plane, so that the ties may have an even bearing on all the stringers.

Elevating Outer Rail. Where any framed or pile trestle bridge is built on a curve, the blocking, or other means for elevating the outer rail, will be as per detail plans furnished for same. When mud mills are used for supporting either framed trestle bents or jack stringers, the soil shall be removed and a foundation of gravel placed, all of such a depth and rammed in such a manner as the Engineer shall direct, without cost to the Company.

Inspection. All rejected materials must be removed from the Company's premises within 5 days from the date of notice to do so.

Payment. The price bid shall include the framing and erection of all the timber embodied in the finished structure (exclusive of the piling, which shall be paid for as specified under "Piling"). The price shall include the cost of hauling from the railroad station, or wharf, of all the lumber, spikes, bolts, washers, etc., furnishing, framing, and erection; all to be done as shown on the plans and described in the specifications.

PILING

Quality and Dimensions. All piles shall be of young, straight, sound, and thrifty white oak, yellow pine, or other timber equally good for the purposes, acceptable to the Engineer. Piling shall be treated with creosoted oil where shown on the plans, and shall not be less than 14 inches in diameter, 2 feet from the butt.

Piles having a length of 60 feet and over shall have a diameter at the point of not less than 7 inches.

Piles having a length of from 40 to 60 feet shall have a diameter at the point of not less than 7½ inches.

Piles having a length of from 30 to 40 feet shall have a diameter at the point of not less than 10 inches.

Piles of less length than 30 feet shall have a diameter at the point of not less than 10 inches, exclusive of the bark. When sawed off, at no point shall they be of greater diameter than 18 inches. They shall be so straight that a line stretched from the center of the pile at the butt to the center of the pile at the tip will not leave the center of the pile at any point more than 2 inches for piles 20 feet long, 4 inches for piles 30 feet long, 6 inches for piles 40 feet long, and 8 inches for piles 50 feet long. No short or sharp bends will be allowed. All knots shall be trimmed close to the body of the pile, and the bark peeled before placing the pile in the leads of the driver.

Payments. Piling shall be paid for at the price per linear foot, in place, given in the proposal. No part of the pile shall be paid for except that which remains in the work.

Driving Piles. All piles shall be driven to a depth to secure a penetration into the underlying material satisfactory to the Engineer. It is probable that this result can best be obtained by the use of a water jet at the bottom of the pile, the nozzle of same being carried below the point of the pile. After piles shall have been jetted to a sufficient depth to secure the required stability, they shall be driven until they do not move more than one-half inch under the blow of a hammer weighing 2000 pounds, falling 25 feet at the last blow. If required, 5 additional blows from the same height shall then be delivered and the pile shall then be considered as driven, provided the one-half-inch limit be not exceeded under any of the last 5 blows. They must be driven vertically, excepting where batter piles are shown, and at regular distances apart from centers, transversely and longitudinally, as required by the plans, or directions of the Engineer; they must be cut off squarely at the butt, and be well sharpened to a point or cut squarely off, as the Engineer may direct, and the heads shall be bound with iron hoops, of such dimensions as he may direct, both without additional cost to the Company. Where batter piles are required, they shall be driven at the angle shown on the plans. All piles when thus driven to the required depth, shall be cut off square and horizontal at the proper height given by the Engineer, and only the actual number of linear feet of the pile left for use in the structures, after being driven and sawed off, shall be paid for. No splits or imperfect piles will be accepted. A follower of approved description shall be used when directed by the Engineer. Any open space that may be left around the driven piles shall be thoroughly filled with beach sand.

After creosoted piles have been driven and cut off to the proper height, the heads shall be treated to an application of hot creosote oil of quality as herein specified, followed by a further application of asphalt thinned with oil.

Price. The price shall include the hauling of the piles from the point of delivery to the point where they are to be driven, and shall be per linear foot of piling actually left in the work.

Specifications for Standard Piling*

Quality of Material. Piling shall be of white, post, or burr oak, tamarack, Norway or Southern long-leaf yellow pine, white or red cedar, red or yellow Douglas fir, or red or swamp cypress.

All piling shall be cut from sound live trees of slow growth, firm grain, and free from ring shakes, decay, large unsound knots, or other defects that will impair their strength or durability. They shall be butt cut above the ground swell, and be uniformly tapering from the butt to the point. They shall be so straight that a line stretched from the center of the pile at the butt to the center of the pile at the point, will not leave the center of the pile at any point more than 2 inches for piles 20 feet long, 4 inches for piles 30 feet long, 6 inches for piles 40 feet long, and 8 inches for piles 50 feet long. No short bends will be allowed. The ends shall be cut square and all bark, branches, and knots shall be trimmed off, finishing the pile in a workmanlike manner. The bark must be peeled before placing the pile in the leads of the pile driver.

Diameter of Piles. The diameter of piles after the bark is peeled from them shall be as follows for the different kinds of timber:

	White Oak	Southern L.L.Y. Pine	Norway & Tamarack	White Cedar	Red Cedar	Red or Yel. Doug. Fir.		Red or Swamp Cypress
						Under 40′	Over 40′	
Maximum diameter at butt		16″	18″			18″	20″	16″
Minimum diameter at butt		14″	14″	14″	12″	14″	16″	14″
Min. diameter 6′ from butt	12″							
Min. diameter at point less than 30′ long..........	10″	10″	10″	9″	9″	10″		10″
Min. diameter at point from 31′ to 39′ long....	9″	10″	9″	8″	8″	10″		9″
Min. diameter at point 40′ and over in length......	8″	10″	9″	8″	8″		8″	8″
Per cent of heart.........		80				75	75	100

Driving Piles. All piles shall be driven into the hard bottom until they do not move more than one-half inch under the blow of a hammer weighing 2000 pounds, falling 25 feet at the last blow, or a hammer and fall producing the same mechanical effect.

If required, five additional blows from the same height shall be delivered, and the pile shall then be considered as driven, provided the one-half inch limit be not exceeded under any of the last five blows. They must be driven vertically except when batter piles are shown, at regular distances apart from centers, transversely and longitudinally, as required by the plans or directions of the Engineer.

They must be cut off squarely at the butt, and be well sharpened to a point and, when necessary in the opinion of the Engineer, shall be shod with approved wrought-iron shoes and the heads bound with iron hoops, of such

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* Summary of Specifications for Piling adopted by the American Railway Engineering and Maintenance of Way Association.

dimensions as he may direct, both without additional cost to the Company. When batter piles are required they shall be driven at the angle required on the plans, and shall require but slight bending before framing. All piles when thus driven to the required depths, shall be cut off truly square and horizontal at the proper height, and shall be so trimmed as to leave no horizontal projection outside the cap. Only the actual number of linear feet of the pile left for use in the foundation or trestle, after being driven and sawed off, shall be paid for. No split or imperfect piles will be accepted.

TREATMENT OF TIMBER WITH CREOSOTE

Quality, Size, etc., of Timber. *Bridge Timber.* All bridge timber shall be of Georgia or Florida long-leaf yellow pine and must be inspected under the Interstate Rules of 1905 for the classification and inspection of yellow pine lumber, to meet the requirements of either Prime Inspection or Merchantable Inspection, as may be necessary to meet the conditions and which will be determined in advance when the order is placed. All bridge timber shall be treated with dead oil of coal tar, and each piece after treatment must contain not less than 12 pounds of oil per cubic foot.

Piles. All piles shall be of young, straight, sound, and thrifty Carolina or short-leaf yellow pine, acceptable to the Engineer, and shall be treated with creosote oil as herein specified as to quality and method of treatment. They shall be not less than.......... inches in diameter..........feet from butt, and shall have a diameter at the point of not less than..........inches, exclusive of the bark. Both the outside and inside bark shall be thoroughly and carefully removed before the piles are placed in the cylinder for treatment. When sawed off, at no point shall they be of greater diameter than 18 inches; they must be so straight that the pile at no point deviates by more than one-half of its diameter from a straight line, and gradually tapers from end to end. The ends must be cut square and all branches and knots trimmed off to finish the pile in a workmanlike manner. All piles shall be treated with dead oil of coal tar, and each pile after treatment must contain not less than 12 pounds of oil per cubic foot.

Crossties. All crossties shall be of Georgia or Florida long-leaf yellow pine of such quality as shall satisfy the requirements of Standard Inspection according to the Interstate Rules of 1905. They shall be..........long,..........thick, and..........in width. Ties shall be sawed or hewn smooth on four sides, with the faces true and parallel; free from deep score marks, splinters, and other injurious inequalities of surface; and shall be sawed square. The variation in thickness shall not be more than one-half inch, and in length not more than 1 inch. Ties shall be treated with dead oil of coal tar and each tie after treatment must contain not less than 10 pounds of oil per cubic foot.

Switch Ties. All switch ties shall be of Georgia or Florida long-leaf yellow pine of such quality as shall satisfy the requirements of Standard Inspection according to the Interstate Rules of 1905. Switch ties shall be treated with dead oil of coal tar, and each piece after treatment must contain not less than 10 pounds of oil per cubic foot.

Treatment. *Steaming.* It is preferred that the timber shall be thoroughly air seasoned for 90 days before treating; that which is not thoroughly seasoned shall be steamed. To obtain the removal of sap and water and to open the pores of the wood, the timber shall be subjected to the direct action of live steam admitted to the treating cylinder under a pressure of not less than 20 pounds and not to exceed 30 pounds per square inch, as recorded by a steam gage attached to the treating cylinder (which pressure must be sustained within the cylinder for from 30 to 50 minutes). The pressure and time of steaming shall be regulated according to the size and condition of the stock used. The time of steaming shall range from 2 to 6 hours, depending on the character and condition of the timber. The cylinder shall be frequently drained by a valve located at its lowest point. The timer used in any one cylinder charge shall all be of the same class, kind, and quality; that is to say, any one cylinder charge shall be exclusively long-leaf, short-leaf, or loblolly pine, and in no case shall these be mixed.

Injection. When, in the opinion of the Engineer, the timber shall have undergone the steaming process for a sufficient length of time, a vacuum shall be created in the cylinder, the temperature being at all times maintained above the boiling point. A vacuum of from 22 to 26 inches shall continue for from 1 to 6 hours, or until the timber has been thoroughly seasoned and no sap or moisture comes from or remains in the cylinder. During this vacuum process the lumber in the cylinder shall be kept at a temperature of about 175° F. by means of steam coils in the cylinder. While the above vacuum is maintained, the oil, as herein specified, shall be admitted to the cylinder under pressure at a temperature of at least 175° F. and the pressure pump shall be kept in operation until the timber has absorbed the prescribed amount of oil per cubic foot, the same to be determined by such system of measurements and tests as the Engineer shall elect. When the cylinder is nearly full, the valve leading to the vacuum pump shall be closed and the oil slowly forced into the cylinder and the pressure maintained until the wood has absorbed the required amount.

If, in the judgment of the Inspector, a better and more satisfactory treatment can be obtained by breaking the vacuum before filling the cylinder with the creosote oil, and then forcing the oil into the wood with pressure, the Inspector shall have the power to order such method of injecting with creosote oil. This is not intended to obviate or relieve the necessity of applying the final air pressure as hereinafter provided.

After releasing the pressure and emptying the cylinder of oil, air pressure in excess of the oil pressure shall be applied, to render the penetration more perfect and make the outside of the timber cleaner and drier.

The entire charge of timber shall absorb the oil to a depth of not less than 2 inches on all exposed surfaces. Such pieces as fail to receive the required penetration shall be returned to the chamber with a subsequent charge for further treatment.

Oil. The oil used in treatment shall be a dead oil of coal tar commonly known as creosote oil, and shall be the best obtainable grade of coal tar creosote. Its specific gravity shall not be less than 1.04 at 35° C. It shall not contain more than 2½% of water. Compensation, by the injection of a proportionately larger amount of oil into the timber being treated, for a greater amount of water in the oil will not be allowed. The oil shall be completely liquid at 38° C. and must be free from suspended matter. It shall yield not more than 10% by weight when distilled up to 210° C. Between 210° and 235° C., the distillate by weight shall not be less than 25% or more than 30%, and at least 30% weight shall not distill below 260° C. The oil must be free from acetic acid and acetates, and the residue above 355° C., if it exceeds 5% in quality, must be soft. The sample of oil for test shall be taken from the side and near the middle of the treating cylinder, after the pump has begun the injection of oil. During the analysis of the oil, the thermometer bulb shall be kept about one-eighth of an inch above the surface of oil in the retort.

Loading. The timber shall be piled on the treating trucks in such manner as to give all sides of the timber access to the creosote oil. All pieces treated in any one cylinder load shall be of uniform character and sectional dimensions. Both the outside and inside bark shall be carefully removed from all piling before it is placed in the treating cylinder. If any of the timber, furnished under contract, is acceptable to the purchaser and contains less than the prescribed amount of dead oil of coal tar per cubic foot, the Contractor agrees to make an allowance on each piece of timber equal to the difference in the quantity of oil contained in each piece and the prescribed amount per cubic foot at the rate of ten (10) cents per gallon.

Inspection. The timber before treatment and the method of treatment shall be subject to the inspection of such inspectors as shall be appointed by the Purchaser, and he shall be afforded, free of charge, every facility for performing such inspection. The Contractor shall, upon the request of the Inspector, furnish the Purchaser with samples of the oil being used, and shall allow the Inspector at any time to take such samples of oil for testing as he may require. The Contractor shall grant to the Purchaser or his inspectors access at all reasonable times to all of the records of the works pertaining to the treatment of timber for the Purchaser.

The Contractor shall provide and install such apparatus as is necessary to enable the Inspector to determine the amount of oil absorbed by the timber, this amount being based upon gage readings taken before the introduction of the oil into the cylinder and after the forcing back of the oil after treatment; also to determine the various temperatures and pressures required, and to examine the products of the vacuum.

The Inspector shall be allowed, if he desires, the use of the laboratory and the apparatus therein for making such distillation tests as he may require, and for the inspection of such operation in connection with the work.

Should he desire to ascertain the depth of penetration of oil in any timber, a five-eighths-inch auger must be furnished to enable him to bore such timber, and he shall be at liberty, if he so desires, and without cost to the Purchaser, to saw in two one tie from each 500 ties under treatment, to ascertain the quality of the work being done.

Inspection and acceptance, or lack of inspection and lack of acceptance or rejections, on the part of the Purchaser, or his inspectors, shall not be any bar to subsequent rejection for cause.

Method of Distillation. In making the tests the oil shall be distilled according to the common method; that is, using an 8-ounce asbestos-covered retort with standard thermometer bulb one-half inch above the surface of the oil; the creosote calculated on the basis of the dry oil shall give the distillates as above required at the various temperatures.

IRON WORK FOR TIMBER TRESTLES

Iron Work. All bolts and nuts shall be of wrought iron. Wrought iron shall be double rolled, of the best quality of American refined iron, tough, fibrous, ductile, and capable of standing a tensile strain of 48,000 pounds per square inch before rupture, and an elongation of 22% in 8 inches, with fracture wholly fibrous. It shall bend cold with the fiber through 180° around a diameter not greater than twice the thickness of the specimen tested, without fracture on the outside of the bent portion. When nicked and bent, the fracture shall show at least 90% fibrous.

Cast Iron. All castings shall be tough, close-grained gray iron, sound, smooth, clean; free from cold shuts, blowholes, blisters, and all defects; and shall be made accurately to the dimensions shown on the plans. Sample pieces, 1 inch square, cast from the same heat of metal in sand molds, shall be capable of sustaining, on a clear span of 12 inches, a central load of 2400 pounds when tested in the rough bar. A blow from a hammer shall produce an indentation on a rectangular edge of the casting without flaking the metal.

Cast Washers. Cast washers shall be of cast iron. The diameter shall be not less than 3½ times the diameter of the bolt for which it is used, and its thickness shall be equal to the diameter of the bolt; the diameter of the hole shall be one-eighth inch larger than the diameter of the bolt.

Wrought Washers. Wrought washers shall be of wrought iron or steel; the diameter shall be not less than 3½ times the diameter of the bolt for which it is used, and not less than one-fourth inch thick. The hole shall be one-eighth inch larger than the diameter of the bolt.

Bolts. Bolts shall be made with square heads, standard size, the length of the thread to be 2½ times the diameter of the bolt. The nuts shall be made square, standard size, with threads fitting closely the thread of the bolt. All threads shall be cut according to the United States standard. Drift bolts shall have square heads and chisel points.

Spikes. Steel wire spikes may be used up to a length of 6 inches; where greater lengths are required, wrought iron or steel shall be used.

TRACK LAYING

HANDLING SUPPLIES

Work to Be Performed. The work to be performed will consist of furnishing all material (except rails, angle bars, bolts, frogs, mates, switches, spikes, and electrical bonds and ties, which will be furnished by the railroad company, f. o. b. cars on siding at..............................), all tools, machinery, and apparatus; the doing of all the work necessary for the efficient construction

of a railroad with passing sidings, as called for by these specifications and the requirements of the Engineer; and in accordance with the plans and drawings, leaving the whole work in a finished and perfect condition in every respect, from a point near.................................at.................................on the.................................Railroad, known as station................................., to a point in.................................
................................., near the................................., as located over the right of way of said railroad company for a distance of.................................miles.

Delivery of Materials. The railroad company will furnish the material above specified, f. o. b. cars on siding at.................................
Upon the arrival of the carloads of material, the railroad company will turn over to the Contractor the bills of lading covering the material, and the Contractor will then be held responsible for the inspection as to count and accounting for the material.

Unloading Cars. The Contractor will be required to remove from the cars, promptly on their arrival, all material, and will be held responsible for any demurrage arising from his failure promptly to remove the material from said cars. The materials shall be piled in such a manner and at such points as the Engineer shall prescribe.

Sub-Delivery. The Contractor will be required, at his own cost and expense, to furnish and provide all labor and appliances required for handling and sub-delivery of all materials furnished him by the Company.

Material on Hand. The Contractor must at all times keep such a record of materials on hand, and of their location, that he will know whether he is supplied with sufficient material to complete the work in accordance with the specifications, as no additional time will be allowed the Contractor to complete his work by reason of his learning at too late a time that additional material is required to complete the work within the time specified. All materials delivered along the line of the proposed railroad before the completion of the grading shall be placed outside the line of the slope stakes.

PREPARING ROADBED

Grading. Before a tie is laid, and just before the track laying is begun, a small gang of experienced graders shall go ahead of the tie layers with the engineer corps, who will give the grades and the superelevation of the curves.

The graders, in charge of a competent foreman, must be provided with the necessary sight boards, and other tools and implements required, and must carefully level off the surface of the roadbed to the grade stakes set for same, and no indifferent leveling of grading will be allowed.

No blocking up under crossties, with timber or broken rock, will be allowed.

LAYING THE TRACK

Ties. The ties shall be spaced so as to give 16 ties to each 33 feet of rail. At rail joints the ties shall be spaced 18 inches between centers. On tangents they shall be laid truly at right angles to the rails, while on curves they shall be laid radially, and the ends lined up parallel with the rails on the side of the track which the Engineer may direct. The ties must not be notched under any circumstances, but should they be twisted, they must be made true with the adz, in order that the rails may have an even bearing over the whole breadth of the tie.

Rails. *Bending.* If the rails are bent in handling they shall be perfectly straightened before being laid in the track. Rails used on sharp curves shall be curved in a bending machine accurately and truly to ordinates, which will be furnished by the Assistant Engineer. In no case will forcing, springing, or sledging the rails be allowed.

Laying. To avoid bad joints and short rails, the track laying shall proceed from the ends of the road and it shall be continuous for the entire length of the same. The rails shall be laid to the stakes given by the Engineer, and on curves they must be bent to the proper curvature before being laid upon the ties. On tangents the rails shall be level, and on curves the proper elevation must be given to the outer rail and carried uniformly around the curve. This elevation shall be commenced from 50 to 200 feet back of the point of curvature as directed by the Engineer and, depending on the degree of the curve, shall be increased uniformly to the latter point, where the full elevation is attained. On curves sharper than 4 degrees, an additional spike shall be put on the outside of the outer rail.

Spiking. There must be four spikes to each crosstie—two inside and two outside of the rails; they must be driven with a proper amount of "stagger", so as to avoid splitting the crossties; and the two inside spikes must be driven in the same edge of tie, so as to keep the tie at right angles to the track. In driving spikes on the gage side, care must be taken to place the gage at right angles with the rail. The spikes must be driven as nearly perpendicularly as possible; and not more than 4 inches from center to center of spike on a line parallel with the rail; and no blow must be struck after the head of the spike is fairly down on the rail flange. Great care must also be taken not to strike the rail, and none but experienced and expert spikers must be employed on the work.

Joints. The joints of the rails shall be exactly at the middle of the joint ties, and the joint on the one line of rail shall be opposite the middle of the rail on the other line of rail of the same track. A distance must be left between the ends of the rails to allow for expansion; in winter five-sixteenths of an inch, in summer one-sixteenth of an inch. The use of iron shims for securing this spacing will be imperatively insisted upon, and the Contractor must provide himself with a sufficient quantity of them, of the thickness above specified. Joints on or within 4 feet of cattle guards or open culverts must be avoided wherever possible. Care must be taken to place the angle bars squarely in position. The head of the bolts must be struck with a 2-pound hammer, while pressure is applied with a 30-inch wrench to tighten the bolt. The gage of the track shall not vary more than one-sixteenth of an inch from the standard of this railroad, which is 4 feet 8½ inches. The gage shall be widened on curves, if directed by the Engineer, but not otherwise. Such elevation shall be given to the outer rail on curves as the Engineer shall direct.

Bonding. All the joints of the track rails shall be single bonded with the Improved Open Double Electric Protected Rail Bonds having a capacity equal to No. 0000 B. & S. gage round copper wire.

The rail drilling to receive the bonds must be performed on the ground and all holes carefully cleaned out and the bond terminals thoroughly polished so as to form a perfect contact of the entire circumference of the terminal of the bond with the rail. Care must be taken not to disturb the bond after it is put in place.

Special Work. In laying switches, frogs, mates, and other special work, care shall be taken to place them accurately in the position determined by the Engineer. The gage at switches, on tangent, shall be one-sixteenth of an inch tight. If the special work does not appear to fit, no attempt whatever shall be made to force it, except by direction of the Engineer. Special work shall be laid on ties specially provided for the purpose, which shall be so laid as to give a firm and a continuous bearing upon the ballast. Particular attention should be given to having them well lined up to avoid low joints at the head blocks of switches. Guard rails shall be used on curves sharper than 9 degrees, and at turnouts; they shall be of proper length, and properly adjusted and securely fastened. Plans of switch stands, frogs, and fixtures will be furnished, showing minor details of placing in position, etc., or instructions of the Engineer shall be followed.

Joints Tightened. After the surfacing has been completed the joints shall be carefully gone over and tightened up as described under "Joints".

Maintenance Before Acceptance. Before any construction car or engine is allowed to run over the rails, the track must be lined and so firmly tamped to a good level that there shall be no chance of straining or bending the rails. Material for tamping must not be dug out of embankments or bermes, nor shall any material be taken from the side slopes of cuts in such way as to disfigure them. When track material is being hauled by the Contractor's trains over track already laid, such track shall be kept in good line and surface by the Contractor. The Contractor shall maintain and keep the track in good repair until the same is accepted, and no length of track shall be accepted and taken off the hands of the Contractor, except at the option of the Engineer, until the whole shall have been completed.

Measurement of Track for Payment. In making payment for track laying, all measurements shall be made per linear foot of single track, measured on the center line; and where turnouts occur the measurement shall be made once on the main track and again on the turnout from the point of switch of the turnout to be measured. At steam or electric road crossings, measurements shall be made once on the main track and again on the line of the intersecting road. The price for track laying shall include the unloading and hauling of materials; the placing of ties, rails, angle bars, and special work; and the bending, bolting, spiking, lining, and ballasting of the same.

BALLASTING

Gravel Ballast. Gravel shall be clean, free from clay, earth, loam, and stones larger than would pass through a 2½-inch ring in any direction; it must not contain more than one-third sand, and shall be subject to the inspection and acceptance of the Engineer.

Cinder Ballast. Cinder ballast shall be free from all objectionable materials and of a quality approved by the Engineer.

Broken Stone. Stone ballast shall consist of clean broken granite, trap, or other hard stone, to be approved by the Engineer, and must be crushed so that its greatest dimension will pass through a 2½-inch ring.

Lining. After the rails have been spiked to the ties, the entire track must be raised to the finished grade and carefully aligned to the stakes given by the Engineer. The space under the ties must then be filled with ballast of approved quality, satisfactory to the Engineer. Care must be taken in raising the track and tamping same not to deform the rails, splice bars, or bonds. The space between the ties shall be filled with ballast to the lines and slopes as shown on the standard section of roadbed.

Tamping. The ties shall be tamped from 15 inches inside the rail to the ends of the ties; if possible, tamp the ends of the tie outside the rail first and allow the material train to pass over it before tamping the inside of the rail, giving special attention to tamping under the rail; tamp the center of the tie loosely with a shovel when using gravel or cinder ballast; where stone ballast is used, do not tamp the center of the tie. Ties must be tamped solidly from the end, using tamping bar or tamping pick, as the Engineer may direct. Care must be taken not to disturb the roadbed. When gravel ballast is used it shall be firmly packed or rammed between the ties to the prescribed slope, so that it will readily shed the water and shall not be banked above the bottom of the ends of the ties; a space of not less than 1 inch shall be left between the top of the ballast and the base of the rail to allow the water to run off readily, care being taken to carry the ballast in the middle of the track to the full height shown in the standard drawings.

SURFACING

Every care shall be taken to maintain the crown of the roadbed in the center as shown on the standard drawings and, when the condition of the roadbed, on account of washing or settlement, does not allow of the exact depth of ballast beneath the ties, the Contractor shall make the necessary excavation or fill without cost to the Company. Should any material for ballast be taken out of the side slopes of cuts, it must be done in such a way as not to disfigure them. Material for ballast shall not be taken from embankments. In surfacing, the level board shall be used, at head, at joints, at quarters, and at centers. After the completion of surfacing, all materials that shall have been allowed to accumulate in the ditches on either side of the roadbed, shall be removed, and the road properly ditched and cleaned up. All necessary cross drains shall be laid at proper intervals.

GENERAL SPECIFICATIONS FOR CROSSTIES

Timber. Crossties will be accepted of the following varieties of timber: Oaks of the various kinds known as white, rock, and post (no red oak will be received), second growth white chestnut, cherry, maple, butternut, tamarack, and yellow pine of the long-leaf, Southern hard-pine variety, cut from untapped trees and grown not north of South Carolina.

Sizes. *First Class.* First class crossties shall be 8½ feet in length, 7 inches in thickness, and not less than 7 inches in width of face on both sides at the small end.

Second Class. Second class crossties shall be 8 feet in length, 6 inches in thickness, and not less than 6 inches in width of face on both sides at the small end; and in each class there must be at least one-fourth of the whole number that are not less than 9 inches in width of face.

Manufacture. All ties must be made from sound, thrifty, live or green timber; free from loose or rotten knots, wormholes, dry rot, wind-shakes, splits, or any other imperfections affecting the strength or durability of the timber.

Not more than 1 inch of sapwood will be allowed on the edges or corners, and none at all on either face of the ties. They must be hewed or sawed with the faces perfectly true and parallel, of the exact thickness specified. The faces must be "out of wind", smooth, and free from any inequalities of surface, deep score marks, or splinters. The ties must be cut or sawed square on the ends to the exact lengths given; they must be generally straight in all directions; and they will not be accepted if more than 3 inches out of straight in any direction; and they must be peeled or stripped entirely free from the bark before being delivered. No split ties will be accepted under any circumstances, and "culls" only at the option of the Company and at such prices as may be agreed upon from time to time.

Delivery. All ties delivered along the line of the railway must be stacked up in neat square stacks of 50 ties in each, with alternate layers crossing each other, and on ground, wherever possible, as high or higher than the grade of the railroad, and in such position as to admit of being counted and inspected with ease and facility. Ties delivered at suitable and convenient places, acceptable to the Company, will be inspected, and bills made for all ties received and accepted up to the last day of each month, and payment will be made for same on or about the ________________ day of the succeeding month.

GENERAL VIEW OF DRY DOCK No. 1 IN PROCESS OF CONSTRUCTION AT BALBOA TERMINALS

The view is looking west and shows the entrance to basin and shop buildings.

Courtesy of Panama Canal Commission, United States Government, Washington, D. C.

CIVIL ENGINEERING SPECIFICATIONS AND CONTRACTS

PART II

TYPICAL ILLUSTRATIVE SPECIFICATIONS
(Continued)

SPECIFICATIONS FOR OVERHEAD CONSTRUCTION OF AN ELECTRIC RAILWAY

Materials Furnished by the Company. The Company will furnish f. o. b. cars..City, all poles and trimmings, span wire, trolley wire, and overhead construction materials with the exception of solder, tape, and paint.

Contractor's Obligations. The Contractor shall remove from railroad stations all poles and overhead materials, and shall store and protect same, and be responsible for their safe keeping. The Contractor shall be responsible for demurrage accruing from neglect to remove the materials from the cars promptly. The Contractor shall furnish all labor, tools, and appliances for the complete erection of the overhead construction.

Poles. The poles shall be of iron, 28 feet long, weighing approximately 600 pounds. They shall be made of 7-, 6-, and 5-inch section of pipe, telescoped and swedged together.

Setting. The Company will furnish permits for the erection of poles located as shown on the plans. The Contractor shall set poles 6 feet in the ground in 1-3-6 Portland cement concrete, in holes not less than 18 inches in diameter. Poles shall be set with a rake of 8 inches, on straight track, away from the line of strain. On curves, poles shall be set with a rake of 14 inches. In case water is found in pole holes, the lower portion of the hole must be protected by sinking a barrel, or by other similar precaution. Before poles are placed in concrete, they shall be given one coat of approved asphalt paint for the lower 7 feet. Asphalt paint shall be furnished by the Contractor.

All pavements, awnings, water, gas, or sewer pipes, or other structures damaged during the erection of the poles must be replaced in as good condition as found, at the Contractor's expense.

On completion of work, the poles shall be painted with one coat of lead and oil paint, of approved color. The paint shall be supplied by the Contractor.

Span Construction. The entire line shall be of span construction. The span wires shall consist of seven-strand five-sixteenths-inch galvanized steel cable; and the spans shall be secured to the poles by double-bolt pole rings. At each end of the span wire there shall be put in a globe strain insulator which shall connect with the outer bolt of the pole band. The spans shall be drawn taut and the ends shall be made up to the strains. At all curves the pull-off wires shall be secured to an anchor pole with a heavy band; a turnbuckle and a heavy insulated strain shall be put in between the pull-off wires and the pole. Each pull-off wire shall have in addition to this insulation a giant strain insulator at the pull-off fitting. Wherever pull-off wires cross the main trolley wire, they shall be secured to the cross wire with standard soldered ear and bell insulator.

Trolley Wire. Trolley wire shall be No. 0000 B. & S. gage round copper wire. At terminals wire shall be secured to poles through heavy double strain insulators and bridled to terminal poles. Trolley wire shall be strung tight and shall be at least 20 feet from the track, except at railroad crossings, where it must be 22 feet from the track. At each side of all railroad crossings there shall be installed a strain ear secured to an extra span wire run above regular span wire, with globe strain insulation in the bridle. Trolley wire must be located in the true center of the track on a straight track, and at all curves it must be so pulled over that the trolley wheel on the car will always stay on the wire.

The insulated hangers shall be the Keystone bell type. The ears shall be deep-grooved milled ears, soldered to the wire. Great care must be used in soldering; flux used shall be Yeager soldering salt or its equal.

Frogs and Lightning Arresters. The Contractor shall install all of the necessary frogs over special work; install the necessary insulated crossings at .... Avenue; and install 4 lightning arresters attached to the poles and the necessary single No. 0 B. & S. gage wire in connections from same to the track. These lightning arrester lead wires are to be brought down inside the pole, through a hole bored in the pole below the pavement line, and the wires shall be connected to the cross bond in the track and securely soldered to the same.

Joints. All joints in the trolley wire shall be made with long soldered-copper sleeves.

S. S. "ALLIANCA" PASSING THROUGH GATUN LOCKS

The steamer is in upper west chamber, water elevation 56.6 feet.

Courtesy of Panama Canal Commission, United States Government, Washington, D. C.

Strain Guys. The strain guys shall be erected on each side of the curves between..............................Avenue and.............................. Avenue, leading into..............................Avenue. Single strain guys shall be placed on each side of each railroad crossing. These strain guys shall lead to the nearest poles and have a globe strain insulator cut in, 2 feet from the strain ear, and also at turnbuckle.

It is the general intention of these specifications that the Contractor shall erect the complete overhead construction ready for the operation of cars.

SPECIFICATIONS FOR A STONE ROAD

Work to be Performed. The work to be performed will consist in furnishing all material, tools, machinery, and labor necessary for the efficient and proper grading of the roadway, side ditches, and side banks; for the laying, spreading, and rolling of road metal; and leaving the roadway complete in every manner, ready for immediate use.

Plans and Drawings. The plan, profile, and cross sections on file in the office of the State Commissioner of Public Roads and at the office of..County Engineer, ..., show general location, profile, details, and dimensions. The work will be constructed in all respects according to the above-mentioned plans, profile, and cross sections, which form part of these specifications.

Any variation of location, profile, size, and dimensions from that shown on the plans, as may be required by the exigencies of construction, will, in all cases, be determined by the Engineer; but the Contractor shall not, on any pretense, save that of the written order of the contracting parties, deviate from the intent of the plans or specifications.

On all drawings, figured dimensions are to govern in cases of discrepancy between scale and figures.

Grading. Under this head will be included all the excavation and embankment required for the formation of the highway; cutting all ditches or drains about or contiguous to the road; removing all fences, walls, buildings, trees, poles, or other encumbrances; the excavation and embankment necessary for reconstructing cross or branch roads in cases where they are destroyed or interfered with in the formation of the roadway; and all other excavations and embankments connected with or incidental to the construction of the said road.

Excavation. The roadway to the width of.............................. feet as shown on the plan must be excavated or built to the same curvature as that of the surface of the road when finished; the grade, from center to sides, must be as shown on plans.

The earth taken from any cut or ditch shall be deposited wherever the Engineer may direct, either within or without the line of the road; but no earth shall be removed from the line of the road without the order of the Engineer.

The grading shall be completed for the full width of the road, from gutter to gutter, before any macadamizing is commenced.

Embankment. Material taken from the excavations, except when otherwise directed by the Engineer, shall be deposited in the embankments, either on the roadway or sidewalks. Rejected or excess material will be used to increase the width of the embankments or deposited in spoil banks or waste piles, wherever and however the Engineer may direct.

When there is not sufficient material in the excavations of the road to form the embankments, the deficiency must be supplied by the Contractor from without the road; the character of said material and place of excavation must be approved by the Engineer; and said material is to be paid for at the same price per cubic yard as specified in the contract for other excavation.

The embankments will be formed in layers of such depth, generally 1 foot, and the material deposited and distributed in such a manner as the Engineer may direct, the required allowance for settling being added.

Slopes. Slopes in both embankments and excavations shall be 1½ horizontal to 1 vertical, unless otherwise ordered by the Engineer.

Roadbed. *Subfoundation.* When the excavations and embankments have been brought to a proper depth below the intended surface of the roadway, the cross section thereof conforming in every respect to the cross section of the road when finished, the same shall be rolled with a 10-ton steam roller until approved by the Engineer. If any depressions form under such rolling, owing to improper material or vegetable matter, the same shall be removed and good earth substituted, and the whole shall be rerolled until thoroughly solid and to above-mentioned grade. Water must be applied in advance of the roller when, in the opinion of the Engineer, it is necessary.

Telford Foundation. After the subfoundation has been formed and rolled, as above specified, and has passed the inspection of the Engineer, a bottom course of stone, of an average depth of 10 inches, is to be set by hand as a close firm pavement; the stones shall be placed on their broadest edges lengthwise across the road in such a manner as to break joints as much as possible, and the breadth of the upper edge shall not exceed 4 inches. The interstices are then to be filled with stone chips, firmly wedged by hand with a hammer, and projecting points shall be broken off. No stone of greater length than 10 inches or width of 4 inches shall be used, except each alternate stone on the outer edge, which shall be double the length of the others and well tied into the bed of the road; all stones with a flat smooth surface must be broken; the whole surface of this pavement shall be subjected to a thorough settling or ramming with heavy sledge hammers, and shall be thoroughly rolled with a 10-ton steam roller. No stone larger than $2\frac{1}{2}$ inches shall be left loose on top of telford.

Macadam. *First Course of Broken Stone.* After the road bed has been formed and rolled as above specified, and has passed the inspection of the Engineer, the first layer of broken stone, consisting of $2\frac{1}{2}$-inch stone, or stone that will pass through a ring 3 inches in diameter, shall be deposited in a uniform layer, having a depth of 6 inches, and rolled repeatedly with a 10-ton steam roller until compacted to the satisfaction of the Engineer. No stone in this course shall be less than 2 inches in length. Water must be applied in advance of the roller, when, in the opinion of the Engineer, it is necessary.

The depth of loose stone in this and all other courses must be measured by blocks the required thickness of the said loose stone. These blocks shall be placed at frequent intervals amid the loose stone when being spread.

Binder Between First and Second Course. On the first course of stone a quantity of..................................binder shall be spread in a uniform layer, and the rolling shall be continued until the stones cease to sink or creep in front of the roller; water will be applied in advance of the roller, if ordered by the Engineer. The quantity and quality of this and all other binding shall be at all times subject to the approval of the Engineer.

Second Course of Broken Stone. The second course of broken stone shall consist of $1\frac{1}{2}$-inch stone; that is, every piece of stone shall be broken so that it can be passed through a ring 2 inches in diameter, and no stone shall be more than 2 inches nor less than 1 inch long. This course is to be spread in a uniform layer of.......................inches in depth, and rolled until thoroughly settled into place to the satisfaction of the Engineer. Water will be applied, if ordered by the Engineer.

Binder on Second Course of Stone. Binder on this course of stone must be applied in the manner already given for binder on first course of stone as directed by Engineer.

Surface. When the two courses are rolled to the satisfaction of the Engineer, a coat of 50 per cent of three-fourths-inch stone and 50 per cent of screenings, properly mixed, is to be spread of sufficient thickness to make a smooth and uniform surface to the road; then the road shall again be rolled until it becomes thoroughly consolidated, hard, and smooth.

Rolling shall be done by the Contractor with a 10-ton roller, approved by the Engineer.

Any depressions formed during the rolling, or from any other cause, are to be filled with 1½-inch stone or three-fourths-inch stone, or both, and screenings approved by the Engineer, and the roadway shall be brought to the proper grade and curvature as determined by him.

Water must be applied in such quantities and in such manner as directed by the Engineer.

Manner of Rolling. In the rolling, the operator must start from the side lines of the stone bed and work towards the center, unless otherwise directed. The rolling shall at all times be under the control of the Engineer, who may, from time to time, direct such methods of procedure as in his opinion are required by the necessities of the case.

Quality of Material. All stone must be as nearly cubical as possible; broken with the most approved modern stone-crushing machinery; free from all screenings, earth, and other objectionable substances; of uniform size and of the same kind and quality, or of a kind and quality equally good in every particular as that shown in the Engineer's office. The 1½-inch stone or three-fourths-inch, and the screenings for binder and the final finish must be of the best trap rock, and must be free from loam or clay.

The Contractor must furnish samples to the Engineer of the kind of stone to be used in the work before the opening of the bids.

Shouldering. A shoulder of firm earth or gravel is to be left or made on each side, extending at the same grade and curvature of the road to the side ditches or gutters. This shoulder is to be rolled according to the directions of the Engineer.

Side Ditches or Gutters. The side ditches or gutters are to be excavated as per stakes furnished by the Engineer, in order to give an easy flow of water, so that no water shall be left standing on the road or in the ditches; and for this excavation no extra payment will be made.

Underdrains. Underdrains, if found necessary, shall be constructed by the Contractor (at prices named in bids) of good 4-inch tile, laid upon a board of not less than 1 inch in thickness and 6 inches in width, whenever and wherever the Engineer and Supervisor shall decide; the top of the tile shall be at least ....inches deep, unless otherwise directed by the Engineer;

the joints of the tile shall be covered with salt, hay, or material equally good; and the trench shall be filled with pervious earth.

When directed by the Engineer a stone drain may be used in place of the tile drain. A trench 1 foot wide and 1 foot 6 inches in depth shall be excavated below the subgrade, said excavation to be filled with loose broken stone to a depth required by the Engineer.

No Extra Price. No allowance in measure of depth of pavement will be made on account of any material which may be driven into the roadbed by rolling. The pavement when completed must conform to the grade and the cross sections, and be satisfactory to the Engineer, whose decision shall be final.

No extra work will be paid for unless the price has been agreed upon between the contracting parties, including the State Commissioner of Public Roads, and endorsed upon the agreement, witnessed by the Engineer.

All clay or gravel for shouldering or binder, and all extra hauling, is to be done at the Contractor's expense.

Broad Tire Wagons. All wagons and carts used during the construction for hauling stone, earth, or any other material must have tires not less than 3½ inches in width.

Liabilities of Contractor. *Road Repairs for One Year.* The Contractor shall keep the finished roadway and earthwork in repair for the period of 1 year from the date of its completion and acceptance, during which time he shall be liable for the wear and tear caused by ordinary travel; and, in addition thereto, he shall be liable for as much longer as for any period or periods during said year it shall be out of proper condition. If, during the time of the Contractor's liability, the roadway or any part of the work shall, in the judgment of the Engineer, require repairing, and he shall duly notify the Contractor to make such repairs as are required; and if the Contractor shall refuse or neglect to do so, to the satisfaction of the said Engineer, within 5 days from the date of the service of the notice, then the said Engineer shall have the right to have the work done properly by other parties and pay the expense for the same out of the 5 per cent retained.

Preserving Stakes and Bench Marks. The Contractor shall be required to preserve all stakes and benchmarks made and established on the line of work until duly authorized by the Engineer to remove the same.

Title Stones. The Contractor shall not disturb the position of title stones (the corners of properties adjacent to the road), but where they appear he shall either lift or lower them, under the personal supervision of the Engineer.

Preserving Clear Roadway. The Contractor must also preserve the roadway on which he is working from needless obstruction, and where necessary he must construct safe and commodious crossings, to be maintained in good order. He shall afford all proper and reasonable means for the accommodation of the public, and leave the roadway complete in every manner, ready for immediate use.

Provision for Drainage. If it is necessary in the prosecution of the work, to interrupt or obstruct the natural drainage of the surface or the flow of artificial drains, the Contractor shall provide for the same during the progress of the work in such a way that no damage shall result to either public or private interests. He shall be held liable for all damages which may result from any neglect to provide for either natural or artificial drainage, which he may have interrupted.

Right to Build Bridges, Culverts, etc., and to Suspend Work. The right of the county to build bridges, culverts, lay pipes, or other appurtenances in said road during the progress of the work is expressly reserved, as well as the right to suspend the work or any part thereof during the construction of the same, for the purposes above stated, without further compensation to the Contractor for such suspension than an extension of time for completing the work equal to the length of time his work may have been delayed.

Stopping Work on Account of Weather. The Engineer may stop any portion of the work if, in his judgment, the weather is such as to prevent the work from being properly done. No allowance of any kind will be made for such stoppage, except an extension of the time for the completion of the work as herein provided.

SPECIFICATIONS FOR CONCRETE MACADAM

Cement. The cement shall be first-class hydraulic cement which shall conform in all respects to the Standard Specifications of the American Society for Testing Materials. All cement shall be approved in writing by the State Highway Commissioner, before ordering, and shall preferably be delivered on the work in barrels. The Contractor shall furnish samples of the cement to the State Highway Commissioner, before any of it is used on the work.

Water. Water shall be fresh and clean, free from earth, refuse, and injurious mineral matter.

Broken Stone. Broken stone shall be good hard trap rock or hard blue limestone, clean and sound, broken into sizes ranging from one-half inch to 1½ inches in diameter. It must be thoroughly cleaned of refuse before using.

Sand. All sand shall be clean, coarse, sharp, and free from loam and vegetable matter.

Concrete Mixing. This concrete shall consist of the above materials properly proportioned for a 1-3-5 mixture, and shall be mixed with a sufficient quantity of water to cause the free mortar to rise to the top of the mass of concrete when tamped into place. It shall be thoroughly mixed by hand or machine and to the satisfaction of the State Highway Commissioner or Engineer in charge.

Placing. After the roadbed has been prepared according to these plans and specifications, a layer of concrete, proportioned as specified above, shall be placed to a depth of 6 inches, on one-half the width of the roadway. The inside edges shall be a dovetailed line as shown on the accompanying plans.

Tamping. The concrete shall be thoroughly tamped with a 25-pound tamper, until free mortar appears on the surface to the depth of 1 inch. The roadway shall then be covered with three-fourths-inch screenings, free from dust, and the same shall be lightly tamped into the free mortar until they are embedded for three-fourths of their depth.

Expansion Joints. If in the judgment of the State Highway Commissioner or Engineer in charge, expansion joints are required, they shall be formed at intervals of every 40 feet, by placing one-half-inch by 8-inch boards in the concrete, at right angles to the center line of the road. These boards shall be properly cut to fit the subsurface and the finished grade of the concrete, and shall be withdrawn from the concrete one hour after placing same, and the space left open thereby shall be filled with hot pitch or some other approved bituminous filler.

Protection of Work. After the concrete shall have been placed it shall be protected from traffic for at least 1 week. While constructing one-half of the roadway, traffic may be permitted on the other half.

Connecting up Work. After one-half of the roadway has been completed, the remaining half shall be laid in the same manner as the first half, making expansion joints continuous with the first half.

No roller shall be permitted on the concrete roadway until 2 weeks after the whole has been completed.

Other Materials. Bids will also be received for other proprietary methods of making a concrete road. If another proprietary method is used it will be placed and the work done in general under the specifications of the manufacturer in conjunction with the regular specifications of the Department.

Grading, drainage, and telford or macadam foundations, and all other things to be done in the reconstruction must be done under the general specifications of the State Highway Department for road reconstruction.

PAVEMENTS AND CURBING

GENERAL

Removal or Adjustment of Fixtures. The adjustment or resetting of any manholes, fire hydrants, lamp posts, gas stops, telegraph or electric light poles, or other fixtures shall be considered as an appurtenant to the work of paving and repaving; and shall be included as such in the work to be done by the Contractor for the prices bid for paving and repaving. Such adjustment or resetting shall be done by the companies owning them, or, if the property of the City, by the proper municipal Department; but, in either case, it shall be done at the expense of the Contractor.

Granite Blocks on Gravel Base. For granite block paving on gravel base in driveways or gutters, the filling shall be thoroughly compacted to a subgrade 10 inches below the finished grade, and a layer of approved paving gravel spread on it to a least thickness of 4 inches. The blocks shall be placed vertically on edge in straight rows at right angles to the curb line, in close contact, breaking joints; and they shall be thoroughly rammed three times with a rammer weighing not less than 55 pounds; and the finished surface shall conform exactly to the required grade. While the blocks are being rammed, approved paving gravel or sand shall be swept into the joints until they are completely filled. All irregular or uneven surfaces shall be taken up and reset and re-rammed to the proper grade.

Repaving, Resetting Curb, etc. In repaving and in the resetting of curbs and crossing stones, the foundations shall be prepared and all the work shall be done as required for new paving of the same kind. Old materials that may be suitable for replacing may be used only after satisfactory preparation by special permission, and as directed.

Revision of Old Paving. Any revision of old paving, gutter ways, crossings, or curbs, where the new work joins the old work, shall be made as directed, and paid for as provided in the proposal.

Cleaning. Upon the completion of any pavements the Contractor shall clean them promptly of all refuse or surplus materials.

Gutters. The finished grade for the gutters shall generally be 5 inches below the top of the curb, except where given differently on the drawings, or where a change is directed by the Engineer, to insure proper surface drainage.

Crowning or Rise. The crowning or rise of the finished pavements in the driveways shall be uniform from the gutters toward the center of the street; and at the rate of $2\frac{1}{2}$ per cent for granite block or vitrified-clay brick or block pavement, and $2\frac{1}{4}$ per cent for asphalt pavement; except at intersections, or where the surface drainage demands a different crown, or as may be directed by the Engineer. Gutter and crown stakes must be set every 50 feet. The rise of the sidewalk pavement shall be as directed by the Engineer.

DRIVEWAY PAVEMENTS OF VITRIFIED-CLAY BRICKS OR BLOCKS, GRANITE BLOCKS, AND ASPHALT

Bed. The bed for driveway paving shall be graded from curb to curb, and thoroughly compacted by rolling with a heavy steam roller, weighing not less than 5 gross tons, until the surface shall be accurate to subgrade and parallel to it. The subgrade shall be below the intended finished grade, as follows: for vitrified-clay brick or block pavement, 11 inches; for granite block pavement, 15 inches; for asphalt pavement, 9 inches. All soft and spongy places shall be excavated and refilled with gravel or broken stone before rolling. The use of a horse roller will be allowed where, in the judgment of the Engineer, the use of a steam road roller may be impracticable on account of steep grades or other local conditions.

Concrete Foundation. *Mixing and Laying.* Upon the bed shall be laid a layer 6 inches thick of Portland cement concrete in which is used stone crushed to pass a $1\frac{1}{2}$-inch ring. The concrete shall be rammed with 25-pound rammers until free mortar appears on the surface, which surface shall be parallel to and below the top of the finished pavement, as follows: 5 inches for vitrified-clay brick or block pavement; 9 inches for granite block pavement; and 3 inches for asphalt pavement.

Carting and Wheeling. No carting or wheeling will be allowed on the concrete until covered by paving.

Tests. The concrete foundation shall be capable of sustaining such test as the Engineer shall deem necessary.

Kept Clean and in Advance of Paving. In paving, the Contractor must keep the concrete base to the proper grade or slope at least 100 feet in advance of his paving, and the latter must be laid in sections the full width of the street. The concrete surface shall be thoroughly cleaned of gravel, rubbish, or covering of any description, before any mortar or sand is placed in which the bricks or blocks are to be bedded.

VITRIFIED-CLAY BRICK OR BLOCK PAVING

Samples for Testing. When paving with vitrified-clay bricks or blocks is required, the Contractor shall submit sample bricks or blocks, and afford every facility for inspection and testing at least 10 days before desiring to use them. The failure of any shipment on any work to meet the requirements may prohibit the further use of the same manufacture on that work.

Size and Quality. The bricks or blocks must be vitrified fireclay, re-pressed, and especially burned for street paving, not less than 9 inches long, 4 inches wide, and 3 inches thick. They shall be tough, homogeneous, compact in structure, and burned to a uniform consistency. They shall be free from laminations or "fire cracks" or "checks" of more than superficial extent; shall be free from nodules of lime or magnesia or other soluble matter; and shall show no signs of cracking after 48 hours' immersion in water maintained at normal temperature (60-70° F.).

Variations in Size. All bricks or blocks will be allowed a proper shrinkage, but they must not vary more than 3 per cent from the accepted samples. All bricks or blocks so distorted in burning as to lie unevenly in the pavement will be rejected.

Shape. The bricks or blocks must have two or more ribs or projections upon one of the vertical sides, extending from top to bottom; on the opposite vertical side of the brick or block, a groove or channel extending longitudinally from the end of the brick or block, and connecting with a like transverse groove extending across each end; thus serving by contact with the flat side of an adjoining brick or block, to secure a separation, in order that cementing material, flowing into the grooves, may effect a practical encircling of each brick or block, thus keying or locking together the entire pavement.

Testing. Samples of bricks or blocks for testing will be selected at random from actual shipments delivered on the work, and must yield the following results:

Five of the bricks or blocks so sampled will be tested transversely and shall develop an average strength sufficient to sustain a load of 3000 pounds per inch of width. The bricks or blocks in this test shall be supported edgewise, on rounded knife edges placed 6 inches apart; the breaking load being applied centrally. Five bricks or blocks shall be placed in a standard polygonal rumbler (20 inches wide, 30 inches in diameter), together with 10 cast-iron bricks (weighing 6 pounds each), having rounded edges. This rumbler will be revolved

2000 times at the rate of 35 revolutions per minute, and the brick must not show an average loss of more than 18 per cent. The bricks or blocks coming from the rumbler shall be dried for 24 hours at a temperature of not less than 212° F.; and after 48 hours' immersion in water, maintained at a normal temperature, shall not show an absorption of more than 4 per cent.

Laying. The bricks or blocks must be set vertically on edge in close contact with each other, in straight rows across the street, excepting at intersections, which shall be paved at an angle of 45 degrees to the lines of the intersecting roadways, and those in adjoining rows so set as to break joints regularly. No bats or broken bricks or blocks shall be used except at curbs, or adjoining passenger railway rails, where half bricks or blocks must be used to break joints. The bricks or blocks shall be bedded in a layer of Portland cement mortar 1 inch in thickness, freshly mixed, and laid upon the concrete foundation as the placing of the bricks or blocks progresses. They shall be true to the required finished surface when completed, and shall be settled in place, after depositing, by placing a plank upon their tops and ramming the plank as required, with wooden rammers, before the mortar bedding has time to set and as the work progresses.

Grouting. After the bricks or blocks are laid, they shall be grouted with Portland cement grouting, consisting of one part cement to one part clean bar sand, mixed with water to such consistency that it will readily permeate the joints, filling all joints flush with the surface.

Car Tracks. When car tracks cross the deck of a bridge, a line of fitted granite blocks or slag blocks shall be laid on each side of each rail, placed longitudinally or as stretchers. The blocks so used shall be made especially for street paving, shall have beveled edges on top, and be of size and quality to be approved by the Engineer upon the submission of samples properly labeled, the accepted sample to be the standard. All voids under the heads and side bearing flanges, between the webs of the rails and the paving blocks, shall be filled with special molded bricks, thoroughly grouted with Portland cement grout to fill all crevices.

GRANITE BLOCK PAVING ON CONCRETE BASE

Granite Blocks. Granite blocks shall be fitted blocks of approved Eastern granite, with square heads and bottoms, and in sizes from 6 to 6½ inches in depth, 3½ inches in width, 8 to 12 inches in length; 4 inches in width, 8 to 12 inches in length; and 4½ inches in width, 8 to 12 inches in length; to be sorted at the quarries at the above sizes, kept separate, and delivered and set separately; all the faces of the blocks shall be non-warped and parallel; free from bunches, depressions, and inequalities exceeding one-fourth inch; and no stones shall measure less than the above-named lowest figures.

Laying. Upon the concrete foundation for granite block paving shall be placed a layer 3 inches thick of sharp, approved, coarse New Jersey paving sand, upon which the blocks shall be bedded. Granite blocks shall be properly assorted or gaged, those of the same width and depth to be placed in consecutive rows; blocks differing in width more than one-fourth inch will not be allowed in the same row. They shall be placed vertically on edge in close contact with each other across the street; in straight rows and at right angles to the curbing, except at intersections, where they shall be placed at an angle of 45 degrees to the lines of the intersecting roadways. Blocks in adjoining rows shall be set to break joints by a space not less than 4 inches, and when thoroughly rammed they shall be brought to the exact grade. Joints shall not be more than one-half inch in thickness. At all times during the progress of the work 100 lineal feet of the paving must be laid continually in advance of filling and ramming, to permit the proper inspection of the blocks and the work. The pavement must be laid so that the blocks shall be uniform in width in sections across the full width of the street.

Ramming—Filling Joints. The pavements shall be rammed three times with 55-pound rammers, until no further settling occurs under the ramming. While being rammed the joints shall be kept well filled with dry pebbles. Any blocks that do not conform to the exact grade shall be reset and re-rammed. The pebbles for filling joints shall be quartz, hard, clean, well washed, and not easily crushed, one-eighth to one-fourth inch in diameter, entirely free from dust, dirt, or foreign material, and thoroughly dry when delivered. Immediately after the final ramming the pebbles shall be swept out to a depth of 1 inch from the top of the pavement, and the joints filled with hot paving pitch, applied in liquid form. The pitch must be prepared for paving purposes, so that it can be easily applied in the liquid state when artificially heated, and used to fill the joints thoroughly and not spread over the face of the paving. While the paving pitch is still hot, dry sand shall be spread very thinly over the entire surface of the pavement.

Dry Material. If the weather be damp while the paving is being done, or if the pebbles become wet, they shall be artificially heated and kept hot until they are flooded with the paving pitch.

Tracks. When passenger railway tracks are to be laid, one line of granite blocks shall be laid longitudinally, or as stretchers, along each side of each rail. All voids under the heads and treads of the rails shall be filled with specially molded bricks, and then thoroughly grouted to fill all voids.

TELFORD PAVING

Roadbed. The bed shall be thoroughly compacted by rolling with a steam roller weighing not less than 5 gross tons, to be parallel to and 12 inches below the finished surface, as given by the District Surveyor.

Sub-Stone Pavement. Upon the bed shall be placed a sub-stone pavement not less than 8 inches deep, consisting of hard approved stones, not less than 12 inches in their longest diameter, placed vertically on edge, in rows square across the driveway, so as to break joints. Projecting points in the subpavement shall be broken off with knapping hammers, after which more stone shall be broken by hand on top and wedged between the pavement stones until all cavities are filled.

Surface Layers. A layer of clean loam, not less than 1 inch thick, shall be deposited on top of the sub-stone pavement. Sufficient crushed stone, crushed to pass a 1½-inch ring, of hard trap rock, free from dirt, shall be deposited on the surface, and rolled with the steam roller previously specified, so that there shall not be less than 4 inches of the crushed stone on top of the foundation stone. After rolling the crushed stone, a covering of fine stone, breaker scale, or screenings of trap rock shall be evenly spread, kept wet, and rolled continuously, until the whole shall be a compact mass, 2 inches above the finished surface as fixed by the Engineer.

CURBING

Materials. Curbing shall be furnished where required by the drawings, and shall be either of steel protected granolithic or of first quality granite. Granite shall be neither laminated nor stratified, shall be hammer-dressed on the face at least 12 inches deep over all of the top surface, and 3 inches deep on the back to receive the sidewalk pavement.

All joints shall be close joints, the full depth and width of the stones.

Dimensions. Curbing shall be either 6 or 8 inches wide on top, as specified; 8-inch curbing shall be 24 inches in depth and 10 inches in width at the base; 6-inch curbing shall be 22 inches in depth and 8 inches in width at the base.

Straight curbing shall not be less than 6 feet in length, and curved curbing shall not be less than 5 feet in length, and no closure shall be less than 4 feet in length. Where curved curbs are required in excess of 8 feet in length the stone may be in two pieces, either of which may be less than 5 feet in length, but the joint must be in the center.

Foundations. Curbs shall be set upon a solid foundation prepared for them, of coarse gravel or spalls, backed with gravel, all solidly rammed.

The foundation of the sidewalk paving back of the curbs shall be thoroughly compacted by ramming, before the sidewalk paving is laid.

Curbstones set adjacent to inlets shall be square on their ends the full depth of the stones, and the castings for inlet covers, stop boxes, or other municipal or other castings, shall be cut into the curbing, flush with the top of the curb.

Curved Curbs. When curved curbs are placed, the Contractor shall extend the crossing stones to conform to the radius curbs. All curved curbing shall be cut exactly true to the radius ordered, and set to the lines and grades to be obtained from the Engineer.

Joints. All joints of curbing shall be thoroughly back filled, and made water-tight from the base to the top of the curbing with Portland cement mortar, made of one part Portland cement and two parts clean sand, thoroughly mixed into a stiff mortar.

All curbs moved or displaced, or any sidewalks injured or destroyed by the Contractor, or those employed by him, either while grading for the paving or in the handling, placing, or removal of materials, supplies, etc., must be reset, replaced, or repaved in proper manner by the Contractor at his expense.

GRANITE BLOCK PAVING ON SAND BASE

Preparation of Foundation. The spaces to be paved between the lines shown on the plans shall be graded and thoroughly compacted by rolling with a heavy steam roller, weighing not less than 12 gross tons, until the surface shall be brought accurately to subgrade and parallel with and 10 inches below the finished surface. All soft places shall be dug out and filled with paving sand. The subgrade must be compacted to a solid foundation, and must be approved before the block paving is laid. Sharp, approved, coarse paving sand shall be spread upon the foundation, to a depth of at least 4 inches, upon which the blocks shall be bedded.

Granite Blocks. Granite blocks shall be fitted blocks of approved granite 3½ to 4 inches wide, 6 to 6½ inches deep, 8 to 12 inches long, with square heads, smooth faces, and rectangular edges. They shall be subject to inspection and shall be gaged and sorted by men furnished by the Contractor; any blocks rejected shall be immediately removed from the vicinity of the work. Those of the same width and depth shall be placed in consecutive rows, and blocks differing in width more than one-fourth inch shall not be allowed in the same row. They shall be placed vertically on edge in close contact with each other across the space to be paved; in straight rows and at right angles to the curbing, except at intersections, where they shall be placed at an angle of 45 degrees to the lines of the intersecting roadways. Blocks in the adjoining rows shall be set to break joints by a space of not less than 4 inches, and when thoroughly rammed they shall be brought to the exact grade. Joints shall not be more than one-half inch in thickness. At all times during the progress of the work, about 100 lineal feet of the paving shall be laid continuously in advance of filling and ramming, to permit the proper inspection of the work. The pavement shall be laid so that the blocks shall be uniform in width in sections across the full width of the space being paved.

Filling Joints. The joints between the blocks shall then at once be filled with paving sand and shall be rammed three times with 55-pound rammers until no further settling occurs under the ramming. While being rammed the joints should be kept well filled with paving sand. Any blocks that do not conform to the exact grade shall be reset and rammed.

Payment. Payment will be made for this paving at the price per square yard given in the proposal, which price shall include everything except such excavation as may be necessary for preparing the subgrade.

ASPHALT PAVING

Samples to be Submitted. If asphalt pavement is to be laid, the Contractor shall submit to the Commissioner of Highways samples of the materials he intends to use, together with certificates and statements as follows:

(1) Specimens of asphalt and asphaltum, with a certificate stating where the specimens were mined.

(2) A specimen of the asphaltic cement, with a statement of the elements of the bituminous cements used in the composition of the paving surface.

(3) Specimens of sand intended to be used.

(4) Specimens of pulverized carbonate of lime, granite, or quartz intended to be used.

(5) A certificate, if the material proposed to be used has not heretofore been used in the City of................................, showing some other locality where pavement of such material has been laid, its area, date of acceptance, which must have been at least 2

years previous to the issuance of the certificate, and showing that said pavement has worn well and satisfactorily; all to be signed and acknowledged by the chief municipal officer having charge of said work in the city or cities where such pavement has been laid.

Such specimens, certificates, and statements must be, in the judgment of the Engineer, equal in all respects to similar conditions exacted by the Department of Highways for other asphalt pavement in the City of..................................

Subgrade for Asphalt. The backfilling on the top of the trench shall be of clean gravel or sand, or other wholesome earth, free from all spongy or vegetable material; and thoroughly rolled with a roller weighing not less than 10 tons, so that the top of the filling is parallel to the crown of the street and 9 inches below it; except beneath the stone block pavement adjoining rails, manhole heads, and stopcock boxes, where the depth below the finished grade shall be 13½ inches. When the roller cannot reach every portion of the roadbed, the bottom shall be rolled by a small roller, or tamped, as directed by the Engineer, and water shall be sprinkled on such bottom when required. Upon the foundation thus prepared, there shall be laid a bed of hydraulic cement concrete 6 inches in thickness, and made as follows:

Cement. All cement must be of the best quality, of fresh-ground best American Portland cement, and shall be tested and approved by the Engineer before being used.

Portland Cement Concrete. Concrete shall be composed of 1 part of cement, 3 parts of clean sharp sand, and 7 parts of broken stone; or 1 part of cement, 3 parts of clean sharp sand, 4 parts of broken stone, and 3 parts of pebbles by measure.

Mixing. The cement and sand shall be mixed dry; the broken stone having been first wetted shall then be added and the mass turned over, with the addition of the necessary water, and worked until the broken stone is completely incorporated.

Pebbles. The pebbles shall be hard, clean, free from sand, screened and washed, and of a size that has passed a sieve of 1½-inch mesh and rejected by a three-fourths-inch mesh.

Broken Stone. The broken stone shall be solid trap, limestone, or granite, free from dust or dirt, and of a graded size not larger in any dimension than will pass through a 2-inch ring; and it shall be crushed and screened before being brought upon the work; and no crushing shall be done on the work.

Concrete to be Rammed. The concrete shall be placed in proper position and there rammed with wooden rammers until thoroughly compacted; the surface shall be 3 inches below

S. S. "CRISTOBAL" PASSING THROUGH GATUN UPPER LOCKS

The gates have just opened and the ship is about to pass into Gatun Lake.

Courtesy of Panama Canal Commission, United States Government, Washington, D. C.

the grade of the top of the finished pavement and exactly parallel thereto.

The concrete foundation shall be capable of sustaining such test as the Engineer shall deem necessary.

No carting or wheeling shall be allowed on the concrete until it is sufficiently set, and then only on planks laid down for the purpose.

Mixing Concrete. The whole operation of mixing and laying each batch, which shall not contain more than 1 barrel of cement, must be performed as expeditiously as possible by the employment of a sufficient number of skilled men and, if necessary, must be protected from the action of the sun and wind until set. No concrete will be allowed to be used which has been mixed more than 30 minutes.

Bituminous Binder. *Composition.* Upon this concrete foundation must be laid a fine bituminous concrete or binder, to be composed of clean broken stone not exceeding 1¼ inches in their largest dimensions, thoroughly screened, and either coal-tar residuum, commonly known as No. 4 paving composition, or the same bitumen used in the body of the pavement.

Stone to be Heated. The stone must be heated by being passed through revolving heaters and must be thoroughly mixed by machinery, with the paving composition in the proportion of 1 gallon of paving composition to 1 cubic foot of stone.

Laying of Binder. This binder must be hauled to the work and spread with hot iron rakes in all holes or inequalities and depressions below the true grade of the pavements, to such thickness that, after being thoroughly compacted by tamping and hand rolling, the surface shall have a uniform grade and cross section, and the thickness of the binder at any point shall be not less than three-fourths inch. No binder shall be laid during a rain, nor shall any binder be laid that is too cold to be manipulated easily; overheated binder shall be removed entirely from the work.

The upper surface shall be exactly parallel with the surface of the pavement to be laid.

Wearing Surface. Upon this foundation must be laid the wearing surface, or paving proper, the basis of which must be pure asphaltum, unmixed with any of the products of coal tar.

The wearing surface will be composed of:

(1) Refined asphaltum; (2) heavy petroleum oil; (3) fine sand, containing not more than 1 per cent of hydrosilicate of alumina; (4) fine powder of carbonate of lime, granite, or quartz.

Heavy Petroleum Oil. The heavy petroleum oil must be freed from all impurities and brought to a specific gravity of from 18° to 22° Baumé, and a fire test of 250° F., or, if the formula of the Contractor requires it, the powdered carbonate of lime may be omitted, and the heavy petroleum oil may be replaced by sufficiently fluid natural bitumen.

Asphaltum. The asphaltum used must be equal in quality to that mined from the Pitch Lake on the Island of Trinidad, or from the Alcatraz mine, Santa Barbara County, California, and must be specially refined and brought to a uniform standard of purity and gravity, of a quality to be approved by the Engineer.

Asphaltic Cement. From these two hydrocarbons shall be manufactured an asphaltic cement which shall have a fire test of 250° F., and, at a temperature of 60° F., shall have a specific gravity of 1.19, said cement to be composed of 100 parts of pure asphalt, and from 15 to 20 parts of heavy petroleum oil.

Pavement Mixture. The asphaltic cement being made in the manner above described, the pavement mixture must be formed of the following materials, and in the proportions stated:

Asphaltic cement	From 12 to 15
Sand	From 83 to 70
Pulverized carbonate of lime, granite, or quartz................	From 5 to 15

Sand. The sand shall be of such size that none of it shall pass a No. 80 screen, and that the whole of it shall pass a No. 10 screen.

Powdered Stone. The powdered carbonate of lime, granite, or quartz shall be of such a degree of fineness that from 5 to 15 per cent by weight of the entire mixture for the pavement shall be an impalpable powder of limestone, and the whole of it shall pass a No. 26 screen.

How Mixed. The sand and asphaltic cement are to be heated separately to about 300° F. The pulverized carbonate of lime, granite, or quartz, while cold, shall be mixed with the hot sand in the required proportions, and then mixed in a suitable apparatus with the asphaltic cement at the required temperature, and in the proportions which will effect a perfect mixture.

Laying of Pavement Mixture. The pavement mixture prepared in the manner thus indicated must be brought to the ground in carts, at a temperature of about 250° F. and, if the temperature of the air is less than 50° F., iron carts, with heating apparatus, shall be used in order to maintain the proper temperature of the mixture; it shall then be carefully spread by means of hot iron rakes in such manner as to give a uniform and regular grade. The surface shall be compressed by hand rollers, after which a small amount of hydraulic cement shall be swept over it, and it shall then be thoroughly compressed by a steam roller weighing not less than 250 pounds to the inch run, the rolling to be continued for not less than 5 hours for every 1000 square yards of surface. After having received its ultimate compression, the pavement must have a thickness of not less than 2 inches.

Gutters. The gutters for a width of 12 inches next the curb must be coated with hot, pure asphalt, and smoothed with hot smoothing irons in order to saturate the pavement, to a depth to be directed by the Engineer, with an excess of asphalt.

Rock Asphalt. If rock asphalt be used, the material shall be an amorphous limestone, which is naturally, thoroughly, and uniformly impregnated with bitumen: (1) From the Sicilian mines at Ragusa and Verwohle, equal in quality and composition to that mined by the United Limmer and Verwohle Rock Asphalte Company, Limited. (2) From the Swiss mines at Val de Travers, equal in quality and composition to that mined by The Neuchatel Asphalte Company, Limited. Or (3) from the French mines at Seyssel and Mons, and the Sicilian mines at Ragusa, equal in quality and composition to that mined by the Compagnie Génerále des Asphaltes de France, Limited, and it shall be prepared and laid as follows:

Preparation. The rock shall be finely crushed and pulverized; the powder shall then be passed through a fine sieve. Nothing whatever shall be added to or taken from the powder obtained by grinding the bituminous rock. The powder shall contain 9 to 12 per cent natural bitumen; 88 to 91 per cent pure carbonate of lime; and must be free from quartz, sulphates, iron pyrites, or aluminum.

Powder to be Heated. This powder shall be heated in a suitable apparatus to 200°-250° F., and must be brought to the ground at such temperature, in carts made for the purpose; then carefully spread on the binder foundation previously prepared to such depth that, after having received its ultimate compression, it will have a thickness of not less than 2 inches.

Surface to be Rolled. The surface shall be rendered perfectly even by rammers and smoothers, and shall be rolled with a steam roller weighing not less than 250 pounds to the inch run, the rolling to continue for not less than 5 hours for each 1000 square yards of surface in the case of Trinidad asphalt; in the case of rock asphalt pavement the ultimate compression may be by heated pilons.

Special Permission to Lay Rock Asphalt. Rock asphalt shall not be used in any case without written permission from the Commissioner of Highways.

Space Next to Rails, Manholes, etc. On each side of the rails of the car tracks, around all manholes and stopcock boxes, the

Contractor, when required, shall lay a line of granite or syenite paving blocks, as headers; long and short stones alternating and toothing into the pavement, laid on a foundation of 6 inches of concrete, which must extend to the depth of the crossties and beneath and around the girders and stringers; on which shall be laid a bed of fresh cement mortar, 2 inches in thickness; and on the mortar so laid shall be laid the stone blocks, the top surface of which shall conform to the grade of the pavement. The joints of the blocks shall be filled with paving cement, as hereinafter described.

Space within Car Tracks. Whenever the space within car tracks has been laid with granite or syenite blocks, the said space shall be repaved with said blocks or said asphalt, according to the determination of the Engineer.

REFINED ASPHALT

Solid Bitumen Base

Materials and Tests. The refined asphalt to be used for paving mixtures herein required shall be derived in the following manner:

1. By heating crude, natural, solid asphalt, requiring refinement, to a temperature of not over 450° F., until all the water has been driven off. Crude, natural, solid asphalt shall be construed to mean any natural mineral bitumen, either pure or mixed with foreign matter, from which, through natural causes in the process of time, the light oils have been driven off until it has a consistency harder than 100 penetration at 77° F. At least 98½ per cent of the contained bitumen in the refined asphalt, which is soluble in cold carbon disulphide, shall be soluble in cold carbon tetrachloride. In no case shall such asphalt be prepared at the refinery with any product not hereinafter provided for.

2. By the careful distillation of asphaltic petroleum with continuous agitation until the resulting bitumen has a consistency not harder than 30 penetration at 77° F.

(a) All shipments of material shall be marked with a lot number and penetration; and ten samples, taken at random from each lot, shall not vary more than 15 per cent from the average penetration, provided no part of any shipment shall be below 30 penetration at 77° F.

(b) The solid bitumen so obtained shall be soluble in carbon tetrachloride to the extent of 98½ per cent.

(c) When 20 grams of the material are heated for 5 hours at a temperature of 325° F. in a tin box 2½ inches in diameter, after the manner officially prescribed, the material shall not lose over 5 per cent by weight nor shall the penetration at 77° F. after such heating be less than one-half of the original penetration.

(d) The solid bitumen at a penetration of 50 shall have a ductility of not less than 20 centimeters at 77° F. If the penetration varies from 50, an increase of at least 2 centimeters in ductility will be required for each five points in penetration above 50; and a corresponding allowance will be made below 50 penetration. This test shall be made with a briquette of cross section of one square centimeter, the material being elongated at the rate of 5 centimeters per minute. (Dow molds).

Note.—Combinations of asphaltic bitumens having the ductility and other characteristics above mentioned are admitted under Section 2.

3. Refined asphalt produced by combining crude natural asphalt with either of the following:

(a) Residuums obtained by the distillation of petroleum oils as specified under fluxes.

(b) Asphalts obtained by the distillation of petroleum oils as specified.

Use of Bitumen Mixtures. *Fluxes.* In the use of these mixtures of refined asphalts for asphaltic cements, only asphaltic or semi-asphaltic fluxes shall be used, except in those cases where the solid natural asphalt is of such character that when mixed with paraffin flux, without the addition of any other material, it will produce an asphaltic cement complying with the requirements set forth under that head. In such cases any of the fluxes elsewhere specified may be used.

Inspection. The preparation and refining of all asphalt admitted under these specifications shall be subject to such inspection at the paving plants and refineries as the Engineer may direct.

Flux

Material. The fluxing material may be a paraffin, a semi-asphaltic, or an asphaltic residue which shall be tested with and found suitable to the asphalts to be used.

Tests. *Penetration.* The residuums must have a penetration greater than 350, with a No. 2 needle at 77° F. under 50 grams weight for 1 second.

Solubility. All residuums shall be soluble in cold carbon tetrachloride to the extent of 99 per cent, and must remain soft after heating for 5 hours at 400° F.

Miscellaneous. (a) The paraffin residuum shall have a specific gravity of from 0.92 to 0.94 at 77° F. It shall not flash below 350° F. when tested in the New York State Closed Oil Tester, and shall not volatilize more than 5 per cent of material when heated 5 hours at 325° F. in a tin box $2\frac{1}{2}$ inches in diameter, as officially prescribed. The residue after heating shall flow at 77° F. and shall be homogeneous and shall show no coarse crystals.

(b) Semi-asphaltic residuum shall have the same general characteristics as paraffin residuum except that it shall have a specific gravity of 0.94 to 0.98 at 77° F.

Asphaltic Cement

Proportions of Asphalt and Flux. The asphaltic cement prepared from materials above designated shall be made up from the refined asphalt or asphalts, and the flux, where flux must be used, in such proportions as to produce an asphaltic cement of a suitable degree of penetration. The proportion of the refined asphalt, comprising the cement, shall in no case be less than 40 per cent by weight.

When the weight of flux in the asphaltic cement prepared from solid natural asphalt exceeds 25 per cent thereof, asphaltic or semi-asphaltic flux shall be used.

Refined asphalts and flux comprising the asphaltic cement shall, when required, be weighed separately in the presence of the authorized inspectors or agents of the Engineer.

Method of Mixing. Refined asphalts and flux used in preparing the cement shall be melted together in a kettle at a temperature ranging from 250° to not over 375° F.; and shall be thoroughly agitated when heated by air, steam, or mechanical appliances, until the resulting cement has become thoroughly mixed into a homogeneous mass. The agitation must be continued during the entire period of preparing the mixtures. Cement shall always be of uniform consistency and, if any portion should settle in the kettle, between intervals of using the same, it must be thoroughly agitated before being drawn for use.

Tests. (a) The asphaltic cement shall have a penetration of from 40 to 75, which shall be varied within these limits to adapt it to the particular asphalt used in the paving mixture and to the traffic and other conditions. The exact amount of penetration shall be fixed by the Engineer.

(b) When 20 grams of the asphaltic cement of the penetration to be used in the paving mixture shall be heated for 5 hours at a temperature of 325° F., in an oven as officially specified, there must not be volatilized more than 5 per cent of the bitumen present, nor shall the penetration at 77° F. after such heating be less than one-half of the original penetration.

(c) A briquette of the asphaltic cement, having a cross section of one square centimeter, when at a penetration of 50, shall elongate to the extent of not less than 20 centimeters at 77° F. If the asphaltic cement as used in the paving mixture varies from 50 penetration, an increase of at least 2 centimeters in ductility will be required for each 5 points in penetration above 50, and a corresponding allowance will be made below 50 penetration. (Dow method.)

Specifications for Sand and Binder Stone

Sand. The sand shall be hard grained and moderately sharp. It shall be so graded as to produce, in the finished surface mixture, the mesh requirements elsewhere herein specified. It shall contain not to exceed 6 per cent of sand that will pass a No. 200 mesh sieve.

Binder Stone. Stone to be used for asphaltic concrete binder shall be hard and durable, free from all foreign substances, and of uniformly varying sizes, from 1 inch down.

Laying the Pavement

Asphaltic Concrete Binder. *Preparation.* Asphaltic concrete binder shall be made as follows: The binder stone and sand as above specified shall be heated to 200°-325° F. in suitable appliances. Stone and sand shall be measured off separately; and then be mixed with sufficient asphaltic cement prepared as heretofore specified, in such proportions that the resulting aggregate will contain by weight material passing a No. 10 mesh screen, between 25 and 35 per cent and bitumen in quantity from 5 to 8 per cent of the entire mixture.

Binder thus prepared shall be a compact mass containing a minimum of voids.

Laying. The asphaltic concrete binder shall be brought to the work in wagons covered with canvas or other suitable material, and upon reaching the street shall have a temperature of 200°-325° F. It shall be placed upon the concrete foundation and raked to a uniform surface to such depth that, after being rolled and thoroughly compacted, it shall have an average thickness of 1 inch and shall be 2 inches below, and parallel to, the surface of the finished pavement. The surface, after compression, shall show at no place an excess of asphaltic cement, and any spot covering an area of 1 square foot or more, showing an excess of asphaltic cement, shall be cut out and replaced with other material. Smaller spots may be dried by the use of stone dust and smoothers. Any asphaltic concrete binder broken up during the process of laying must be removed and replaced with new material. No more binder shall be laid at any one time than can be covered by a 2 days' run of the paving plant on surface mixture.

Asphaltic Surface Mixture or Wearing Course. *Specifications.* The surface mixture shall consist of asphaltic cement, Portland cement or stone dust, and sand proportioned by weight, so that the resulting mixture will contain average proportions of the whole mixture as follows:

Bitumen soluble in cold carbon disulphide	9.5 to 13.5%
Portland cement or stone dust passing a No. 200 sieve	10.0 to 15.0%
Sand passing a No. 80 sieve	18.0 to 36.0%
Sand passing a No. 40 sieve	20.0 to 50.0%
Sand passing a No. 10 sieve	8.0 to 25.0%
Sand passing a No. 4 sieve	Up to 10.0%

NOTE.—Sieves to be used in the order named.

The item designated as "Portland cement or stone dust passing a No. 200 sieve", within the limits named herein, includes, in addition to the Portland cement or stone dust, fine sand passing a No. 200 sieve not exceeding 4½ per cent of the total mixture, and such 200-mesh mineral dust naturally self-contained in the refined asphalt.

Mixing. Sand and asphaltic cement shall be heated separately to about 300° F.; the maximum temperature of the sand at the mixers shall in no case be in excess of 375° F. and the maximum temperature of the asphaltic cement shall not exceed 325° F. at the discharge pipe. The Portland cement or stone dust shall be mixed with the hot sand and in the required proportions; and then these shall be mixed for at least 1 minute, with the asphaltic cement at the required temperature and in the proper proportions, in a suitable apparatus so as to effect a thoroughly homogeneous mixture.

The proportion of asphalt cement shall at all times be determined by actual weighing with scales attached to the asphaltic cement bucket. The weight of the bucket shall be checked up at least twice every day.

The Portland cement or stone dust and sand must also be weighed unless a method of gaging approved by the Engineer shall be used.

For the determination of the temperatures required by the specifications throughout the process of manufacture, the contractor shall provide and maintain at the plants suitable registering thermometric instruments to be approved by the Engineer. Proper weighing devices must also be installed and maintained for the determination of the quantities of materials used.

The Contractor shall furnish every facility for the verification of all scales or measures.

The sand gradings and bitumen may be varied within the limits designated at the discretion of the Engineer.

Laying the Wearing Surface. The asphalt wearing surface shall be hauled to the work in wagons provided with a canvas or other suitable cover. As placed in the street it shall have a minimum temperature of 250°-280° F. as suitable for the asphalt used. It shall be dumped at such distance from the work that all of the mixture can be turned and distributed to the place where it is to be raked; and shall be spread, while hot, to such depth upon the asphaltic concrete binder—which must be thoroughly dry, free from leaves, or other foreign matter—that after receiving its ultimate compression by rolling, it shall have an average thickness of two inches. The initial compression shall be effected by means of a small roller, after which a small amount of Portland cement or mineral dust shall be swept over the surface. Final compression shall be effected by a roller of not less than 200 pounds per inch tread. The rolling shall be carried on continuously at the rate of not more than 200 square yards per hour.

All tests herein provided must be conducted according to official methods on file in the office of the Chief Engineer. All penetrations indicated herein, unless otherwise specified, refer to the depth of penetration in hundredths of a centimeter of a No. 2 cambric needle weighted to 100 grams at 77° F. acting for 5 seconds.

No asphalt shall be laid when, in the opinion of the Engineer, the weather conditions are unsuitable for its proper laying; and no asphalt shall be laid unless the surface on which it is to be laid is dry.

After the surface shall have been finished, no horse or vehicle traffic of any kind shall be permitted on the pavement until it shall have hardened sufficiently.

Should an asphalt pavement have to be laid adjacent to the tracks of a street railroad, granite paving blocks will be laid next to the track, for which the Contractor will be paid the price named in the proposal for new granite block paving upon cement concrete foundation.

The granite blocks shall be laid upon a cement concrete foundation, mixed in accordance with these specifications, which shall extend to the depth of the bottom of the crossties.

The top of the blocks shall be even with the surface of the tread of the rail, which must conform with the grade of the street. The blocks shall be laid before the wearing surface is laid upon the driveway, thoroughly backed with cement concrete, carefully rammed to a firm bed. All joints must be thoroughly filled with cement grouting composed of one part fresh ground Portland cement and one part clean approved sand.

Asphalt-filled manhole covers and frames, when ordered by the Engineer, shall be placed on all manholes where such frames and covers have not already been placed. Payment for all such frames and covers will be made at the prices named in the proposal.

WOOD-BLOCK PAVEMENT

Material Specifications. The wood-block pavement layer shall be..........................inches thick, as required by the traffic and conditions of the street; and constructed of the materials and in the manner hereinafter specified.

Long-Leaf Yellow Pine. The wood from which the blocks are made must be regular, sound, commercial, merchantable, long-leaf yellow pine, which shall be well manufactured, saw-butted, free from large coarse knots or very coarse grain, and free from the following defects: unsound, loose, and hollow knots, worm holes, knot holes; through, round, or other objectionable shakes; wane, checks, bark; incipient or other decay.

Other Woods. Other woods, as Oregon or Washington Douglas fir, scientifically and practically equal or superior to the above mentioned long-leaf pine, which can be equally well creosoted and which are satisfactory to the City Engineer, can be used, provided that only one kind and quality of wood is used on the same street or contract and further provided that only one kind of wood is treated and creosoted at one time.

Wood Blocks. The paving blocks, cut from the lumber or wood above specified, shall be well manufactured, truly rectangular, and uniform. They shall be dressed on all sides; except the top and bottom, both of which shall be evenly and smoothly sawed. No block shall vary in width and depth more than one-sixteenth of an inch from others used on the same street or contract. The depth shall be..........................inches as already specified. The length shall be not less than 6 nor more than 10 inches. The width shall be not less than 3 nor more than 4 inches, provided that all blocks used in one street or contract shall be of the same width.

Creosote Oil. *Amount per Cubic Foot.* The blocks shall be treated, preserved, or creosoted as hereinafter specified and each block shall contain at least 18 pounds of creosote oil per cubic foot of wood; or when a block contains much natural pitch it shall receive as much creosote as can be forced into it by the same process and pressure as is used in the treatment of blocks of the same kind of wood which will receive 18 pounds of creosote oil per cubic foot; provided, however, that the combined creosote and natural pitch in all blocks be at least 19 pounds per cubic foot.

Quality Tests. The creosote oil shall be a dead oil of coal tar or a coal-tar product. It shall not contain more than 3 per cent of water; and if it does contain this amount of water, a corresponding correction must be made so that an equivalent additional amount of creosote is forced into the blocks. It shall contain only traces of acetic acid and acetates. Its specific gravity at 100° F. (38° C.) shall be at least 1.03 and not more than 1.10, so as to assure its thoroughly penetrating the wood blocks. It must not leave more than a trace on a filter paper when filtered between 60° F. and 77° F. Fractional distillation of 100 grams of the creosote oil shall produce percentages of dry oil by weight within the following limits:

Up to 150° C. (302° F.) no distillate
Between 150° C. (302° F.) and 170° C. (338° F.) not to exceed 1.5 per cent
Between 170° C. (338° F.) and 235° C. (445° F.) not to exceed 33.0 per cent
Between 235° C. (455° F.) and 300° C. (572° F.) not to exceed 35.0 per cent

The residue shall be soft and adhesive. The creosote oil shall contain about 25 per cent of crystallizable naphthalene and at least 15 per cent anthracene oils. At least 95 per cent of the creosote oil shall be equally soluble in carbon bisulphide and in absolute alcohol.

Treating the Blocks. *Sterilizing.* The wood blocks, after being cut and ready for treatment, shall be placed in a suitable iron receptacle or cylinder and there sterilized with dry steam under a pressure of at least 30 pounds, and not to exceed 50 pounds per square inch during at least 3 hours and as much longer, not to exceed 7 hours, as the condition of the wood and the season of the year requires. The temperature within the cylinder during the process of steaming shall be between 250° F. and 280° F. At intervals during this process the condensed steam, sap, and other liquid matter shall be drawn from the receptacle by means of valves. At the completion of the steaming process, all condensed steam and other fluid matter shall be blown from the cylinder through an opening in its bottom, and the steam shall be caused to pass out through an opening in its top.

Vacuum Treatment. The draining and exhaust valves of the cylinder shall then be closed and a vacuum pump shall immediately produce, as quickly as possible, a vacuum of at least 24 inches, and as much more as may be necessary; this vacuum shall be maintained in the cylinder until moisture and gases cease to come from the cylinder. During this process the wood blocks within the cylinder shall be kept hot by means of steam coils within it.

Forcing Creosote Oil into the Blocks. Immediately after the vacuum treatment and while the vacuum exists, the creosote oil at a temperature between 180° F. and 200° F. shall be run into the cylinder and forced and maintained under such pressure that the wood blocks shall absorb and be impregnated with creosote oil to the amount as required above. The excess of creosote oil in the cylinder shall then be withdrawn; the blocks drained and prepared for shipment.

Water Absorption. The blocks when ready for use shall not absorb more water than an average of 4½ per cent of their dry weight, after being heated at 100° F. during 12 hours and then placed under water 12 hours.

Indentation Pressure Test. The blocks ready for use must meet the indentation pressure test made as follows: The blocks to be tested are first dried at 100° F. during 12 hours. Then a polished steel die of 1 square inch on its lower face, with square edges and corners, and perpendicular sides, is placed on a dried block, firmly supported in a compression testing machine. A pressure of 8000 pounds is applied quickly and maintained exactly 1 minute. The die must not descend and indent the block more than one-eighth of an inch. The measurements are to be taken from the time when the die is lightly pressed against the block to the instant the 8000-pound pressure has been applied 1 minute. The die is placed anywhere within one-half inch of the edges of the block and so as to compress lengthwise the wood fibers.

Inspection of Blocks. The wood blocks shall be inspected by the City Engineer at the place of manufacture, or on arrival in the city where they are to be used, or when piled adjacent to the street to be paved. All blocks not in conformity with the requirements of these specifications will be rejected and must be removed from the locality of the pavement to be laid.

Laying Blocks. The wood blocks are to be laid upon the mortar bed immediately after the said bed is ready to receive them. Except when otherwise directed by the City Engineer, the blocks are to be laid with close joints and at right angles to the curbs; in uniform courses; and so that all longitudinal joints shall be covered by a lap of at least 3 inches. No closure or end blocks less than 3 inches long shall be used.

Tight Joints and Rolling. The blocks shall be driven or forced together as closely as possible during laying, and shall be properly rolled or rammed to a firm bearing and uniform surface.

Defective Blocks. No rolling or ramming shall be done within 10 feet of the surface where blocks are being laid. All blocks which are broken, split, or otherwise damaged, defective, or displaced shall be removed immediately after rolling or ramming and replaced with sound blocks.

Filling Joints. After the blocks have been laid and properly rammed, their joints shall be filled or grouted with either a suitable bituminous paving joint cement approved by the Engineer, or by a cement grout. The bituminous cement must be such as not to be too soft in warm weather, and not too brittle in cold weather to be a durable and adhesive filler. It must be heated until it is so liquid that it will run freely into and fill the joints. The cement grout shall be composed of two parts of clean sand and one part of an approved brand of Portland cement, mixed to a perfectly liquid form; and the surface of the block shall be slushed with the same, and the joints shall be swept until they are completely filled.

Surface Sand. Immediately after the grout or bituminous cement has filled the joints, there shall be spread over the entire pavement a one-half-inch layer of clean, very coarse, dry sand; or a layer of clean, hard, dry, crushed stone screenings with particles not exceeding one-fourth inch and not smaller than one-thirty-second of an inch in size. This layer of either coarse sand or crushed stone screenings is to remain on the pavement while it is subjected to traffic for a period of at least a month, or until any excess is removed as far as possible or necessary by the City.

Expansion Joints. Expansion joints shall be constructed between the curbs and wood paving blocks to provide for the possible expansion and contraction of the blocks by heat or cold or other conditions. These expansion joints shall be constructed from three-fourths inch to 1 inch wide, according to the width of the street, as directed by the Engineer; and shall extend the whole depth of the blocks; and shall be filled with a suitable bituminous paving joint cement acceptable to the Engineer. Expansion joints of any required width shall be constructed at such other locations as the Engineer may direct. Expansion joints must be completely filled with suitable strips of wood previous to filling the joints with the paving joint cement.

Any bituminous cement adhering to curbs or sidewalks must be removed by the contractor. The pavement and sidewalk shall be free from all surplus materials as soon as the Contractor has finished paving the street.

GRANOLITHIC SIDEWALK PAVEMENTS

Bed. The sidewalk shall be excavated and graded from the curb to the house line, or to the width required, to a subgrade 18½ inches below and parallel to the top of the finished pavement. The bed shall be thoroughly compacted by ramming to the prescribed lines.

Cinder Foundation. On the subgrade so prepared a foundation of clean, hard coal cinders, not less than 14 inches thick, shall be placed in two 7-inch layers, which shall be well consolidated by ramming with a rammer weighing at least 75 pounds, and having a face at least 8 inches square.

The cinders shall be well watered during ramming, and the top surfaces shall be brought to a height exactly 4½ inches below and parallel to the finished surface.

Concrete Base. On this cinder foundation shall be placed 3 inches of Portland cement concrete. This base shall be cut by joints into blocks not larger than 6 feet square, the joints to extend clear through the concrete.

Wearing Course. On this concrete base, and before the concrete has attained its initial set, shall be placed the finished or wearing course. This course shall consist of a stiff mortar composed of equal parts of Portland cement and the sharp screenings of crushed granite or stone of equal quality, to be approved by the Engineer, the largest particles of which shall pass through a three-eighths-inch ring; and it shall be free from dust, loam, or earthy substances; and shall be laid to a full depth of 1½ inches, carefully floated and troweled to a smooth, even surface. A drier mixed in the proportion of 1 part sand to 2 parts Portland cement shall be sprinkled in a dry state over the surface, and then floated and troweled. This treatment shall be repeated 3 times; after which the joints shall be cut through the wearing surface directly over the joints in the concrete base, troweled with a small jointer, and the entire surface indented in a manner to be approved by the Engineer.

Tinting. When directed, the drier mixture shall receive the blue, black, or other tinting matter to produce the shade approved by the Engineer.

Sprinkling. When the pavement is completed, it shall be kept covered for 3 days, during which time it shall be kept moist by sprinkling.

BRICK PAVEMENT

For brick sidewalk paving the sidewalk shall be excavated or filled and graded from curb to house line or to the width required; and firmly and uniformly compacted, by ramming or rolling, to a subgrade of not less than 6 inches below the intended finished grade of pavement, and parallel to it. All soft and spongy places shall be dug out and properly refilled. Upon the bottom so formed shall be placed a layer of sharp clean bar sand, upon which the paving brick shall be laid. The bricks shall be straight, hard, first quality paving bricks laid in the best workmanlike manner. Samples of bricks must be submitted for approval at least 10 days before they are desired for use.

SODDING

Quality of Sod. The Contractor shall furnish and place grass sod on the slope of the embankment and at other places as directed by the Chief Engineer. The sod shall be of good quality of earth covered with heavy grass; sound and healthy; free from weeds; at least 1 foot square and 2 inches thick; cut with a bevel on the sides so that when laid they will lap at the edges. No poor, lean, or broken sod will be allowed in the work.

Laying. The sod shall be carefully set so as to have a full bearing on their lower surfaces, and shall be properly rammed and well rolled, and wherever required by the Chief Engineer they shall be pinned down with wooden pins not less than 12 inches long. The surface of the top soil shall be dampened immediately before laying the sod. Care shall be taken to have all surfaces conform to the proper lines and grades, and any sliding or settling which may occur, before the final acceptance of the work, shall be repaired by the Contractor.

Grass sodding, in place, shall be paid for at the price given in the proposal.

GENERAL SPECIFICATIONS FOR THE DESIGN OF ELEVATED TANKS AND STANDPIPES

LOADS

Definitions. (1) The dead load shall consist of the weight of structural and ornamental steelwork, platforms, roof construction, piping, etc.

(2) The live load considered shall be the contents of tanks, the movable load on platforms and roofs, and the wind pressure.

(3) The weight of water shall be assumed to be 63 pounds

per cubic foot; and that of crude oil 56 pounds per cubic foot, 1 cubic foot of fluid being equal to 7.48 gallons.

(4) The live loads on platforms and roofs shall be taken at 30 pounds per square foot or a 200-pound concentrated load applied at any point.

(5) The wind pressure shall be assumed at 30 pounds per square foot, acting in any direction. The surfaces of cylindrical tanks exposed to the wind shall be calculated at two-thirds of the diameter multiplied by the height.

(6) The movable live load on platforms and roofs shall not be considered as acting together with the wind pressure.

UNIT STRAINS

Sums of Dead and Live Loads. All parts of the structure shall be proportioned so that the sum of the dead and live loads shall not cause the strains to exceed those given in Table I.

TABLE I

Maximum Tension, Compression, and Shearing Stresses for Tanks and Standpipes

Strains in Various Members	Pounds per Square Inch
Tension in tank plates (net area)	12,000
Tension in other parts of structure (net area)	16,000
Compression (reduced)	16,000
Shear on rivets and pins	12,000
Shear on bolts and field rivets	9,000
Shear in plates (gross section)	10,000
Bearing pressure on rivets and pins	20,000
Bearing pressure on field rivets	18,000
Fiber strain in pins	24,000

Compression Factor. For compression members, the permissible unit strain of 16,000 pounds shall be reduced by the formula

$$p = 16{,}000 - 70\frac{l}{r}$$

where p = permissible working strain in compression, in pounds per square inch
l = length of member, from center to center of connections, in inches
r = least radius of gyration of section in inches

The ratio $\frac{l}{r}$ shall never exceed 120 for main members and 150 for struts.

Wind Stresses. Stresses due to wind may be neglected if they are less than 25 per cent of the combined dead and live loads.

Unit strains in bracing and other members taking the wind stresses may be increased to 20,000 pounds per square inch, except as shown above.

The pressures given in Table II will be permissible on foundation and bearing plates.

TABLE II

Maximum Allowable Pressures on Foundation and Bearing Plates

FOUNDATION MATERIAL	TONS PER SQ. FT.
Soft clay	1
Ordinary clay	2
Dry sand and dry clay	3
Hard clay	4
Gravel and coarse sand	6
BEARING PLATES	**LBS. PER SQ. IN.**
Brickwork with cement mortar	200
Portland cement concrete	350
First-class sandstone	400
First-class limestone	500
First-class granite	600

DETAILS OF CONSTRUCTION

Calking. The plates forming the sides of cylindrical tanks shall be of different diameters, and shall be calked from the inside. No foreign material shall be allowed when calking.

In oil-tank work, both the inside and the outside of the tank shall be beveled for calking.

Joints. Joints for horizontal seams and for radial seams in the spherical bottoms of tanks shall preferably be lap joints.

For vertical seams lap joints shall be used for one-fourth-, five-sixteenths-, and three-eighths-inch plates; for all other thicknesses, butt joints with double and triple rows of rivets on both sides of joint shall be used.

Rivets. Rivets five-eighths inch in diameter shall be used for one-fourth- and five-sixteenths-inch plates; rivets three-fourths inch in diameter for three-eighths- to five-eighths-inch plates, inclusive; and rivets seven-eighths inch in diameter for eleven-sixteenths- to 1-inch plates, inclusive.

Plates. Plates more than five-eighths inch thick shall be subpunched and reamed.

The minimum thickness of the plates for the cylindrical part shall be one-fourth inch. The thickness of the plates in spherical bottoms shall never be less than that of the lower ring in the cylindrical part of the tank.

The facilities at the plant where the material is to be fabricated will be investigated before the material is ordered.

All plates shall be punched before being bevel sheared for calking.

Spherical Bottoms. Radial sections of spherical bottoms shall be made in duplicates of the number of columns supporting the tank, and shall be reinforced at the lower parts, where holes are made for piping.

When the center of the spherical bottom is above the point of connection with the cylindrical part of the tank, there shall be provided a girder at said point of connection to take the horizontal thrust. The horizontal girder may be made in connection with the balcony. This also applies where the tank is supported by inclined columns.

The balcony around the tanks shall be 3 feet wide with a one-fourth-inch floor plate, and shall have a suitable railing 3 feet 6 inches high.

The upper parts of spherical bottom plates shall always be connected on the inside of the cylindrical section of the tank.

Connections between Tower Columns and Tank. In order to avoid eccentric loading on the tower columns and local stresses in spherical bottoms, the connections between the columns and the sides of the tank shall be made in such a manner that the center of gravity of the column section intersects the center of connection between the spherical bottom and the sides of the tank. Enough rivets shall be provided above this intersection to transmit the total column load.

If the tanks are supported on columns, riveted directly to the sides, additional material must be provided in the tank plates riveted directly to the columns to take the shear. The shear may be taken by providing thicker tank plates or by reinforcement plates at the column connections. Connections to columns shall be made in such a manner that the efficiency of the tank plates is not less than that of the vertical seams.

High Towers. For high towers, columns shall have a batter of 1 to 12. The height of the tower is understood to be the distance from the top of the masonry to the connection of the spherical bottom, or the flat bottom, with the cylindrical part of the tank.

Standpipes. The bottom plates of standpipes shall be not less than five-sixteenths inch thick, and shall be provided with tapped holes, $1\frac{1}{4}$ inches in diameter, with screw plugs spaced at 4-foot centers to allow a filling of cement on top of the masonry, while the bottom is being erected, in order to secure the proper bearing.

Near the bottom of the standpipe there shall be provided one 12- by 18-inch manhole of elliptical shape.

Near the top of each tank and standpipe there shall be provided one **Z**-bar acting as a support for the painters' trolley and for the stiffening of the tank. The section modulus of the same shall be not less than $\frac{D^2}{250}$ where D is equal to the diameter of the tank, in feet. If the upper part of the tank is held by the roof construction, this may be reduced.

Stiffening Angles on Large Tanks. On large tanks, circular stiffening angles shall be provided in order to prevent the tank plates from buckling during windstorms. The distance between the angles shall be located by the following formula:

$$d=\sqrt{t\frac{900}{D}}$$

where d = approximate distance between angles, in feet
t = thickness of tank plates, in inches
D = diameter of tank, in feet

Roof Plates. The top of the tank will generally be covered with a conical roof of thin plates, and the pitch shall be 1 to 6. For tanks up to 22 feet in diameter, the roof plates will be assumed to be self-supporting. If the diameter of the tank exceeds 22 feet, angle rafters shall be used to support the roof plates.

Plates of the following thicknesses will be assumed as self-supporting for various diameters: three-thirty-seconds-inch plate, up to a diameter of 18 feet; one-eighth-inch plate, up to a diameter of 20 feet; three-sixteenths-inch plate, up to a diameter of 22 feet.

Rivets in the roof plates shall be from one-fourth to five-sixteenths inch in diameter and shall be driven cold. These rivets need not be headed with a button set.

A trapdoor, 2 feet square, shall be provided in the roof plate.

Near the top of the higher tanks a platform with a railing shall be provided, for the safety of the men operating the trapdoor.

An ornamental finial shall be provided at the top of the roof.

Ladder. A ladder 1 foot 3 inches wide shall be provided from a point about 8 feet above the foundation to the top of the tank, and also one shall be provided on the inside of the tank. Each ladder shall be made of two 2½- by ⅜-inch bars with three-fourths-inch rungs. On large high tanks, 30 feet or more in diameter, a walk shall be provided from the column nearest the ladder to the expansion joint on the inlet pipe.

Overrun. In designing tanks, 6 inches additional height shall be allowed for overrun.

Bracing. The bracing in the towers shall not be adjustable.

Anchor Bolts. The size of the anchor bolts shall be determined by the uplift when the tank or standpipe is empty. The unit strains in the anchor bolts shall not exceed 15,000 pounds per square inch, and the minimum section shall be limited to a diameter of 1¼ inches.

Miscellaneous. The concrete shall be assumed to have a weight of 140 pounds per cubic foot and shall be sufficient in quantity to take the uplift.

Any parts of the tank, standpipe, or tower, in which difficulties may arise in field riveting, shall be assembled in the shop, and marked properly before shipment.

The structural material shall conform to the "General Specifications for Steel Railroad Bridges" as adopted by the American Railway Engineering and Maintenance of Way Association.

The workmanship shall be in accordance with the Manufacturers' Standard Specifications of Feb. 6, 1903.

Before leaving the shop all work shall be painted with one coat of approved paint, excepting the laps in contact on the tank work. All parts which will be inaccessible after erection shall be well painted. After erection, the structure shall be covered with one coat of the same paint.

Three-ply frost-proof casing shall be provided, if necessary, around the inlet pipe. This casing shall be composed of two layers of 1- by 2½-inch lumber, and each layer shall be covered with tar paper, and one outside layer of ⅞- by 2½-inch dressed and matched flooring. The lumber shall be in lengths of about 12 feet. A 1-inch air space shall be provided between the layers of lumber, and wood rings or separators shall be nailed to them every 3 feet. The frost casing may be made square or cylindrical.

CONTRACT, OR ARTICLES OF AGREEMENT

Nature and Purpose. A contract is an agreement between two or more parties to do a certain thing, such as delivering material, performing work, etc., and is based upon a mutual understanding between the parties to the agreement as to the nature of the work to be done, the kind of materials to be supplied, etc., and the amount of the consideration to be paid.

Everything that will prevent misunderstanding as to the intention of the parties to the contract should be embodied in and form a part of the contract. Hence, as already stated, the advertisement, the proposal, the drawings, the specifications, and the written articles of agreement should all form essential parts of the contract. There should be as many copies of the contract executed as there are parties to it, each party retaining a copy.

Number of Parties to a Contract. It is claimed by some authorities that there can be but two parties to a contract. However, we have many examples of agreements between corporations, where there are as many parties to the contracts as there are interests. There are also contracts between financiers, promoters, engineers, and contractors often involving many parties.

ESSENTIAL ELEMENTS

The four essential elements of all contracts, without which no contract is valid, are as follows:

(1) Appropriate parties; or parties with capacity to contract.
(2) Mutual consent to the terms of the agreement—a mutual understanding.
(3) A definite subject—matter to be acted on.
(4) A valid or lawful consideration, actual or presumed—a something in exchange for its legal equivalent.

The Parties. To every contract there must be at least *two parties,* but there may be more than two. The parties may be either individuals, firms, or corporations and are designated in the agreement as the party of the first part and the party of the second part; when there are other parties, which is unusual, they are designated as the party of the third part and the party of the fourth part. The party who has something to be done, or who is to pay the money, is generally designated as the party of the first part. The person or corporation who proposes to do the work for a consideration, or to sell something, is generally designated as the party of the second part, although there is no fixed rule in this matter.

Appropriate Parties. Any person, firm, or corporation *may* be a *competent* party. There are exceptions to every rule. Generally corporations may contract only within the scope of their charter and by-laws by which they are usually limited.

Generally speaking, any person of sound mind and legal age may make a contract. There are, however, exceptions differing in different localities. As an instance, married women are limited in their right to make contracts in certain States. But as their powers are being extended, a local attorney at law should be consulted in making contracts with them.

A contract with a person of unsound mind is not binding upon the weaker person.

Unsoundness of mind may be either temporary — as, from intoxication—or constitutional. When, therefore, there is the slightest evidence of mental unfitness, no contract should be made, as litigation is thereby courted. It is needless to say that a contract should never be executed under threat.

Corporations. In a contract, a corporation is considered as a single individual, regardless of the number of its members. It is of the greatest importance that it be known which officers of a company are authorized by its charter or by-laws to execute contracts. The president and the vice-president of a corporation are generally authorized to execute contracts for their company. The execution is usually witnessed by the officers' signatures and the seal of the company, attested by the secretary, the signatures generally being acknowledged before a notary public or a commissioner of deeds. Important contracts shall also have the approval of the board of directors of the company. It is important that the limitation of the powers of the company's charter be known before the contract is drawn.

Full Description of Parties. The parties to a contract must be so fully described that there can be no mistake made as to their identity. A firm's full name and place of business, together with the names of the individuals comprising it, should be given. An individual should be identified by his residence and occupation and a corporation by its full title, and the name of the State or Country wherein it was incorporated.

Signatures to Agreement. It is necessary that the names of the parties used in the body of the agreement be exactly in accord with the signatures at the end thereof; discrepancies in the names might invalidate the contract.

United States Government a Party. The United States Government cannot be sued for noncompliance with a contract, although it may bring suit against the other party to the contract—so a State may not be sued by an individual. A public official cannot be held personally liable for obligations made by him in his official capacity.

Mutual Consent. A contract is not legal unless both parties thereto have agreed to the same thing.

Hence an offer must be accepted before it becomes binding and until accepted may be withdrawn. It has been said that an offer by letter should be accepted by return mail; an offer by telegram, by return telegram, etc. All offers should be in writing to eliminate controversies; therefore they should be accepted or rejected promptly.

If the party accepting impose any new conditions, they, in turn, must be agreed to by the other party, before a contract can be entered into.

Subject Matter. The subject matter of a contract may be anything that is not immoral or illegal, and it must concern some act to be carried out. The subject matter must be described so fully and clearly that both parties will understand all conditions of the agreement, as a contract that is obscure or ambiguous leads to controversy and perhaps litigation. In case of dispute as to the meaning of the subject matter, custom and usage have great weight in the courts.

Consideration. The consideration, or the price or reason of the promise, should be clearly and fully set forth in the agreement. The consideration makes the contract legal and must be real and substantial.

ANALYSIS OF CONDITIONS

Provide for all Conditions. It is of great importance that all probable and possible events in connection with the contract be foreseen and provided for in drawing the agreement. It requires great experience and ability to be able to foresee and provide for all conditions that may arise in the course of the work. It is, therefore, best for the Engineer to follow the standard form of some acknowledged authority until he becomes experienced in contract drawing, making such changes as are necessary to suit his conditions.

Duties of Parties. Each contract must stand on its own basis; that is to say, where the work to be done is legal; methods of doing it legal; the parties making it competent to act; and the agreement set forth in writing. The agreement so made becomes law between the parties. In case of disputes the courts can only construe contracts, so as to determine what the intentions of the parties were; hence the necessity of the contract specifically setting forth the duties and obligations of the respective parties thereto. It must be remembered that though the Engineer draws the contract, the courts may be called upon to construe it.

Guaranty. A guaranty in the form of a bond or certified check is generally required of bidders on public works. This is to reimburse the owner for the cost of re-advertisement and delay in case the successful bidder fails to execute the contract, and to compensate for loss or damages incident to delay in completion of the work, caused by the failure of the bidder.

Bond. A surety bond, to enter into contract, should be required of the Contractor on all contracts for public works, and on all other important contracts (the amount of such bond being set forth in the notice to bidders), for the faithful performance of the contract and prompt payment for labor and material, and as a protection to the Company against all damage to persons or property caused by negligence of the Contractor or his employes.

In some contracts for public works, one bond is required to cover the performance of the contract; another one to protect the material, men, and labor; and still others, covering other requirements due to local laws. There is no rule for the amount of the bond to be given by the Contractor. Bonds must generally be sued upon in order to recover, throwing the burden of proof upon the Company.

Payment Clauses. In the payment clauses in the contract, under various conditions, the Engineer is authorized to withhold payment until the objectionable conditions are removed by the Contractor. It is, therefore, sometimes considered that a "withheld payment" is one of the best means of securing the desired end—the old story of "touching a man's pocketbook" to gain results. The withheld payment throws the burden of proof on the Contractor, in case of dispute; is simple and direct, and, therefore, easy of application. It has been said with truth that "the guaranty of good work is intelligent and faithful inspection, withheld payments, and the Contractor's bond."

Arbitrators. The employment of the *arbitration clause* is not to be recommended, as in case of controversies it is rare that the parties to the contract will abide by the conditions of the arbitration clause, generally preferring to throw the dispute into the courts, rather than trust their interests to the unknown qualifications of arbitrators.

They may decline even to appoint arbitrators. If, however, each party appoints an arbitrator to act in the matters of controversy and executes an instrument agreeing to abide by the decision of the arbitrators chosen, according to the terms of the contract, they are irrevocably bound by the findings of the board. The following clause has been used by the writer in a few cases:

Arbitration. In the case of any difference or dispute arising between the Company and the Contractor, during the execution of the work, other than the meaning of the specifications and drawings, which shall be interpreted by the Engineer, the same shall be referred to 3 disinterested arbitrators, one to be appointed by each of the parties to this contract and the third by the two thus chosen, the decision of any 2 of whom shall be final and binding on the parties thereto; and cost and expenses of said arbitration, including reasonable witness fees, shall be imposed upon either of the parties hereto, or divided between said parties in an equitable manner by the arbitrators, and shall be paid by said party or parties in accordance with the arbitrators' decisions.

Manufactured Products. In contracts involving the supply of manufactured materials such as structural steel or building materials, when the party supplying same is subject to strikes, floods, etc., a clause such as the following is often inserted in the contract to limit the liability of the Contractor, and is considered equitable.

Strikes, Floods, etc. The times herein mentioned for completion of the work are subject to delays due to transportation, strikes, fires, floods, storms, or other causes beyond the Contractor's control. Should the work be delayed by any of the foregoing causes, the Contractor shall have additional time, not less than the extent and sum of said delays, in which to complete his work under this contract. This extension of time shall be commensurate with the specified excusing cause or causes.

NOTE.—Local Laws. The local lien and labor laws should be most carefully looked into before the drawing of a contract. They are different in different States. Some prescribe the hours of labor and amount of pay for workmen; others provide that the person furnishing the materials of construction and the laborers shall have a preferred claim to that of the Contractor; still others require that the contract be filed with some official, to prevent serious and expensive legal disputes among the owner, contractor, material men, sub-contractors, laborers, etc. Too much importance cannot be given to the drawing and filing of contracts where the local lien and labor laws are in force. Local customs and usages, in the matter of measuring plaster, brick work, masonry of different kinds, etc., must be provided against in the contract.

FORMS OF AGREEMENT

In preparing a form of agreement, it is well to have a list of the various essentials to a well-drawn civil engineering contract before the writer, in order to avoid the omission of important clauses. The following provisions should be included in the agreement:

Opening Clause. A correct form for the opening clause. There are many forms that are correct and it is not material which is used. To make the form more readily understood, names and dates in the examples given below have been filled in.

THIS AGREEMENT, Made and Entered Into this tenth day of July, in the year of our Lord 1914, by and between Green Mountain Railroad Company, a corporation created by and existing under the laws of the State of New Jersey, and having its principal office at 509 South Broad Street, in the City of Newark, in said State, hereinafter called "Company", party of the first part; and Smith, Jones, and Company, of the City of Chicago, State of Illinois, a firm composed of John G. Smith, James S. Jones, and William F. Brown, having its principal place of business at 14 South Front Street, in the City of Chicago, and State of Illinois, party of the second part, hereinafter called the "Contractor", Witnesseth:—

or

ARTICLES OF AGREEMENT, Made and Concluded this tenth day of July, A. D. 1914, by and between Brooklyn Terminal Company, a corporation created by and existing under the laws of the State of New York, and having its principal office at 18 South Water Street, in the Borough of Brooklyn, City of New York, in the said State, hereinafter called "Company", party of the first part; and James Dolan, Contractor, residing at 710 Burns Avenue, in the City of Boston, State of Massachusetts, party of the second part, hereinafter called the "Contractor", Witnesseth:—

Parties. It is advisable to designate the parties to the contract for the sake of brevity by one word as: *Company, Engineer, Contractor, Agent, Trustee, Owner, Purchaser, Incorporator, Board, City,* etc., as the case may be.

Arrangement of Clauses. Following the opening clauses should come the specific *covenants* and *agreements* of the respective parties to the contract, which should be set forth as clearly and unequivocally as possible.

Plans and Specifications. Where the plans and specifications are properly drawn they should, of course, show the quantity and quality, and, as far as possible, the amount of work to be done, material to be furnished, and the time and method of making payments; also the time of beginning and of completing the work, and other details of the operation; hence the articles of agreement must specifically state that the work and labor to be done, and materials to be furnished and delivered, must be in strict and exact accordance with the proposal, plans, and specifications attached to the Articles of Agreement which are made a part of the contract.

Materials, Workmanship, and Damages. Usually the Articles of Agreement should also state that the materials and workmanship are to be the best of their kinds, and should provide for the proper inspection thereof; for their approval or rejection; for the replacing of defective material or workmanship; for a time within which the work should be performed; and for a specific stipulation that upon failure of the Contractor to complete the work within the time specified, a fixed sum shall be deducted from the contract price for each and every day that the work remains incomplete, as *ascertained* and *liquidated damages* and *not* as *a penalty.*

In fixing the amount of liquidated damages for each day's delay, due consideration should be given to the actual loss to the Company for such delay, as courts are inclined to look with disfavor upon anything in the nature of a penalty.

Prosecution of Work. The Articles of Agreement should also contain a covenant for due prosecution of the work, and should provide means and methods by which the Company may proceed to furnish the materials or complete the work upon the failure or neglect of the Contractor to comply with the terms of the contract.

Surety. It should also provide for the entry of security for the proper performance of the contract by bond or otherwise. Personal bonds should be avoided whenever possible, and good surety company security accepted instead. The bond is a very important factor in the contract and the clause should be very carefully drawn and in such a manner (if it is possible) that the necessary changes in plans and specifications may be made without vitiating the bond. It is of the greatest importance that before any changes or alterations are made, the person or surety company on the Contractor's bond be notified of the Engineer's intention, and their consent obtained before proceeding with the work.

Protective Clause. It should further provide for proper protection of the work and precautions against accidents and an assumption of liability by the Contractor of all damages to persons or property resulting from the prosecution of the work. Provision should be made against assigning, transferring, or subletting the contract; and should specify that it is subject to all local laws regulating the employment of workmen and the protection of material men and sub-contractors; and for the protection of the Company the contract should contain an appropriate clause drawn in accord with the local laws waiving the right of the Contractor, material men, laborers, or sub-contractors to file liens. This last covenant should be drawn by a local attorney; in most instances the contract should be filed in accordance with the law of the place where the work is to be done.

Contract Price. The Agreement should also contain the amount to be paid and method of payment.

Special Clauses. The Articles of Agreement may properly contain special clauses providing for the handling of different contingencies that may arise in the performance of the work; and it is the duty of the Engineer to foresee all possible complications that may arise, and to provide means of protecting the parties in case of such complications.

The specifications usually provide for extra work, alterations in plans and specifications, and settling of disputes; in which case, special reference to the plans and specifications, etc., renders it unnecessary to refer again to them in the Agreement; but if the specifications do not so provide, special clauses should be inserted in the agreement.

Date. The contract may be dated in either the beginning, or the closing clauses, or both. It is not well to write out the date in full in both clauses.

Seals. As already stated, when corporations are parties to contracts the corporate seal should be attached. When individuals are parties to contracts a scroll around the word "seal" written with ink is generally considered sufficient. The initials of the signer should be written across the "seal".

Witness. A notary public is the best witness to a contract, as it is easy to locate him and prove his authority in case of doubt as to the authenticity of the signature.

Conclusion. The usual wording for the conclusion of the agreement is:

IN WITNESS WHEREOF, the parties herein named have hereunto set their hands and seals, the day and year herein first above named.

By John Smith
(Party of the first part)
President

Attest: [SEAL]

James Jones
Secretary

Witnesses:

William Brown .... [SEAL]

.... [SEAL]

James Malone [SEAL]
(Party of the second part)
Contractor

TYPICAL AGREEMENTS

The following forms of agreement will be of service to the student. The order in which the clauses are arranged is not vital, and none of the forms contain all of the suggested clauses, so the Engineer in drawing the agreement must be governed by the conditions surrounding the work and the parties.

General Form

THIS AGREEMENT, Made this twenty-second day of September in the year of our Lord one thousand nine hundred and ten (1910), between the Ohio Railroad Company, a corporation of the State of Ohio, hereinafter called the party of the first part, and Patrick

O'Conner, Contractor, residing at 128 Washington Avenue,
City of Wilmington, State of Delaware,

hereinafter called the part y of the second part,

WITNESSETH, That the said part y of the second part, for and in consideration of the payments hereinafter specified and agreed to be made to the Contractor by the said party of the first part, hereby covenant s, contract s, and agree s, to furnish and deliver all the materials, and to do and perform all the work and labor required to be furnished and delivered, done and performed in building Section No. III of the Imton Extension of the Ohio Railroad from Greenburg to Graytown, all in the State of Ohio, including grading, masonry, buildings, track, and signals, complete and ready for operation, all in strict and exact accordance with the proposal and specifications hereto attached, which said proposal and specifications are hereby made a part of this agreement as fully to all intents and purposes as though herein set out at length.

The said part y of the second part further contract s and agree s that all of the materials used in the said work shall be of the best of their several kinds and qualities, and that all of the said materials and work shall be subject to the inspection and approval of the Chief Engineer of Ohio Railroad Company and in case any of the said materials or work shall be rejected by the said Chief Engineer as defective or unsuitable, then the said materials shall be replaced with other materials, and the said work shall be done anew immediately, to the satisfaction and approval of the said Chief Engineer at the cost and expense of the said part y of the second part.

It is further distinctly understood and agreed that the said work shall be completed on or before the First day of January, nineteen hundred and twelve (1912) and if the said work be not completed within the time specified, it is understood and agreed that the sum of One Hundred Dollars ($ 100) per day shall be deducted from the amount due the said part y of the second part for each and every day the said work shall remain incomplete or unfinished after the said time, not as a penalty, but as ascertained and liquidated damages; which sum so deducted shall remain the property of the said party of the first part. Or shall the said party of the second part in the opinion of the said Chief Engineer be prosecuting the said work with an insufficient stock of materials for the prompt completion thereof within the specified time, or be improperly performing the said work, or shall the Contractor neglect or abandon it before completion or unreasonably delay the same, so that the conditions of the contract are being wilfully violated or carelessly executed, or in bad faith, or shall the Contractor neglect or refuse to renew or again perform such work as may be rejected by the said Chief Engineer as defective or unsuitable, or shall the Contractor in any other manner in the opinion of the said Chief Engineer make default in the performance of this contract, then and in any such case the said Chief Engineer shall promptly notify the said party of the second part in writing of such neglect or default. If such notification be without effect within twenty-four hours after the delivery thereof, then and in that case the said Chief Engineer may notify the said party of the second part to discontinue all work under this contract; and the said Chief Engineer shall thereupon have full authority and power immediately to purchase such materials, tools, and machinery, and to employ such workmen as in his opinion shall be required for the proper completion of the said work at the cost and expense of the said party of the second part or his surety, or both; or the said Chief Engineer may, without notice, declare this contract null and void, and the security bond and the retained percentage and the material delivered and used in, on, or about the said work shall then become the property of the said Railroad Company..

The said party of the second part further contracts and agrees to properly enclose the said work, and to place signal lights thereon all night, when and where necessary, and to be responsible for and pay all loss or damage to either person or property which may, in any manner, arise by reason of the prosecution of the said work, during the progress of the same, and in case of the happening of such loss or damage the amount thereof may be retained by the said party of the first part out of any payments due or to grow due hereunder.

HANDLING ROCK ON THE NEW YORK STATE BARGE CANAL
A Bucyrus 70-ton shovel on rock excavator on the line of the canal.

The said part y of the second part agree s not to assign, transfer, nor sublet this contract.

It is further understood and agreed that this contract is entered into under and subject to the provisions of the various local laws in regard to Sub-Contractors, Security, and Workmen.

In consideration of the premises, the said party of the first part agrees to pay to the said part y of the second part Two hundred and fifty thousand dollars ($250,000.).

It is further distinctly understood and agreed that the total amount to be expended for the materials to be furnished and work to be done under this contract shall in no event exceed the sum of Two hundred and seventy-five thousand ($275,000.) dollars.

PARTIES HEREIN NAMED HAVE HEREUNTO SET THEIR HANDS AND SEALS, THE DAY AND YEAR HEREIN FIRST ABOVE NAMED.

Attest:

OHIO RAILROAD COMPANY,

[CORPORATE SEAL]

By John Smith
President

James White
Secretary

[SEAL]

Witnessed by

[SEAL]

Peter Sloan

[SEAL]

Patrick O'Connor.
Contractor

Railway Form

As already stated, there is a great difference of opinion as to whether certain clauses be placed in the agreement or the specification.

There are many conditions affecting contracts that an engineer generally does not appreciate. It is advisable, therefore, to submit the contract and bond before execution to an attorney, for advice as to whether all the requirements of the law have been complied with.

The following form of agreement is that used by one of the great trunk lines of the country, for their contracts for Grading, Masonry, Trestlework, Tunnels, etc.

ARTICLES OF AGREEMENT, Made and concluded this twenty-first day of June A. D. 1914,

by and between Fast Line Railroad Company, a corporation of the State of New Jersey,

of the first part, and Reliance Contracting Company, a corporation

of the State of New Jersey,

second part.

WITNESSETH, that for and in consideration of the covenants and payments hereinafter mentioned to be made and performed by the said party of the first part, the said party of the second part hereby covenants and agrees subject to the approval and to the satisfaction and acceptance of the Chief Engineer of the said railroad Company to build the substructure of the Green River Bridge to do and to finish in a substantial and workmanlike manner, and in strict conformity with the annexed specifications, hereby adopted, accepted, and declared by the parties hereunto to be an essential part of this agreement, the entire work of building cofferdams, excavating same to hard rock bottom, and building all the piers and abutments of the Green River Bridge

And it is mutually agreed between the said parties of the first and second parts, that

1. *Right of Way.* The right of way and use of such lands as may be necessary to enable the said party of the second part to conform to the requirements of the specifications here attached shall be furnished for the construction of the said railway by the said party of the first part, so that the work herein contracted for can be promptly commenced and prosecuted to completion.

2. *Work Executed under Direction of Chief Engineer.* The work shall be executed under the supervision and direction of the Chief Engineer of the party of the first part (hereinafter called the Chief Engineer, being either the regular incumbent of the office of Chief Engineer, or the person who, from time to time, may be designated by the party of the first part to be Acting Chief Engineer). Such Chief Engineer shall possess and exercise all the power hereinafter prescribed, and shall designate the portions of the line upon which work shall be begun and performed, and shall, at all proper times, furnish plans, measure-

ments, stakes, and directions for doing the work, it being distinctly understood that any action herein contemplated as to be taken by the Chief Engineer may be taken and performed, subject to his ultimate approval and adoption, by his subordinates, and when so taken and performed shall, upon such approval and adoption (but not otherwise), be in all respects taken, treated, and considered as the sole and original action of the Chief Engineer. Oral instructions in regard to any work to be performed under this agreement, if accepted by the said party of the second part, shall be accepted at his own risk, and no instructions so given shall relieve the said party of the second part from liability to damages or expenses arising from the performance of the work in accordance with such instructions, or in any other way than in accordance with this agreement, and the said party of the first part hereby reserves to itself the right to accept or reject any or all work done in accordance with such instructions.

3. *Tools, Materials, Mechanics, Laborers at Contractor's Expense.* The said party of the second part shall, at his own expense, cost, and charge, find and provide a full and ample supply of the best and most suitable tools and appliances required to be used in the performance of said work, and provide the best of material of every kind that may be needed for the thorough and expeditious execution of said work, and shall furnish and provide in sufficient numbers all mechanics, laborers, and other workmen, and also all things that may be necessary and requisite for constructing and completing, within the time herein stipulated, the whole of the work herein agreed to be done.

4. *Time of Commencement and Completion.* The work herein contracted for shall be commenced within ....thirty.......... days after the date of this agreement, and shall be completed on or before ....July 1st.......... 191...6..... This stipulation being made with the full knowledge, understanding, and agreement by the party of the second part that the time of commencement, discontinuance, suspension, resumption, and rate of progress of any and all work contemplated in or by this contract, shall be subject and according to such directions as may, from time to time, be given by the Chief Engineer, and that, unless expressly so declared in writing by the Chief Engineer, the date of final completion shall not be postponed by reason of any such direction, or any compliance therewith; and no right of the party of the first part under any clause of this contract, nor any obligation or liability of any contractor, surety, or bondsman shall be waived, lost, or impaired by any extension of the time for performance beyond the date above fixed for completion, but every clause of

the contract or bond shall apply in respect of the time as extended by the written declaration of the Chief Engineer.

5. *Prices.* For and in consideration of the true and faithful performance of the work by the said party of the second part, according to the agreements and conditions contained in this agreement, and the specifications hereto attached, the said party of the first part hereby promises and agrees to pay, in the manner, at the times, and under the conditions hereinafter provided, to the said party of the second part, his executors or administrators, for the work done and materials furnished as aforesaid, at the following rates and prices, to wit:

	DOLLARS	CENTS
For clearing, per acre	50	00
For grubbing, per acre	250	00
GENERAL EXCAVATION AND EMBANKMENT		
For solid rock, per cubic yard	0	85
For loose rock, per cubic yard	0	60
For earth, per cubic yard	0	30
For borrowed embankment, per cubic yard	0	25
For excavation without classification, per cubic yard	0	38
For removing old masonry, per cubic yard	1	50
EXCAVATION IN WATER		
For solid rock, per cubic yard	2	80
For loose rock, per cubic yard	2	00
For earth, per cubic yard	1	00
For excavation without classification, per cubic yard	2	50
TUNNEL EXCAVATION		
For single track tunnels, per cubic yard	4	00
For double track tunnels, per cubic yard	3	75
For shafts, per cubic yard	6	00
BALLAST		
For broken stone, per cubic yard, in place under track well surfaced	1	20
For gravel, per cubic yard, in place under track well surfaced	1	05
For slag, per cubic yard, in place under track well surfaced	1	15

MASONRY

	DOLLARS	CENTS
For 1st class, per cubic yard	10	00
For 2d class, per cubic yard	8	00
For 3d class, or rubble, and box culverts, in cement, per cubic yard	6	00
For 3d class, or rubble, and box culverts, dry, per cubic yard	3	50
For arch masonry, 1st class, per cubic yard	12	00
For arch masonry, 2d class, in cement, per cubic yard	10	25
For arch masonry, 2d class, dry, per cubic yard	2	75
For slope walls, per cubic yard	2	75
For stone paving, in cement, per cubic yard	3	50
For stone paving, dry, per cubic yard	3	00
For concrete No. 1, per cubic yard	8	50
For concrete No. 1, per cubic yard, $\frac{3}{4}$-in. stone, per cubic yard	8	65
For concrete No. 2, per cubic yard	7	75
For brick work, per cubic yard	12	00
For packing in cement, per cubic yard (in tunnel)	6	00
For packing, dry, per cubic yard (in tunnel)	4	25
For packing, dry, per cubic yard (back of abutments and retaining walls)	2	75
For rip-rap, per cubic yard	1	95
MACADAM AND TELFORD ROADWAY		
For Macadam paving, per square yard	0	85
For Telford paving, per square yard	0	93
IRON DRAIN PIPE		
For 4-inch, per lineal foot in place	0	55
For 6-inch, per lineal foot “	0	80
For 8-inch, per lineal foot “	0	95
For 10-inch, per lineal foot “	1	10
For 12-inch, per lineal foot “	1	25
For 16-inch, per lineal foot “	1	95
For 20-inch, per lineal foot “	2	55
For 24-inch, per lineal foot “	3	25
For 30-inch, per lineal foot “	4	95
For 36-inch, per lineal foot “	6	80
For 48-inch, per lineal foot “	11	30
For 60-inch, per lineal foot “	16	85

	DOLLARS	CENTS
TERRA COTTA DRAIN PIPE		
For 4-inch, per lineal foot in place	0	40
For 6-inch, per lineal foot “	0	70
For 8-inch, per lineal foot “	1	00
For 10-inch, per lineal foot “	1	12
For 12-inch, per lineal foot “	1	29
For 15-inch, per lineal foot “	1	56
For 18-inch, per lineal foot “	1	82
For 20-inch, per lineal foot “	2	10
For 24-inch, per lineal foot “	2	67
For 27-inch, per lineal foot “	3	77
For 30-inch, per lineal foot “	4	45
For 36-inch, per lineal foot “	6	10
FOUNDATION TIMBER		
For White Oak, per 1000 feet B. M. in place	51	00
For Yellow Pine, per 1000 feet B. M. “	53	00
For Hemlock, per 1000 feet B. M “	52	00
TRESTLE TIMBER		
For White Oak, per 1000 feet B. M. in place	60	00
For Yellow Pine, per 1000 feet B. M. “	55	00
For Hemlock, per 1000 feet B. M. “	53	00
TUNNEL TIMBER		
For White Oak, per 1000 feet B. M. in place	49	00
For Yellow Pine, per 1000 feet B. M. “	45	00
For Hemlock, per 1000 feet B. M. “	43	50
PILING		
For White Oak, per lineal foot left in the work	0	48
For Hemlock, per lineal foot “ “	0	32
For Yellow Pine, per lineal foot “ “	0	36
TRACK LAYING		
For track laying and lining, including unloading of track materials, spacing of ties, and placing in position of switches and frogs, complete, per mile single track	860	00
STEEL AND IRON WORK		
For wrought iron, per pound in place, spikes, bolts, etc.	0	04
For steel, per pound in place, metal for reinforcing concrete	0	04
For cast iron, per pound in place	0	03

6. *Payment.* During the progress of the work, so long as the party of the second part shall fully comply with the terms of the agreement, the party of the first part shall, upon or about the 15th day of each calendar month, and at such place as may from time to time be designated by the Chief Engineer, make to the party of the second part an advance payment for and on account of the work done and material furnished during the preceding calendar month; quantity, character, and value of such work and material to be estimated and certified by the Chief Engineer or by his subordinates, with his written approval; such advance payment not to exceed ninety per cent of the value as thus estimated and certified. Such certificate may be based on either actual measurements or simple estimate, or both combined, as shall be approved by the Chief Engineer and, except as otherwise determined by the Chief Engineer, no amount so estimated and certified, nor any amount shall in any wise be deemed payable, nor shall the same in any manner be transferable or assignable either by the act of the party of the second part or by the operation of law as a subsisting debt or liability of the party of the first part, until the final estimate shall have been made and become payable as hereinafter provided, nor (except at the option of the party of the first part) until all amounts payable to laborers, sub-contractors, or material men shall have been fully paid, or the payment thereof secured to the satisfaction of the Chief Engineer. The portion of each amount so certified (being not less than a sum equal to ten per cent thereof) reserved by the party of the first part shall be by it retained forever as compensation for or on account of any damages which may be certified by the Chief Engineer to have been by it sustained from any failure of the party of the second part to perform this contract, and the work thereunder, as herein provided; but any part thereof not required as such compensation shall be payable and paid to the same persons at the same time and upon the same conditions as the final payment under this contract, hereinafter provided for. And it is further provided that, at the discretion of the Chief Engineer, a larger proportionate part than ten per cent of each monthly certificate may be retained by the party of the first part as a protection against overpayment for work done, as compared with that remaining to be done; and at all times it shall be wholly discretionary with the party of the first part to make any payments on account of material delivered, and not permanently applied to the work for which it may have been intended.

Each monthly estimate, unless it be specifically decided and therein declared in writing to the contrary by the Chief Engineer, shall cover and certify the quantity, character, and value of all work done or material furnished since the last preceding estimate, which shall by the Chief Engineer be considered as extra work, and the acceptance by the party of the second part of the amount, payable under any monthly estimate, shall be deemed and taken (except as to that part of the price thereof being not less than ten per cent reserved and retained by the party of the first part as compensation as aforesaid) as a waiver by him of any and all claim for or on account of extra work up to that time, and each monthly estimate or certificate of the Chief Engineer shall, unless expressly therein provided to the contrary, be final and conclusive as to any and all extra work rendered or claimed to have been rendered at any time prior to the close of the month for which such estimate or certificate shall be given.

7. *Monthly Estimates Conclusive Only for the Time Being, and Subject to Variation.* Every monthly estimate shall, for the time being be conclusive upon both parties hereto, but being made (except as above provided as to extra work) merely as a basis for payment on account, though with a great desire and effort for accuracy, may be only approximately correct, and therefore shall (except as above provided as to extra work) be subject to correction by the Chief Engineer in any subsequent monthly estimate, or in any final estimate; and no such monthly estimate or certificate for unfinished work shall be considered or taken as an acceptance of the work, or as a release of the said party of the second part from responsibility therefor, nor as controlling the Chief Engineer in the final certificate, which alone shall operate as an acceptance of the work or as a release of the party of the second part.

8. *Final Estimates and Payments.* When this agreement in all its parts and in the manner therein provided shall have been completely performed on the part of the said party of the second part, and such performance shall have been accepted and so certified in writing by the said Chief Engineer, a final estimate of the quantity, character, and value of the work done and materials furnished, according to the terms of this agreement, shall be made by the Chief Engineer, and thereupon and not otherwise or sooner, except at its own election, the said party of the first part shall within 90 days thereafter, pay to the said Contractor, upon his giving a release under seal to the said party of the first part from all workmen and material men, of all claims or demands whatsoever growing in any manner out of this agreement, all sums of money so certified by the Chief Engineer to be then remaining due and unpaid upon the work performed under this agreement, after first deducting therefrom

any and all sums herein provided to be retained by the said party of the first part, it being expressly understood that such final estimate and certificate of the Chief Engineer shall be conclusive upon the parties to this contract.

And it is further distinctly understood and agreed:

1. *Must Obtain Consent to Sublet.* The said party of the second part shall not assign or sublet the whole, or any part of this agreement (for any work to be done thereunder) without first having obtained the consent, in writing, of the said part of the first part thereto.

2. If at any time during the progress of the work it shall appear to the Chief Engineer (*a*) that the work does not progress with reasonable speed; or (*b*) that the force employed, the quantity or quality of the tools, appliances, or workmen provided, or work done or materials furnished are not respectively such as to insure the completion of the work within the agreed time, or are not in accordance with the specifications hereto annexed; or (*c*) that the party of the second part has unreasonably failed to pay laborers and workmen or overseers for work performed under this agreement; or (*d*) that legal proceedings have been instituted by parties other than the party of the first part, against the party of the second part in such manner as to interfere with the prosecution of the work, or to subject the party of the first part in making further payments under this contract to the peril of litigation or outside claims; or (*e*) that the party of the second part is failing in any manner of substance to observe and perform this contract; then, and in any of such events, such fact or condition may be fully ascertained and declared by the Chief Engineer, over his signature, in a writing to be filed with the party of the first part, and a copy thereof shall be served upon the party of the second part, either in person or by mailing the same to him at the address by him last given to the party of the first part, or by posting the same on the door of his office on or near the work, and at any time after the service as aforesaid of such certificate of the Chief Engineer may take any of the following courses:

(*a*) *Penalty.* The Chief Engineer may, by a writing similarly served (of which a copy shall be filed with the party of the first part), declare this contract terminated and annulled, and from the time of such service this agreement, and every part thereof, shall cease and terminate, and shall, as to all further action or right thereunder (including any right of the party of the second part, or any one claiming under him, to receive the unpaid value of any work done), become null and void, except that all sums theretofore reserved by the party of the first part shall belong to and be retained by the party of the first part as liquidated compensation receivable by the party of the first part for the damages not susceptible of exact ascertainment caused the party of the first part by such failure of the party of the second part; or,

(*b*) *Penalty.* The Chief Engineer may, by a writing similarly served (of which a copy shall be filed with the party of the first part), declare that the party of the second part has grossly violated this contract, and that the contract is, therefore, forfeited and the party of the second part in gross default, in which event the party of the second part shall have no further right under this contract, or concerning any work theretofore done thereunder, but, nevertheless, he and his sureties shall compensate the party of the first part for any and all loss or damages which may, from time to time, be certified by the Chief Engineer to have in any wise resulted from such gross violation, ascertained as aforesaid; or,

(*c*) *Penalty.* The Chief Engineer may by a writing similarly served (of which a copy shall be filed with the party of the first part), require the party of the second part to at once supply such increase of force, appliances, or tools, and to cause to be made such improvements in the character of the work and material as may be required in the opinion of the Chief Engineer, to make the same conform to the stipulations of this agreement and the specifications; and if, on the expiration of ten days after such service of such writing, the party of the second part shall have failed to furnish to the party of the first part evidence satisfactory to the Chief Engineer of the intention and ability of the party of the second part to furnish the desired improvements and remedy the specified deficiencies, the said party of the first part may thereupon enter on and take possession of the said work, or any part thereof, with the tools, materials, plants, appliances, houses, machinery, and other appurtenances thereon, and hold the same as security for any or all damages or liabilities that may arise by reason of the non-fulfillment of this agreement within the time herein stipulated; and, furthermore, may employ the said tools, materials, etc., as aforesaid, and such other means as the said party of the first part may deem proper to complete the work at the expense of the said party of the second part, and may deduct the cost of completing the entire work from any payments then due or thereafter falling due, to the said party of the second part, and recover from him and his sureties any and all deficiency.

And immediately upon, from, and after the service, as aforesaid, of any of the three writings last mentioned, all right of occupancy in or upon any lands or property of the party of the first part; and all rights of the party of the second part, or of any person claiming under or through him any further prosecution of or interest in the work shall cease and determine, and the party of the first part may take possession of such lands or property and complete the work thereon in such manner and by such means as it may think best.

And it is further agreed and understood that if, at any time, the party of the second part shall refuse or neglect to prosecute the work with a force sufficient, in the judgment of the Chief Engineer, for its completion within the time specified, then, and in that case, the party of the first part may proceed to employ such a number of workmen, laborers, and overseers as, in the opinion of the Chief Engineer, may be necessary to insure the completion of the work within the time hereinbefore limited, at such wages as the party of the first part may find necessary or expedient, and may pay all persons so employed and charge all amounts so paid as so much money paid to the party of the second part under this contract.

It is further agreed and understood that if the said party of the second part shall not complete the said work within the time herein specified, and the said party of the first part shall, notwithstanding such failure, permit the said party of the second part to proceed with or complete the said work as if such time had not elapsed, such permission shall not be deemed a waiver in any respect, by the said party of the first part, of any forfeiture or liability for damages or expenses thereby incurred arising from such noncompletion of the said work within the time specified, but such forfeiture or liability shall still continue in full force against the said party of the second part as if such permission had not been granted. And it is further distinctly understood and agreed, that time, whenever involved in this agreement, is of the essence of this agreement.

3. *Nonpayment of Wages.* In all cases of nonpayment by the said party of the second part of any sum or sums of money due the laborers or other workmen, for work performed under this agreement, the said party of the first part is hereby authorized to pay such laborers or workmen the amounts due and owing to them by the said party of the first part; and if any action or proceeding at law or in equity shall be instituted, by virtue of any law or statute now in force, or hereafter enacted, for labor and wages on said work, the said party of the first part may pay all damages, wages, recoveries, costs, expenses, and counsel fees arising therefrom, and deduct the same, and also whatever amounts may be paid for wages as before mentioned, from any

moneys due or to grow due to the said party of the second part; and the said party of the first part may, from time to time, retain such reasonable sums as it may deem necessary for its protection in this behalf, and the said party of the second part shall forthwith pay to the party of the first part the amount of any deficiency arising from such payment of laborers or other workmen, and the retention from time to time of such reasonable sums as it may deem necessary for its protection in this behalf, and the said party of the second part shall pay the deficiency arising therefrom upon demand.

4. *Discharge of Employes for Cause.* The said party of the second part shall discharge any foreman or other employe who shall, in the judgment of the said Chief Engineer, be unfaithful, unskillful, or remiss in the performance of his work, or guilty of riotous, disrespectful, or otherwise improper conduct; and no person so discharged from this work, or any other work done for the said party of the first part, shall be employed again by the said party of the second part upon the work to be done under this agreement, without the written consent of the said Chief Engineer.

5. *Use of Intoxicants.* The use or sale of ardent spirits, or other intoxicating beverages upon the work, or in any of the buildings, boarding houses, or other tenements owned, occupied, or within the control of the said party of the second part, or any of his employes, is strictly forbidden, and the said party of the second part shall exercise his influence and authority to the utmost extent to secure compliance with this regulation.

6. *Contractors to be Held Responsible for Violations of Laws and Ordinances.* In all operations connected with the work embraced in this agreement the said party of the second part shall be held responsible for any failure to respect, adhere to, and comply with all local ordinances and laws controlling or limiting, in any way, the actions of those engaged upon the work, or affecting the materials, or the transportation or disposition of them. And the said party of the second part hereby assumes all liability for, and agrees to indemnify the said party of the first part against all loss, cost, or damages for or by reason of any liens, claims, or demands for materials, or from laborers, mechanics, and others, and from any damages arising from injuries sustained by mechanics, laborers, or other persons, by reason of accidents or otherwise, and from damages sustained by depositing materials to public injury, or to the injury of any person or corporation, including costs and expenses of defense, provided that he be duly notified of the bringing of suits in such

cases, and be permitted to defend the same by his own counsel, if he should so elect.

7. *Contractor to be Responsible for Damages.* Where the line of the railway passes through farms, the said party of the second part shall keep up such temporary fences as may be necessary for the preservation of the crops thereon. The said party of the second part shall be responsible for any damages that may be done by him or his workmen during the performance of this work to property adjacent to the line, in consequence of his or their unskillfulness or negligence; and if any such damage shall be done, the said Chief Engineer shall have the right to settle and pay the same; and deduct the amount thereof from the payments to be made upon the estimates. Whenever any work herein embraced shall in any manner interfere with a public or private traveled road, the said party of the second part shall keep a temporary roadway, during such interference, at all times unobstructed and safe for travel, and any damages which may result from failure so to do may be settled and withheld, as above, until paid by the said party of the second part.

8. *Material and Labor Not Provided for in Specification to be Done and Furnished on Written Order of Chief Engineer.* If, in the course of the performance of this contract, or any work thereunder, it shall, according to the written opinion of the Chief Engineer, become necessary for the party of the second part to do any work or to furnish any material not embraced in the foregoing classification, or for which no price is hereinbefore specified, then and in that event the party of the second part shall, if ordered in writing by the Chief Engineer, under and according to his directions, do all such work, and furnish all such material, and upon performance to the satisfaction of the said Chief Engineer, the party of the second part shall at the periods and in the manner herein provided for payments under the contract, receive therefor the reasonable value thereof, as the same shall be ascertained and determined by the Chief Engineer, at approximately the rate of payment above fixed for work or material (if any such there be) of substantially similar character; or, at the discretion of the Chief Engineer, a separate contract for such work and material (if any) may be entered into by the party of the first part with any person, and the person so contracting shall be permitted free access and facility in performing such work and furnishing such material, it being intended hereby to exclude, as far as possible, any claim for "extra" work (so-called), and to provide for the most prompt, expeditious, and economical prosecution of all work necessary to the principal undertaking.

9. *Chief Engineer May Alter Line, Location, etc.* The said Chief Engineer shall have the right to make any alteration that may hereafter be determined upon by him as necessary or desirable in the location, line, grade, plan, form, or dimensions of the work, either before or after the commencement of the same, defined in writing, and by, or without drawings; and in case such alterations increase the quantities, the said party of the second part shall be paid for such excess at the contract rates herein specified; but should such alterations diminish the quantity or extent of the work to be done, they shall not, under any circumstances, be construed as constituting and shall not constitute a claim for damages, on any ground whatever, nor shall any claim be made on account of anticipated profits, nor on any account whatever in respect to the work which may be altered or dispensed with, the intent of this provision being that only the work absolutely done shall be paid for, and at the prices named in this agreement.

10. *Claim for Extra Work.* No claim for extra work shall, under any circumstances, be made, allowed, or considered, unless the same shall have been done in pursuance of an order given in writing, as above provided, by the said Chief Engineer; but nothing shall be deemed or construed as extra work which can be classified, measured, and estimated under the terms of this agreement.

11. *Allowance for Delays.* No extra compensation shall be made to the said party of the second part for hindrances or delays from any cause in the progress of any portion of the work performed under this agreement; but if such delays or hindrances arise from any cause other than the fault of the said party of the second part, then and in that case, the said party of the second part shall be entitled to such extension of time for the completion of this contract as shall, in the opinion of the said Chief Engineer, be sufficient to compensate for any such detention, provided the said party of the second part shall give notice, in writing, to the said party of the first part of such hindrances and delays, stating the cause thereof, within twenty-four hours after the same shall first occur.

12. *Right to Suspend Work.* The said party of the first part reserves the right to suspend or terminate the work embraced in this agreement for reasons not herein specified, and the said party of the second part hereby agrees to discontinue all work within ten days after receiving notice of such suspension or termination, in which case, the said party of the second part shall be entitled to payment in full for all materials actually handled or supplied, at a valuation to be fixed by the Chief Engineer, subject to review, as hereinafter provided, but shall make no claim

for consequential damages or anticipated profits upon work not actually performed or damage of any kind resulting from such suspension or termination.

13. *Repairs in Case of Defective Work.* Any replacement or repairs rendered necessary upon or about the work herein contracted for, by reason of defective material or workmanship furnished or performed by the said party of the second part, shall be made by the said party of the second part upon demand, without cost or expense to the said party of the first part.

14. *Chief Engineer to Settle Disputes.* All questions, differences, or controversies which may arise between the parties hereto in regard to any work to be done under this agreement, whether as to its performance or non-performance, or in any way whatever pertaining to or connected with said work, shall be referred to the said Chief Engineer, and his decision shall be in the nature of an award, and shall be final and conclusive upon both parties, and compliance on the part of the party of the second part with every such decision of the Chief Engineer shall be a condition precedent to the right to receive any payment hereunder.

15. *Modification of Contract.* This contract, and any and every provision thereof, may be modified or extended by the mutual agreement of the parties hereto.

16. *Security.* The contractor will be required to give an approved trust company's bond in the sum of one-half the amount or approximate amount of the Contract, for the faithful execution and completion of the work.

IN WITNESS WHEREOF, The parties herein named have hereunto set their hands and seals, the day and year herein first above named.

Attest:

[CORPORATE SEAL] FAST LINE RAILROAD COMPANY,
James Brown By John Smith
Secretary President

RELIANCE CONTRACTING COMPANY, [L. S.]
[SEAL] By Michael Shinn Pres [L. S.]
Contractor

Attest:
Henry L. Price
Secretary

The following "Directions as to Execution of Contracts" are issued by the United States Government in connection with some of its contracts, and may be studied to the advantage of the student of this subject:

1. The papers should be made in quadruplicate, and each copy should be the exact counterpart of the others, so that any one of them may be used as an original.

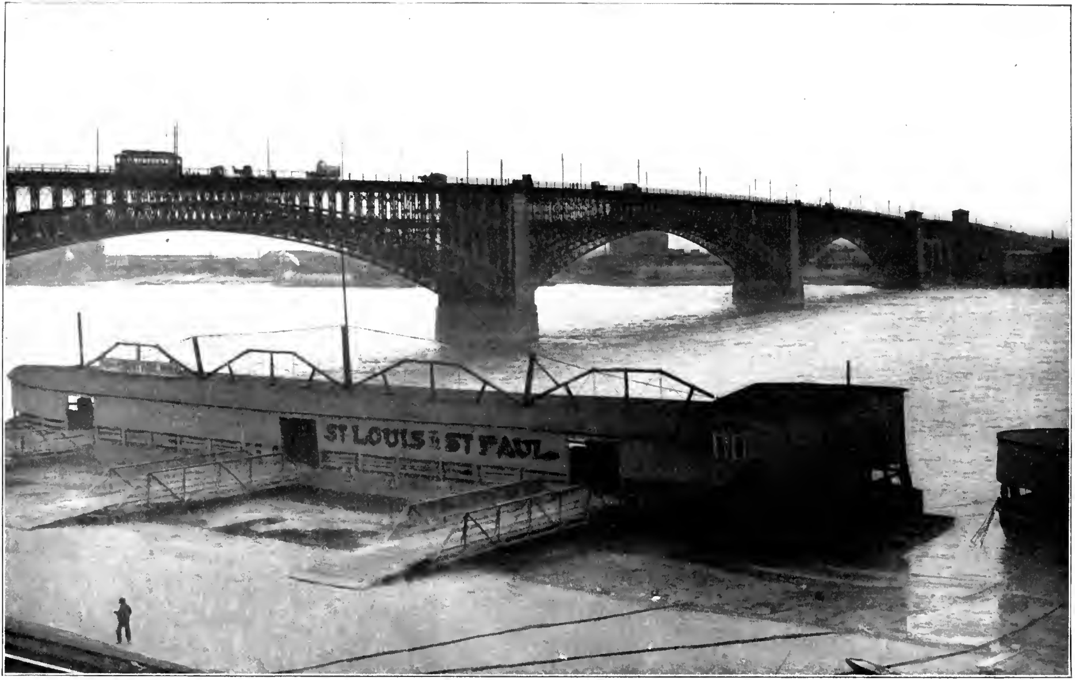
2. Before signatures are appended to the papers, all dates should be written in, and all remaining blank spaces ruled out, with ink.

3. Interlineations and erasures are to be avoided when possible; but when they are unavoidable, either in the specifications, the contract, or the bond, they should be noted, word by word, immediately above the signatures of the witnesses, specifying the number of each line where they occur; and certificate should be made that each specific correction or alteration was made before the contract was signed. A general statement that "erasures and interlineations were made before execution" is wholly insufficient.

4. The full name and residence of each signer of contract and bond should be stated in the body of the instrument and the signature of each person should be witnessed by two other persons who should state their places of residence.

5. When firms contract, the name of the firm and the full name of each member thereof should be written at the beginning of the contract; for instance, "Smith, Brown & Co., of the City of New York, a firm composed of John S. Smith, Charles B. Brown, and John W. Robinson". The contract should be signed in the firm name, viz: "Smith, Brown & Co., by John S. Smith". The bond given to guarantee fulfillment of a firm contract should be in the name of the individuals composing the firm and should be signed and sealed by each of them, or by his duly authorized attorney, proof of whose authority must be attached.

6. When an incorporated company enters into contract, the corporate name of the company should be written at the beginning of the contract and bond; for instance, "The Smith and Brown Dredging Company, a corporation created by and existing under the laws of the State of New York, and having its principal office in the City of New York, in said State". The contract and bond should then be signed with the corporate name, by a person duly authorized to do so, sealed with the corporate seal, and a certificate, showing the signer's authority to sign sealed instruments in its behalf and that the seal affixed is the corporate seal, should be made by the secretary of the corporation or other custodian of its records, in the form prescribed. In cases where



THE EADS BRIDGE OVER THE MISSISSIPPI RIVER AT ST. LOUIS, MISSOURI

A steel arch viaduct for railway and highway traffic, trains running beneath the roadway. Built by James B. Eads in 1867-74. Between approaches, the bridge consists of 3 spans, 497, 515, and 497 ft. In each span are four arches composed of steel tubes 9 inches in external diameter, connected by lateral bracing. The tube sections between joints are straight, curvature being secured by inserting wedge-like plates.

Photo by Strauss.

a corporation or other body organized under law, has no seal, one must be adopted for the occasion, and proof thereof should be made by affidavit of the secretary.

7. The date of the bond must not antedate that of the contract.

8. A firm will not be accepted as surety, nor will a partner be accepted as a surety for a copartner, or for a firm of which he is a member. An officer of a corporation will not be accepted as surety for such corporation. In no case will a married woman or an infant be accepted as a surety, and when an unmarried woman (widow or spinster) is given as a surety, she must be described as such in the body of the bond; nor will a bonded officer of the United States be accepted as a surety; nor will any person be accepted who is an official or employe of any branch of the public service having to do with the contract, performance of which is guaranteed by the bond.

9. There must not be less than two individual sureties, but one corporate surety, duly qualified under the act of Congress of August 13, 1894, may be accepted as sole surety, provided it files or has filed with the Solicitor of the Department of Commerce and Labor full proof of such compliance with the act as qualifies it to act as surety in the case. The Contractor and sureties should sign (or execute) each bond. Each surety, including a corporate surety, must qualify in double the amount of the bond. Individual sureties must justify upon the form of ''Bondsman's Oath'' prescribed, and corporate surety companies upon the form of ''Justification by Corporate Surety''.

10. The affidavits or affirmations of sureties must be made before an officer authorized to administer oaths generally. The authority to administer such oath must be shown by certificate, unless the oath was taken before a judge of a court of record, or before a clerk or deputy clerk of a court of record, a United States commissioner, or a notary public, and the official seal is attached. There should be a separate and distinct impression of the official seal for each oath or affirmation. The official title should follow the signature.

11. Except in the case of proper corporate sureties, a judge or clerk of a state court of record, a judge or clerk or deputy clerk of a United States Court, a United States district attorney or one of his assistants, a United States commissioner, or a postmaster must certify that the sureties are sufficient to pay double the penalty of the bond.

12. An adhesive seal should be affixed to the signature of each principal and surety upon the bond, except when the prin-

cipal or surety is a corporation, in which case the corporate seal should be affixed.

13. When contracts and bonds have been thus prepared, and signed and sealed by the officer making them in behalf of the United States, they should be forwarded to the Board for its approval and the approval of the Secretary of Commerce and Labor.

14. When approved by the Board and by the Secretary of Commerce and Labor, one copy shall be returned to the officer making the contract, for delivery to the Contractor.

PROPOSALS

Proposals or bids are offers or tenders to do a certain thing or to perform certain work, on certain conditions, for a consideration. They are generally in writing.

The Engineer should prepare a blank form of proposal for the bidders to use in making the tender, with the necessary instructions as to the manner in which it is to be filled out, the limit of time when bids will be received, etc.

Notice to Bidders. The notice or instructions to bidders should give the necessary information and instructions, and should cover the following:

The form in which the bids should be sent.

The party for whom the work is to be done.

That the Contractor be skilled and regularly engaged in the line of work bid for.

When and where the plans and specifications can be obtained.

What, if any, deposit must be made with the Company before taking out a set of the plans and specifications.

How to endorse the proposal.

The date and hour when the reception of bids will be closed.

Bidder to visit the site of the work.

Bidder to examine the plans carefully.

Bidder to give the number of days required to do the work and date of completion.

Bidder to follow the printed form.

Bidder to make no conditional bid.

Bidder to write amounts as well as to give figures in filling out proposal.

Bidder to furnish guarantee to enter into contract within ....days of award of contract.

The amount of the one or more bids required (if any) and their character.

The Company's right to reject any or all bids, or to accept any bid.

The relation between the Company and the successful bidder during the period between the acceptance of bid and the execution of the contract.

That a foreign corporation (one chartered in another State than that in which the proposal is to be tendered) must furnish, with its proposal, a certificate from the state authorities entitling it to do business within said State.

That the proposals must contain no omissions, erasures, alterations, additions not called for, nor conditional bids.

In addition to the above, the notice should call the bidder's attention to local laws affecting the employment of labor and the necessity of signing the proposal with the individual's name and place of residence, as well as the firm's name and business address.

If quantities are set forth in the notice, a clause should state that the quantities used are necessarily approximate, and that the Company reserves the right to increase or decrease them. The purpose of sometimes placing the approximate quantities in the notice to bidders is to use them as a basis of comparison to determine the lowest bidder, in unit price contracts.

INSTRUCTIONS TO BIDDERS*

U. S. Government Lighthouse Board. The following instructions to bidders are used by the United States Government in the proposals of the Lighthouse Board. A study of them will give much information on the subject.

(1) All bids and guaranties must be made in duplicate upon the printed form attached hereto, which must not be detached.

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* Failure to comply with these instructions renders the bid informal and liable to be rejected.

(2) Each bid must state in words, as well as in figures, the sum for which the entire work, as shown on the plans and described in the specifications, will be completed and delivered at such time as is named in the specifications.

(3) The work will be subject to the personal supervision of the Lighthouse Engineer or his agent, and all facilities must be afforded him for inspecting the materials and workmanship.

(4) All blanks in the form of bid or guaranty must be filled in. Interlineations and erasures in the bid and guaranty are to be avoided, but when they are unavoidable they should be specifically noted word by word by the signers as having been made before execution. The general statement that "erasures and interlineations were made before execution" is insufficient.

(5) No bid will be received by telegraph.

(6) The bidder's place of residence, with county and State, must be given after his signature, which must be written in full.

(7) Anyone signing a bid as the agent of another, or of others, must file with it legal evidence of his authority to do so.

(8) When firms bid, the name of the firm and the full name of each member thereof should be written at the beginning of the bid; for instance, "Smith, Brown & Co., of the City of New York, a firm composed of John S. Smith, Charles B. Brown, and John W. Robinson". The bid should be signed in the firm name by a member of the firm, thus, "Smith, Brown & Co., by John S. Smith, a member of the firm". When corporations bid, the bid should be signed with the corporate name by some person duly authorized to do so (evidence of whose authority should be appended), and sealed with the corporate seal.

(9) Bidders should satisfy the United States of their ability to furnish the material and perform the work specified. Lack of evidence of such ability will be sufficient cause for rejection of any bid.

(10) Reasonable grounds for inferring that any bidder is interested in more than one bid for the same item will cause the rejection of all bids in which he is interested.

(11) Bids submitted by different members of the same firm or copartnership will not be considered.

(12) The right is reserved to reject any or all bids or any part of a bid, to strike out any item or items in the specifications, and to waive any defects.

(13) All bids must be signed and inclosed in an envelope indorsed "Proposals for the construction of buildings at Punta Gorda Light Station, California", and then inclosed in another envelope and either delivered in person to the office of the Engi-

neer of the Twelfth Lighthouse District at San Francisco, Cal., or addressed and sent to him through the mail, postage prepaid.

(14) All bids will be publicly opened and recorded at the time specified in the advertisement. Bidders are invited to be present and to witness the opening of the bids.

(15) The contract will be in the form attached hereto, and bidders are understood as accepting the terms and conditions contained in such form of contract.

(16) The accompanying advertisement, plans, and specifications, together with these instructions, will form a part of the contract.

(17) Should the bidder to whom the contract may be awarded fail to enter into contract within 10 days after notice is given him that his bid has been accepted, he will be considered a defaulting bidder, and recommendation will be made to the Secretary of Commerce and Labor that thereafter no proposal of his be considered.

(18) A bond, with one corporate surety or two individual sureties, in the sum of 25 per cent of the amount of the bid, will be required for the faithful performance of the contract, conditioned also that the Contractor shall promptly make payment to all persons supplying him or them with labor or materials in the prosecution of the work provided for in such contract. Each surety will be required to justify in double the amount of the bond. If at any time during the contract period the Secretary of Commerce and Labor deems the security furnished by the Contractor insufficient, additional security may be required.

(19) A firm will not be accepted as a surety or guarantor, nor will a partner be accepted as a surety or guarantor, for a copartner or for a firm of which he is a member. An officer of a corporation will not be accepted as a surety or guarantor for such corporation. A married woman or an infant will not be accepted as a surety or guarantor under any circumstances.

(20) No bid will be accepted or contract entered into until approved by the Lighthouse Board and the Secretary of Commerce and Labor.

(21) Transfers of contracts, or of interests in contracts, are prohibited by law. (See U. S. R. S., sec. 3737.)

(22) Payment for the work will be made upon the certificate of the agent of the Lighthouse Board that it has been completed and delivered according to contract.

(23) The entire work must be completed and delivered at the time provided for in the specifications and contract.

(24) Any expense incurred by the United States on account of failure on the part of the Contractor to perform the service

for which he has entered into contract will be sufficient to cause the annulment of the contract, should the Lighthouse Board, with the approval of the Secretary of Commerce and Labor, so decide.

(25) No proposal will be considered unless accompanied by a guaranty or a certified check in manner and form as directed in these instructions.

(26) The guaranty attached to each copy of the bid must be signed by two responsible guarantors, to be certified as good and sufficient guarantors by a judge or clerk of a United States court, a United States district attorney or one of his assistants, a United States commissioner, a postmaster, or a judge or clerk of a state court of record, with the seal of said court attached, or by a guaranty or surety company duly authorized in accordance with the provisions of an Act of Congress approved August 13, 1894.

(27) Each guarantor must justify in the sum of 20 per cent of the amount of the bid. The liability of the guaranters and bidder is expressed in the guaranty attached to the bid.

(28) Plans and specifications must accompany bid.

(29) No person who has failed to perform satisfactorily any contract with the United States or to abide by any bond or guaranty given by him for the performance of any contract or proposal will be accepted as guarantor.

(30) In lieu of the guaranty a certified check in a sum equal to one-fourth of the amount of the bid, payable to the order of the Secretary of Commerce and Labor, will be accepted, and the proceeds of such check shall become the property of the United States, if, for any reason whatsoever, the bidder, after the opening of bids, withdraws from the competition, or refuses to execute the contract and bond required in the event of said contract being awarded to him. All checks submitted will be returned to the bidders immediately after the approval of the contract and bond executed by the successful bidder.

(31) The attention of intending bidders for this work is invited to an Act of Congress approved August 1, 1892, which provides that the service and employment of all laborers and mechanics employed by any contractor or subcontractor upon any of the public works of the United States or of the District of Columbia is limited and restricted to 8 hours in any 1 calendar day, and that it shall be unlawful for any such contractor or subcontractor whose duty it shall be to employ, direct, or control the services of such laborers or mechanics to require or permit any such laborers or mechanics to work more than 8 hours in any calendar day, except in case of extraordinary emergency. A violation of this statute is punishable by a fine or imprisonment, or by both fine and imprisonment.

Provisions for Recording Prices. The notice to bidders should be attached to the form of proposal and form a part of the contract. In the form of proposal it is well to have under the head of Price Bid, two columns; one headed dollars, the other cents, as given below:

Wrought iron, per pound, no dollars three cents
Concrete, per cubic yard, five dollars sixty-five cents
Bessemer steel rails, per ton, twenty-nine dollars no cents

PRICE BID	
DOLLARS	CENTS
No	03
5	65
29	00

The greatest number of mistakes are generally made by bidders in placing the decimal point in the wrong position. The above suggested form helps to prevent this. Of course mistakes in formal bids cannot be rectified after the bid has been opened, no matter how apparent the error may be.

The following cautionary clause is sometimes inserted in the form of proposal:

Caution—Bidders are cautioned against placing a dollar bid in the cents column, and the reverse; as any error of this character, no matter how obviously it may be an error, will cause the rejection of the whole bid as being informal.

TYPICAL PROPOSALS

The following will illustrate the wording used in describing various items in proposals.

PROPOSAL I

(City, County, and State) (Date) January 15, 1914
To the Commissioner of Bridges, City of Bergen, State of Wisconsin.

Sir:—We hereby propose to furnish all materials, appliances, labor, and transportation necessary to perform the work, and submit to all conditions as represented, intended, and implied, both particularly and generally, in the specifications and articles of agreement, for the concrete arch bridge over Black Creek, examined at the office of the City Engineer, and also in the Ordinance of Councils, for the construction of the said work, and perform all additional work that may be required, upon the following terms, to wit:

	PRICE BID	
	DOLLARS	CENTS
Item No. 1. For all excavations of all classes of materials, per cubic yard, the sum of two dollars fifty cents	2	50
Item No. 2. For concrete, Class A 1-3-6, per cubic yard in place, the sum of eleven dollars eighty cents	11	80
Item No. 3. For terra cotta sewer, 12 inches and under in place complete, with all appurtenances per linear foot, the sum of two dollars ten cents	2	10
Item No. 4. For vitrified-brick pavement, in place per square foot, the sum of no dollars thirty cents	0	30
Item No. 5. For reinforcing steel, in place, per pound, the sum of no dollars five cents	0	05
Item No. 6. For placing city hydrants, each the sum of fifteen dollars twenty cents	15	20

NOTE.—When it is likely that some additional work will have to be done by force account, it is wise to have the bidder quote a price per hour, for the various classes of additional labor and use of machinery, the items appearing in the proposal as follows:

Additional Work. For additional labor and use of machinery of the various classes enumerated below, as ordered by the Chief Engineer, including cost of superintendence, use of tools, repairs, oil, waste, and fuel.

	PRICE BID	
	DOLLARS	CENTS
Item No. 7. For foreman, per hour, the sum of no dollars seventy-five cents	0	75
Item No. 8. For riveter, regular working hours, per hour, the sum of no dollars sixty cents	0	60

	PRICE BID	
	Dollars	Cents
Item No. 9. For riveter, overtime, per hour, the sum of no dollars ninety cents	0	90
Item No. 10. For use of team (2 horses and wagon), including driver, per hour, the sum of no dollars seventy cents	0	70
Item No. 11. For use of boiler and hoisting engine, per hour, the sum of no dollars seventy-five cents	0	75
Item No. 12. To be added to all additional materials specially purchased by the Contractor by written order ten per cent		

We agree to complete the whole of the work in 180 working days from the date of notice from the Chief Engineer to proceed.

WITNESS our hand, this 15th day of January, 1914.

John G. Smith, James S. Jones,
William F. Brown
Trading as SMITH, JONES & BROWN, Contractors.

NOTE.—The Contractor shall here give individual as well as firm names.

Address 14 South Front Street, Chicago, Illinois.

The following is a form of guaranty for the bidder executing contract within 10 days of the notice that his bid has been accepted. It should be attached to the proposal, as a part thereof.

GUARANTY

The Standard Construction Company of 17 Wall Street, New York City, a Corporation existing under the laws of the State of New York, hereby undertakes that if the bid of ten thousand five hundred dollars herewith accompanying, dated January 15, 1914, for the construction of the Little Falls bridge on the line of the Ontario Central Railroad, be accepted as to any or all of the items bid for, the said bidder Standard Construction Company will, within ten (10) days after notice of award of contract, enter into a contract with the Ontario Central Railroad Company, to perform all work specified therein at the prices offered by said bid, and will give bond with good and sufficient surety or sureties, as may be required, for the faithful and proper fulfillment of such contract. And said Corporation binds itself and its successors to pay the Ontario Central Railroad Company, in case the said bidder shall fail to enter into such contract or give such bond within ten (10) days after said notice of award of contract, the difference in money between the amount of bid of said bidder on the work so accepted, and the amount for which the Ontario Central Railroad Company may contract with another party to perform said work, if the latter amount be in excess of the former.

IN WITNESS WHEREOF, The name and corporate seal of said corporation has been hereto affixed, this 15th day of January, 1914, and these presents duly signed by its (1) President, pursuant to a resolution of its (2) Board of Directors, passed on the 10th day of January, A. D. 1914.

Attest: [CORPORATE SEAL] (3)

Martin Turner
Secretary

By Henry Burke
President

(1) The president or officer authorized to sign for the Corporation.
(2) The board of directors or other governing body of the Corporation.
(3) Here affix the corporate seal.

NOTE. Instead of a guaranty of the above nature, sometimes a certified check, drawn on a national bank or trust company, is required to accompany the proposal to serve the same purpose.

PROPOSAL II

The following form of proposal may be used in railroad work:

For the grading and structures on the Straight Line Railroad from Station Ten to Station One hundred sixteen the undersigned hereby certifies that he has sufficiently examined the locality and sections of the Straight Line Railroad on which the work proposed for below is situated; and that.........he.........has......... also carefully examined the specifications, terms, and conditions applicable to said work, set forth in the form herewith attached, and having made such examinations and understanding thoroughly the nature and conditions of the work to be let, the undersigned hereby proposes to the........Straight Line Railroad........ Company to do all the work on either or all of the items to which prices are affixed in the following schedule, according to specifications, terms, and conditions aforesaid; and on the acceptance of these proposals for all or either of the items named therein, does......hereby bind........himself........to enter into and execute the work thereon, at the following prices, viz:

	SECTION 1		SECTION 2	
	DOLLARS	CENTS	DOLLARS	CENTS
Grading				
(1) Clearing, per acre, the sum of	50	00	65	00
(2) Grubbing, per acre, the sum of	245	00	280	00
(3) Solid rock, per cubic yard, the sum of	1	50	1	00
(4) Loose rock, per cubic yard, the sum of	0	62	0	68
(5) Earth in cuts, per cubic yard, the sum of	0	30	0	32
(6) Earth borrowed, per cubic yard, the sum of	0	30	0	32
(7) Ditching in earth, per cubic yard, the sum of	0	22	0	25
Excavations in Water for Bridge Foundations				
(8) Solid rock, per cubic yard, in water for bridge foundations, the sum of	3	00	2	55
(9) Loose rock, per cubic yard, in water for bridge foundations, the sum of	1	45	1	45
(10) Earth, per cubic yard, in water for bridge foundations, the sum of	1	20	1	30
Masonry				
(11) First-class masonry, per cubic yard in place, the sum of	8	00	8	00

	Section 1		Section 2	
	Dollars	Cents	Dollars	Cents
Masonry—Cont'd				
(12) Second-class masonry, per cubic yard in place, the sum of	6	50	6	50
(13) Third-class masonry, per cubic yard in place, the sum of	4	00	4	00
(14) Slope wall, per cubic yard, in place, the sum of	2	50	2	50
(15) Rip-rap, per cubic yard in place, the sum of	2	00	2	00
(16) Concrete No. 1, per cubic yard in place, the sum of	11	00	11	00
(17) Concrete No. 2, per cubic yard in place, the sum of	7	50	7	50
(18) Concrete No. 3, per cubic yard in place, the sum of	5	75	5	75
Frame and Pile Trestle				
(19) Framing and erecting pile and timber trestles, per M feet board measure with all appurtenances in place, the sum of	55	00	57	00
(20) Pointing, shoeing, driving, and sawing off piles, per linear foot measured from "cut-off" to point, the sum of	0	13	0	14
Timber in Foundation				
(21) Yellow pine in private crossings, over meadow ditches and box drains, per M feet board measure with all appurtenances in place, the sum of	42	00	42	00
(22) Hauling and laying 12-inch double strength terra cotta sewer pipe, per lineal foot in place, the sum of	0	14	0	16
(23) Hauling and laying 18-inch double strength terra cotta pipe, per lineal foot in place, the sum of	0	28	0	28

Timber in Foundation—Cont'd

	Section 1		Section 2	
	Dollars	Cents	Dollars	Cents
(24) Hauling and laying 24-inch double strength terra cotta pipe, per lineal foot in place, the sum of	0	52	0	52
(25) Hauling and laying 30-inch double strength terra cotta pipe, per lineal foot in place, the sum of	0	80	0	80
(26) Hauling and laying 12-inch cast-iron water pipe, per lineal foot in place, the sum of	0	16	0	20
(27) Hauling and laying 14-inch cast-iron water pipe, per lineal foot in place, the sum of	0	20	0	22
(28) Hauling and laying 24-inch cast-iron water pipe, per lineal foot in place, the sum of	0	40	0	44

The undersigned further propose s to commence work on such section or sections as may be awarded to him within thirty days from the date thereof, and to complete the same on or before the 10th day of July, 1915.

James Malone

Signed this tenth day of January, 1914.

Proposer's residence 805 Queen Street,
Postoffice Address Lancaster,
Pennsylvania.

THE ADVERTISEMENT

Purpose. The advertisement is of minor importance and only in government and some municipal contracts is it considered of sufficient importance to be made a part of the contract.

Under the law, most public work—that is, government, state, county, municipal, and borough work—must be advertised in a certain number of papers, over a certain period, before the public letting takes place.

The Engineer should ascertain the requirements of the law in regard to advertising public work before drawing up a contract, as contracts have been declared invalid upon its being found that they had not been properly advertised.

Of course the object of advertising is to secure competition between parties who are engaged in the kind of business or work to be performed, and hence the advertisement should be so headed as to attract the attention of the firms capable of performing this work.

Essential Features. The advertisement should be concisely worded, as every word is an additional cost to the party for whom the work is to be done; on the other hand, it should give the following information:

(a) A heading that will attract the attention of desirable bidders.

(b) The address where plans and specifications can be seen and procured.

(c) The address where proposals will be received.

(d) The date of the insertion of the advertisement.

(e) The date and hour until which proposals will be received.

(f) The manner of presenting the bid, viz, sealed, or in duplicate or triplicate, etc.

(g) The date of opening the bids.

(h) The kind and approximate quantity of work to be done, or such information as will give an idea of the magnitude of the work.

(i) The locality where the work is to be done.

(j) The right to reject any or all bids.

(k) The name and address of the parties for whom the work is to be done, or their Agent.

Sometimes the entire matter included in the ''Notice to Bidders'' under ''Proposals'' is published. The objection to this is the great cost of so extended an advertisement.

The manner of arranging these requirements will be shown by a few examples.

TYPICAL ADVERTISEMENTS

METAL WORK

To Iron Manufacturers. (a)

Office of the Lighthouse Engineer, Third District,
Tompkinsville, New York (b)..................191........(c)

Sealed Proposals in duplicate (d) will be received at this office (e) until 12 o'clock noon (f).. 191..........(g), for furnishing the materials and labor of all kinds necessary for the completion and delivery of the metal work of the Peck's Ledge Lighthouse (h), Cockenoe Island Harbor, Conn. (i)

Plans, specifications, forms of proposal, and other information may be obtained on application to this office (b).

The right is reserved to reject any or all bids and to waive any defects. (j)

....(k)
Lieutenant Col. of Engineers, U. S. A., Lighthouse Engineer.

(a) Heading, (b) Address, (c) Date of Insertion, (d) Manner of presenting, (e) Proposals received, (f) Bidding closed, (g) Proposals opened, (h) Character of work, (i) Locality, (j) Right to reject, (k) Party letting work.

BRIDGE WORK

The following is an advertisement for the superstructure of the ill-fated Quebec bridge:

The clause in regard to prices of labor is unusual in an advertisement. The clause in regard to other newspapers inserting the advertisement without authority is a very wise one, as it is not an unusual practice for newspapers in municipalities to insert such advertisement without orders from the proper party to do so, and then issue bills for same, which are really nothing less than blackmail.

QUEBEC BRIDGE

Department of Railways and Canals

TENDERS FOR SUPERSTRUCTURE

NOTICE TO CONTRACTORS

Sealed tenders addressed to the undersigned and endorsed "Tender for Quebec Bridge Superstructure" will be received at this office until 12 o'clock noon, not later than September 1, 1910, for the superstructure of a bridge across the St. Lawrence River near the City of Quebec.

Plans and specifications may be seen and forms of tender obtained on and after July 1, 1910, at the office of the Quebec Bridge Board of Engineers, Canadian Express Building, Montreal, and at the Department of Railways and Canals, Ottawa.

Parties tendering will be required to accept the fair wages schedule prepared or to be prepared by the Department of Labor, which schedule will form part of the contract.

Contractors are requested to bear in mind that tenders will not be considered unless made strictly in accordance with the printed forms, and in the case of firms, unless there are attached the actual signatures, the nature of the occupation, and place of residence of each member of the firm.

An accepted bank check for the sum of $500,000.00 made payable to the order of the Minister of Railways and Canals of Canada must accompany each tender, which sum will be forfeited if the party tendering declines entering into contract for the work at the rates stated in the offer submitted and in accordance with the terms stated in the form of contract accompanying the specifications.

Checks thus sent in will be returned to the respective contractors whose tenders are not accepted.

The lowest or any tender not necessarily accepted.

L. K. J.,
Secretary

Department of Railways and Canals,
Ottawa, June 17, 1910.

Newspapers inserting this advertisement without authority from the Department will not be paid for it.

MACADAM ROADS

Denison, Texas.

Sealed proposals will be received by the Commissioners' Court of Grayson County, Texas, up to the hour of 11 o'clock A. M., on August 10, 1910, at the office of said Court in Sherman, Texas, for the construction of approximately 65 miles of macadam roadway in Road District No. 1 of Grayson County, Texas. Said district is situated in the north central part of Grayson County, in and about the City of Denison.

Profiles, plans, and specifications will be on file in the office of J. C. Field, Engineer in charge, Denison, Texas, after July 1, 1910. Copies will be sent applicants on receipt of $2.00, to be returned to depositor if bid is made. A certified check for $5,000.00 on some Grayson County bank must be deposited with each bid, to be returned to unsuccessful bidders; and to be returned to successful bidder, upon his entering into contract and bond in accordance with his bid, within 10 days from its acceptance. Failure so to enter into contract and bond will forfeit check to district.

The right is reserved to reject any and all bids.

H. R. W.,
Auditor, Grayson Co.,
Sherman, Texas

It is useless to multiply examples of advertisements, as many examples of the requirements of a good advertisement can be seen at any time in the leading technical journals.

PRACTICE IN SPECIFICATION AND CONTRACT WRITING

GENERAL INSTRUCTIONS

Examination of Actual Work. Below will be found a few subjects for practice in specification writing. Before attempting to write a specification for any of the subjects given, the student, if possible, should go out and make careful examination of such a piece of work in process of construction. If none is available, make a minute examination of a finished structure, note its strong points and its defects, and seek a remedy for the latter, embodying the ideas in the specification to be written.

If the structure is in process of building, make a thorough examination of the character of the materials entering into the work, watch the process, question the workmen and foremen as to character of foundation and as to any special features embodied in the construction. Examine brands of materials and if better processes of construction are apparent to you, discuss the subject with the foreman or superintendent with the idea of getting his criticism of your suggestions.

Study of Good Specifications. Follow this up by collecting two or three good specifications covering the subject in hand, and make a comparative study of them.

Drawings. If drawings are to be a part of the contract, the sheets must be properly numbered and a list of them set forth in the specification, which list should be inserted just before the detailed description of the work.

Order of Headings. A complete list of headings and subheadings should be made and arranged in their proper order. This is difficult, as there are so many items which have little connection with each other.

The method generally followed is to arrange the clauses as nearly as possible in the order in which the building actually takes place in the work under consideration. For instance, in a railroad specification the headings should be arranged as follows: Clearing, Grubbing, Grading, Tunnels, Excavation, Foundations, Masonry, Pipe Drains, Timber in foundation, Timber in trestles, Bridges, Tracklaying, Surfacing, etc. Of course there are many items that cannot be arranged chronologically; often one clause or heading suggests the following one, which method, carried out consistently, will give the desired result. It is very desirable that specifications for a complete piece of construction be properly indexed.

The following examples are given as good subjects for practice in specification writing:

TYPICAL PROBLEMS

Examples. (1) A single-track railroad handling heavy freight traffic wishes to replace a frame trestle across a stream by a steel plate girder bridge on concrete masonry abutments; clear span 75 feet. The approaches to the bridge back of the abutments are to be filled in with material obtained by widening out an adjacent cut; material in cut, sand, and loose rock; borings show hard gravel at 25 feet. Prepare a complete specification for both sub- and superstructure. The work will eventually be sublet; the masonry to one firm and the steel to another, and the grading and foundations to still another.

The work is located in Northern New York State.

(2) A timber trestle across a meadow in the State of Washington has been burned and must be replaced at once, to open traffic at the earliest possible date. The trestle is 1650 feet long; 1100 feet of the track is but 9 feet above the marsh; the 550 feet remaining varies in depth from 9 to 22 feet; profile shows but 3 feet of earth and gravel overlying the rock at the lowest point.

Prepare a complete specification for replacing the trestle in the most economical manner.

(3) Prepare complete specification for a double-track steel bridge; tracks 13 feet center to center; span 245 feet; live load, Cooper's Class E 50; steel to be erected by a sub-contractor; bridge to be complete; ties laid ready for the rails; two coats of paint after erection.

(4) Prepare a complete specification for a concrete retaining wall 875 feet long, varying in height from 8 feet above track at one end to 24 feet at the other end. The wall is surcharged with a sandy loam embankment, 15 feet high at the end of the wall which is lowest, 2 feet high at the other. Foundations in soft .... rock in Eastern Pennsylvania.

(5) Write a complete specification and articles of agreement for the building of a double-track electric interurban railroad 22 miles long, in Northern New Jersey. The road crosses 2 navigable rivers—one crossing is 1700 feet and the other 650 feet in length. Both loose and solid rock will be encountered; the road crosses under 2 trunk line railroads and over 4 others; it crosses at grade 3 street railways. There are on the line 2 10-foot reinforced-concrete arched culverts; 1240 linear feet of framed timber trestle on concrete footings. Rail 70 pounds per yard. Track in stone ballast. To be operated by overhead trolley. Electric current to be purchased from a local company. Station grounds to be graded.

(6) A street 1 mile long is to be paved with vitrified brick on concrete base; streets crossing 500 feet apart; soil sandy loam. One half of it is to be curbed with new granite curb. The other half has been curbed with blue stone and is badly out of line and grade. Water, gas, and electric conduits are in the street, one-half of which has to be lowered varying in depth from 1 to 5 feet at the summit.

Prepare a complete specification for the above, bearing in mind that each company owning the structures in the street will do the work of altering its pipe and conduits at the expense of the Contractor.

(7) Prepare complete specification for a curved dam to be located in Georgia. It is to be 245 feet long, built of concrete

faced with ashlar masonry; soft rock foundations with the abutting banks of the river of same material; dam will be 18 feet high above river bed; maximum depth of water is 8 feet at ordinary stages; river is subject to frequent freshets; purpose of dam is for flushing out at frequent intervals a large main sewer.

(8) Prepare specification for two docks on creosoted piles; superstructure to be of reinforced concrete; depth of water 20 feet, to be dredged to 32 feet in slip, which is 150 feet wide; docks each to be 65 feet wide and 450 feet long; concrete bulkhead between the two docks. The structure will be located at New Orleans and will have two docks, the upper one for passenger service.

(9) Prepare complete contract for a brick-arch bridge; span 70 feet; rise 12 feet; springing line 7 feet above the sidewalks; bridge carries an avenue 80 feet wide across a 70-foot street; there is on the street a double track electric railway on which cars are very frequent and travel must not be interfered with; end walls and parapet to be of first-class masonry.

(10) A Commission of the Commonwealth of Massachusetts wishes to build, in the City of Boston, a reinforced concrete chimney, 10 feet interior diameter, height 175 feet, foundation on hard blue clay.

Prepare complete contract for same including Advertisement, Proposal, with Notice to Bidders, and form of Bond required, Specifications, and Articles of Agreement.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

ESTIMATING

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1. Estimate the weight of the girder shown in Fig. 120, Page 153, Steel Construction, Part II.

2. Estimate the weights of interior floor beams in Plate G, Steel Construction, Part IV. Use standard connection angles for all beams.

3. Estimate the weight of the beams in Fig. 201 (a), Steel Construction, Part IV.

4. Estimate the weight of the columns in Fig. 205, Steel Construction, Part IV, allowing a unit stress of 12,000 pounds.

5. What is the basis of estimating for structural steel work?

6. Give in your own words your idea of making an estimate of steel work.

7. What would you consider the best way to check an estimate?

8. When are approximate estimates permissible, and how made?

9. Give briefly the analysis of determining cost of structural steel work.

10. What are the elements involved in estimating cost of fabrication?

REVIEW QUESTIONS

ON THE SUBJECT OF

STATICS

---

1. Define concurrent and non-concurrent forces, equilibrant and resultant.

2. What do you understand by the "Triangle law"?

3. What is the total snow load for the truss if the snow weighs 20 pounds per square foot (horizontal)?

4. Compute the total wind load for the truss of Question 9, when the wind blows 75 miles per hour.

5. Make a complete record of the stresses as determined in answer to the preceding question for cases *a*, *b*, and *c*, and for snow load as computed in answer to Question 10. Compute from the record the value of the greatest stress which can come upon each member due to combinations of loads, assuming that the wind and snow loads will not act at the same time.

6. Find the magnitude of the resultant of two forces making an angle of 70° with each other, one being 30 pounds and the other 45 pounds.

7. The lines of action of two forces of 65 and 35 pounds, respectively, make an angle of 120°. Find the magnitude of the force that holds them in equilibrium, and the angles that it makes with each given force.

8. Draw a force polygon for five forces in equilibrium and prove that any diagonal of the polygon is the resultant of the forces on one side and holds in equilibrium those on the other.

REVIEW QUESTIONS

ON THE SUBJECT OF

ROOF TRUSSES

1. Name and describe the three classes of roof trusses, and give a sketch of one truss of each class.

2. Give a sketch of the Fink truss and the modified Fink truss.

3. Given $W=\frac{3}{4}\,al\,(1+\frac{l}{10})$, compute the dead panel load of an eight-panel Fink truss of 80-foot span, if the distances between trusses is 20 feet and the roof covering is composed of corrugated steel.

4. Tell how a felt and asphalt roof is made and laid.

5. What is a non-condensation roofing?

6. Design the purlins if they are to be spaced 6 feet apart and the trusses are to be spaced 16 feet apart. They are to carry 40 pounds per square foot of roof surface.

7. Write one page on the economical pitch and spacing of roof trusses.

8. If the trusses are of 80-foot span and are spaced 20 feet center to center, and are eight-panel Fink, compute the stresses in the knee-braces if they join the columns 8 feet from the top. The columns are 25 feet long; the normal wind pressure on the roof is 12 pounds; the pitch of the roof is $\frac{1}{4}$; the normal wind pressure on the side of the building is 25 pounds; and the columns are considered free.

9. In the trusses of Question 8, above, compute the bending moment in the posts.

10. If in Question 8, above, the girts are placed 4 feet apart, design them.

11. If a post is 25 feet long, has a total direct stress of 20 000 pounds which acts at the center of the column, and a crane load of 10 000 pounds which acts 12 inches from the face of the column, design the section of the column if it consists of four angles and a plate.

12. A compression member of a roof truss consists of two angles placed ¼ inch, back to back, and has a stress of 35 000 pounds. Design the member if it is 6 feet long.

13. If the member of Question 12, above, is a tension member, design it.

14. If the connection plates are ¼ inch thick, determine the number of ¾-inch rivets required for the connections of the member in Question 12 above.

15. Make a sketch showing two details of the end of a roof truss.

16. How is the cost of structural steel determined?

17. If the maximum wheel reaction is 19 000 pounds, and the wheel base is 9 feet, design the runway girder if the trusses are 16 feet apart.

18. If the maximum wheel reaction is 40 000 pounds, and the wheel base is 10 feet, design the runway girder if the trusses are 16 feet apart.

19. Determine the rivet spacing in the second division of the runway girder of Question 18, above, if h_g is 30 inches.

20. Make a sketch giving two gable details, and state the sizes of gutters and conductors.

21. State the different classes of floors employed in mill buildings, and give a sketch of two classes.

REVIEW QUESTIONS

ON THE SUBJECT OF

CIVIL ENGINEERING SPECIFICATIONS AND CONTRACTS

PART I

---

1. Describe the duties and responsibilities of the engineer.

2. What are the essential features of detail drawings?

3. What is the purpose of specifications?

4. Define General Clauses, Specific Clauses.

5. Are verbal instructions binding? Why?

6. What are the duties of an inspector?

7. What are headers and stretchers?

8. Give specifications for sand to be used in grouting.

9. What is meant by Live Load and Dead Load?

10. What are Stress Sheets and their purpose?

11. Give the length of piles generally used and the diameter at both ends for the various lengths.

12. Under what conditions is the contractor liable for loss of grade stakes.

13. What are the duties of a contractor?

14. What provision shall a contractor make to enable the inspection of his work?

15. When inspecting shop work of structural steel what defects should you look for?

16. As engineer what would you consider the essential features of pile driving?

17. What defects would cause you to reject the timber to be used for stringers on a railroad trestle?

18. What are the essential tests for structural steel for buildings?

REVIEW QUESTIONS

ON THE SUBJECT OF

CIVIL ENGINEERING SPECIFICATIONS AND CONTRACTS

PART II

1. What is the purpose of a contract?

2. Make up a form of general agreement to cover the building of a house in your town, you to be the contractor. Do not copy word for word from the text, but try to cover each essential clause.

3. Write specifications and contract to cover the construction of a mill building (wood-construction) in your town.

4. Make up an advertisement or notice to contractor that you have a number of miles of road to construct in a certain locality.

5. Write a complete specification for the building of a double-track electric interurban railroad 25 miles long in western Connecticut. The road crosses a navigable river with a 1500-foot crossing. Both loose and solid rock will be encountered; the road crosses under a trunk line railroad and over one other; it crosses at grade two street railways: there are on the line two 8-foot reinforced-concrete culverts, box type. Rail 70 pounds per yard. Track in stone ballast. To be operated by overhead trolley. Electric current to be purchased from a local company. Station grounds to be graded.

6. Prepare specification for a dock on creosoted piles; superstructure to be of reinforced concrete; depth of water 15 feet, to be dredged to 32 feet in slip which is 150 feet wide; dock to be 65 feet wide and 450 feet long. The structure will be located in Chicago and will have two stories, the upper one for passengers.

7. Prepare a notice to bidders for the following: A Commission of the Commonwealth of Massachusetts wishes to build in the city of Boston, a reinforced concrete chimney, 10 feet interior diameter, height 175 feet; foundation on hard blue clay.

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