THESIS

ANALYSIS OF A NINETY FOOT
REINFORCED CONCRETE GIRDER BRIDGE

ERNEST L. MARKLEY

1922

ANALYSIS OF A NINETY FOOT
REINFORCED CONCRETE
GIRDER BRIDGE

A Thesis

Respectfully submitted

to

The Faculty

of

Michigan Agricultural College

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by

Ernest L. Markley

A candidate for B. S. Degree in

Civil Engineering

June, 1922.

Foreword

In preparing this work the author is greatly indebted to Mr. W.M.Orand, Asst.Bridge Engineer of the Michigan State Highway Department, and Associate Professor C.L.Allen of Civil Engineering Department of Michigan Agricultural College.

The author is also under obligation to Mr. C. A. Melick, Bridge Engineer of Michigan State Highway Department, for his kind assistance in obtaining certain copies and duplicates of material herein contained.

The author has also drawn most freely for his authority from the Concrete Engineer's Handbook, Hool & Johnson, together with information from Ketchum's Bridge Engineer's Handbook, Hool & Whitney's Concrete Designer's Manual, Mark's Mechanical Engineer's Handoob,Carnagie's Packet Companion, Merriman & Jacoby's Roofs and Bridges, Parts I & III, Merriman's American Civil Engineer's Handbook and Boyd's Strength of Materials.

June, 1922.

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Introduction

The bridge, the analysis of which is herein contained, is a 60 foot reinforced concrete girder bridge of standard design recently adopted by the Michigan State Highway Department. Modified, it is expected to be used on all concrete bridges constructed by the Department, over 60 feet in length.

This particular bridge here analyzed is now - June, 1926, in the process of construction. It is known as Trunk Line Bridge #19,503, crossing the Looking Glass River on Trunk Line #14-33 between Lansing and St. John. The site is about one and three-fourths miles northeast of DeWitt, Sec.3, T 5 N- R 2 W, DeWitt Township, Clinton County, Michigan.

The abutments are reinforced concrete, placed over wooden piles and are 34 feet deep from the crown of the roadway. This will eventually permit the dredging of the river to a depth of ten feet below the present river bed. The abutments are constructed with the aid of coffer dams and each abutment is poured at one pouring.

The bridge itself is required to be poured in a formwork built of wood according to specifications, over wooden piles driven in the river bed. It is required that it be poured in either three or five pourings. When poured in three, one girder and one-half the roadway, to the center line of the roadway, is poured first. This is excepting a section over the windows in the girder compression faces which are poured after the second girder and section of the roadway has been poured. When five pourings are made, the bridge is poured in quarters, the joints being made thru the center line of the roadway and transversely at the center.

As to the bridge itself, it is virtually an original design developed principally by Mr. Melick, formerly a Professor in the Civil Engineering Department of Michigan Agricultural College. It is believed that the conception of the design of this bridge, or more truly this girder,for the floor is a reinforced concrete slab,grew from such reasoning as follows: Concrete beams under uniform loading, are designed of uniform cross section for maximum bending moments at the center,and hence grow excessively heavy and uneconomical towrds the ends.

The graph of the bending moments of a beam uniformly loaded, closely approximate a parabolic curve.

If the compression face of the beam can be designed to closely follow the line of a parabola, it should be both safe and economical. Such a beam or girder would be nearly straight on the tensile face and hence would give greater stream clearance. Also it could be designed by the formulae known as the Straight Line Theory and any arch action that might be engendered by reason of the curve of the compression face of girder would all be on the side of safety.

The theoretical difficulty that had to be met was the variable dead loads due to the varying depth of beam, and the practical difficulty of swaying the staid and settled ideas of the older heads in construction. Mr. Melick overcame both these

these obstacles and a bridge of this type has been carrying traffic for sevral months at this time in June, 1933.

Standard Notation for use in Flexure Formulae.

Rectangular beams.

fs = tensile unit stress in steel
fc = compression unit stress in concrete
Es = modulus of elasticity of steel
Ec = modulus of elasticity of concrete

$$n = \frac{Es}{Ec}$$

M = moment of resistance, or bending moment in general

As = steel area

b = breaith of beam

d = depth of beam to center of steel

k = ratio of depth of neutral axis to depth "d"

z = depth below top to resultant of the compressive stresses

j = ratio of lever arm of resisting couple to depth "d"

jd = d - z = arm of resisting couple

p = steel ratio $= \frac{As}{bd}$

Shear, Bond and Web Reinforcement

V = total shear
v = shearing unit stress
u = bond stress per unit area of bar
o = cirdumference or perimeter of bar
s = horizontal spacing of reinforcing members

Beams Reinfroced for Compression

A' = area of compressive steel
p' = steel ratio for compressive steel
fs' = compressive unit in steel
C = total compressive stress in concrete
C' = total compressive stress in steel
d' = depth to center of compressive steel
z = depth to resultant C and C'

Analysis of Stresses in Floor Slab.

"The summation of the moments of all the external forces about any point on a beam is called the bending moment."

The idea of bending moment found above and the flexure formulae made standard by the joint committee and based on the straight line theory of stress distribution, comprise the principal means used for the analysis.

These formulae as they apply to rectangular beams are grouped here. Loading requirements and limitations of stresses will be found of 1920 in the appendix.

Rectangular Beams

$$k = \sqrt{2pn + (pn)^2} - pn = \frac{1}{1 + \frac{fs}{nfc}} = \frac{nfc}{nfc + fs}$$

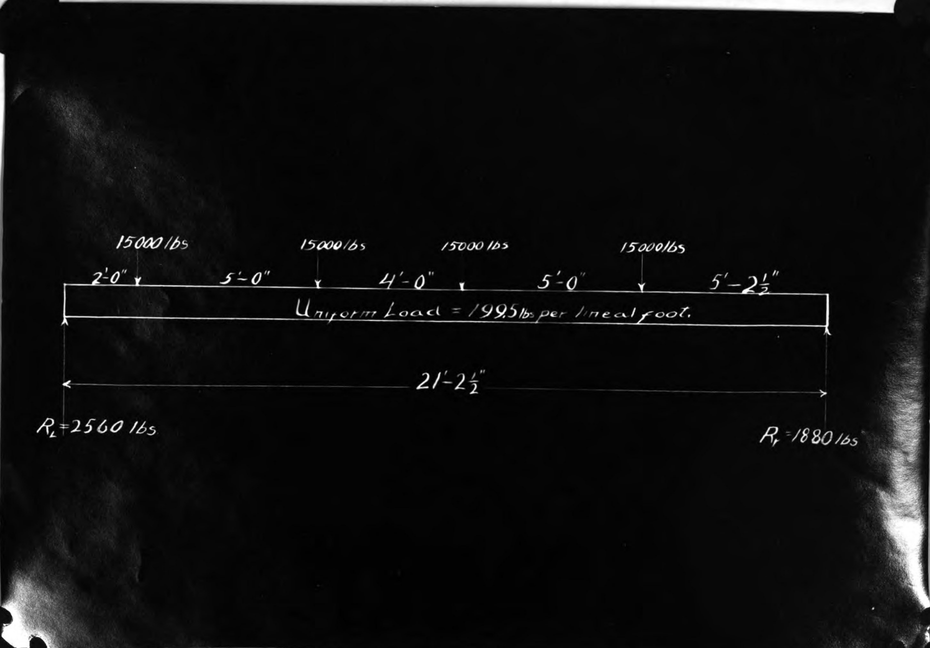
$$j = 1 - 1/3\, k$$

$$p = \frac{As}{bd} = \frac{\frac{1}{2}}{\frac{fs}{fc}\left(\frac{fs}{nfc} + 1\right)} = \frac{fc\,k}{2\,fs}$$

$$Mc = \tfrac{1}{2}\, fc\, kj\, (bd^2) \text{ or } bd^2 = \frac{2M}{fc\,kj}, \text{ or } fc = \frac{2M}{kjbd^2}$$

$$Ms = p\, fs\, j\, (bd^2) = \frac{M}{p\,fs\,j}, \text{ or } fs = \frac{M}{As\,jd}$$

$$fc = \frac{2fs\,p}{k} \text{ or } \frac{fs\,k}{n(1 - k)}$$


15000 lbs
15000 lbs
15000 lbs
15000 lbs
2'-0"
5'-0"
4'-0"
5'-0"
5'-2½"
Uniform Load = 199.5 lbs per lineal foot.
21'-2½"
R_L = 2560 lbs
R_r = 1880 lbs

As Designed

12 tons live load plus 25% impact = 15 tons per truck rear axle or 15000 lbs per truck rear wheel concentration live load = L.L.

Longitudinal distribution of L.L. = 1'.5 + 60% of span (M.S.H.Spec.)

1'.5 + .6 X 20'.0 = 13'.5 distribution in direction of center line of roadway.

$\frac{15000 \text{ lbs}}{13'.5}$ = 1110 lbs.per lineal foot of bridge

Dead Load = D.L.

Wt.of 1' of slab = 1.'29 (average "d") X 21'.2 X 150 lbs = 4105 lbs

Wearing surface -- 22 lbs.per square ft.of1" thickness = 225 lbs

Total D. L. 4330 lbs.

D.L.M. = 1/8 wl^2 = 4330 lbs X 21.'2 = 11,210 ft. lbs.

L.L.M. = $\frac{36 \text{ X}1110}{21.2}$ X 10.2 -5 X 1110 = 13,630 " "

Total M = 24,840 " "

n = 12 (M.S.H.Spec)

$p = \frac{As}{bd} = \frac{1.6 \text{ sq in}}{12" \text{ X } 14"} = .0095$

$k = \sqrt{2 \text{ X } 12 \text{ X } .0095 + (.0095 \text{ X } 12)^2} - .0095 \text{ X } 12 = .377$

$j = 1 - \frac{k}{3} = 1 - .126 = .874$

$fc = \frac{2 \text{ X } 24840 \text{ X } 12}{.377 \text{ X } .874 \text{ X } (14)^2 \text{ X } 12} = 773$

$fs = \frac{24840 \text{ X } 12}{.377 \text{ X } .874 \text{ X } 14} = 15250$

Max.V.= 2560 ft.lbs.

$v = \frac{V}{bjd} = \frac{2560}{12 \text{ X } 14 \text{ X } .874}$ = 17.5 No Web reinforcement needed.

Floor Slab Computed as a New Design under M.S.H.Spec.

Total M.-as found = 2480 ft.Lbs. using 16000 lb.steel = fs

$n = 12$

812 lbs. = 32.5% of 2500 lbs. = fc

$k = \dfrac{nfc}{nfc + fs} = \dfrac{12 \times 812}{12 \times 812 \times 16000} = \dfrac{9744}{25744} = .378$

$j = 1 - \dfrac{.378}{3} = .874$

$p = \dfrac{fc\ k}{2\ fs} = \dfrac{812 \times .378}{32000} = .0096$

$k = p\ fs\ j = .0096 \times 16000 \times .874 = .134$

$d = \sqrt{\dfrac{M}{K\ b}} = \sqrt{\dfrac{24840}{.134 \times 12}} = 12.6$ in.

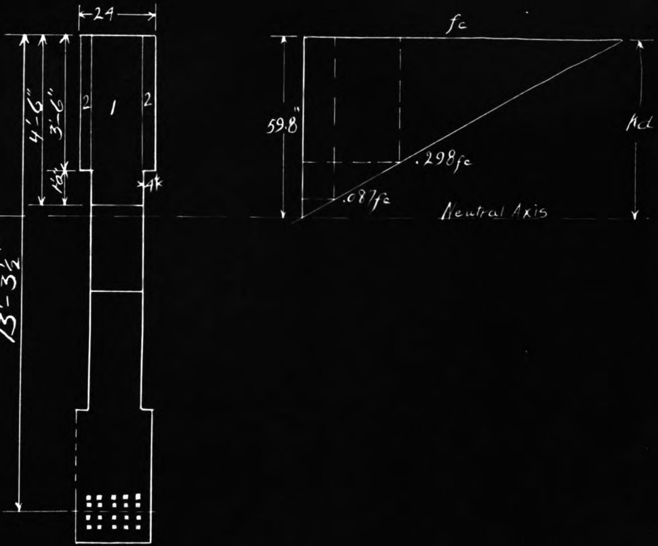
Adding $\frac{d}{9}$ arbitrarily = 1.4 in. + 12.6 in. = 14"

$As = pbd = .0096 \times 12 \times 14 = 1.61$ sq.in.steel

144 rods 1 in.sq.spaced in 90 ft.= 1.6 sq.in.per ft slab.

Max V = 2580 ft.lbs.

$v = \dfrac{V}{bjd} = \dfrac{2580}{12 \times 14 \times .874} = 17.5$ No Web reinforcement needed


24
4'-6"
3'-6"
2
1
2
13'-3½"
fc
59.8"
Kd
.298fc
.087fc
Neutral Axis

Analysis of the Girder

The uniform loads on the girder consist of the load derived from the floor slab, the load of a section in the girder containing the tensile steel, and a uniform live load of 100 lbs. per square foot of roadway. This live load is found to be greater than the maximum loading possible by the use of lines of 18 ton motor trucks.

The area of cross section on concrete containing the tensile steel is:

3 ft.7 in. X 2 ft = 7.16 sq. ft.
1 " 11 " X 10½ in = 1.68 " "

Total 8.84 " "

8.84 X 150 lbs. = 1326 lbs.per lineal foot.
Wt.of 1 ft of slab plus wearing surface for ½ bridge = $\frac{4230 \text{ lbs}}{2}$ = 2115 lbs.per lin. ft.
Total uniformly distribution DL = 2115 + 1326 = 3441 lbs per lin.ft.

The weight of the remainder of the girder was obtained by dividing it into sections. The area of each section was then found and multiplied by the thickness of certain parts. When these results were added and multiplied by the weight per cubic foot of concrete, the weight of the section was closely approximated. Considering this weight concentrated at its center of gravity permitted the assumption of a series of concentrated loads on the girder.

Following this, the right and left end reactions were obtained as for a beam with both uniform and concentrated loads.

Solution of the bending moment at the center and critical section taken about one foot towards the center from the inner end of the corbal is next taken ahd the tests made for streases.

Computation for weight of section of Girder.

Weight of Section A concentrated at 1 ft. 3 in. from center line of girder.

10 ft 4 in X 2 ft.6 in.X 1 ft 4 in. = + 34.25 cu.ft.
3 " 6 " X 2 " 6 " X 0 " 8 " = + 5.83 " "
2 " 3 " X 2 " 0 " X 1 " 4 " = - 6.00 " "

Total 34.08 cu.ft.

34.08 X 150 lbs.per cu.ft. = 5112 lbs.at 1 ft.3 in. left of center.

Weight of Section B.

10 ft.2 in.X 5 ft 0 in X 1 ft.4 in. = + 67.6 cu.ft.
3 " 6 " X 5 " 0 " X 0 ft 8 " = + 11.7 " "
1 " 9 " X 4 " 0 " X 1 " 4 " = - 9.3 " "
Total 70.0 " "

70.0 X 150 = 10,500 lbs.at 5 ft left of center.

Weight of Section C.

9 ft.8in. X 5 ft 7 in X 1 ft 4 in = + 71.6 cu ft
3 " 6 " X 5 " 7 " X 0 " 8 " = + 13.1 " "
1 " 3 " X 4 X 0 " X 1 " 4 " = - 7.4 " "
Total 77.3 Cu Ft

77.3 X 150 = 11,595 lbs.at 10 ft 4 in left of center.

Weight of Section D.

8 ft.0 in X 8 ft.0 in.X 1 ft 4 in = + 85.33 cu ft
3 " 6 " X 8 " 0 " X 0 " 8 " = + 18.67 " "
Total 104.00 " "

104 X 150 = 15,600 lbs.at 17 ft 1 in left of center.

Weight of Sectioh E.

4 ft.4 in.X 9 ft 0 in.X 1 ft 4 in = + 52 cu.ft.
3 " 6 " X9 " 0 " X 0 " 8 " = + 21 " "
Total 73 " "

73 X 150 = 11880 lbs.at 35 ft 7 in left of center.

Weight of Section F.

4 ft. 5 in. X 3 ft. 0 in. X 3 ft 6 in. = + 47.9 cu ft
1 " 1½ " X 3 " 0 " X 3 " 3 " = + 12.3 " "
60.1

60.1 X 150 = 9,015 lbs.at 39 ft 9 in left of center.

Weight of Section C.

3 ft 5 in X 2 ft 0 in X 8 ft 4 in = 56.89 cu ft
3 " ¾ " X 2 " 0 " X 8 " 4 " = 51.02 " "

Total 107.9

107.9 X 150 = 16,185 lbs.at 39 ft 8 in left of center.

Using 100 lbs. per sq.ft.including impact,these results

a live load = 10 X 100 = 1000 lbs.per lin.ft.of girder.

Left Reaction

W =	4441 lbs.	X 87.67 ft	X 43.83 ft	=	17,064,880	ft.lbs.
g =	16185 "	X 83.5 "		=	1,351,448	" "
f =	9015 "	X 76.58 "		=	690,549	" "
e =	11880 "	X 69.43 "		=	824,472	" "
d =	15,600 "	X 60.92 "		=	950,040	" "
c =	11,595 "	X 54.17 "		=	628,449	" "
f =	10,500 "	X 48.83 "		=	512,400	" "
a =	5,112 "	X 45.08 "		=	230,551	" "
a' =	5,112 "	X 42.58 "		=	217,771	" "
b' =	10,500 "	X 38.83 "		=	407,000	" "
c' =	11,595 "	X 33.5 "		=	388,428	" "
d =	15,600 "	X 26.75 "		=	417,300	" "
e' =	11,880 "	X 18.25 "		=	216,810	" "
f' =	9,015	X 11.08 "		=	100,067	" "
g' =	16,185	X 4.17 "		=	67,490	" "
					23,987,655	

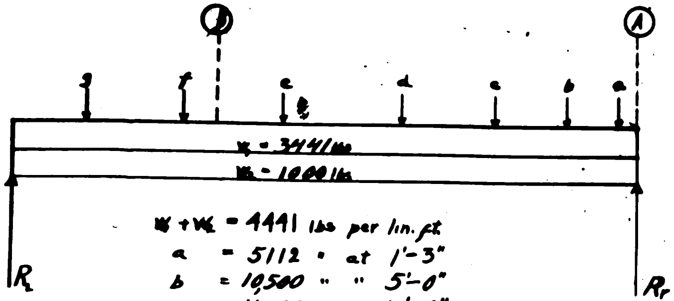
23,987,655 ÷ 87.67 = 273,380 lbs.

Right Reaction = 273,380 lbs.because of symmetry.

Computations for the Bending Moment

273,380 lbs.	X 43,83 ft.		=	11,983,250
	Minus			
4441 lbs.	X 43'10"	X 21' 11"	=	4,263,760
5112 "	X 1' 3"		=	6,390
10500 "	X 5' 0"		=	52,500
11595 "	X 10' 4"		=	119,480
15600 "	X 17' 1"		=	266,448
11880 "	X 25' 7"		=	303,890
9015"	X 32' 9"		=	295,240
16185"	X 39' 8"		=	641,960
				5,949,670

11,983,250
− 5,949,670
6,033,580 ft.lbs.B.M. at center
or
72,402,960 in.lbs.

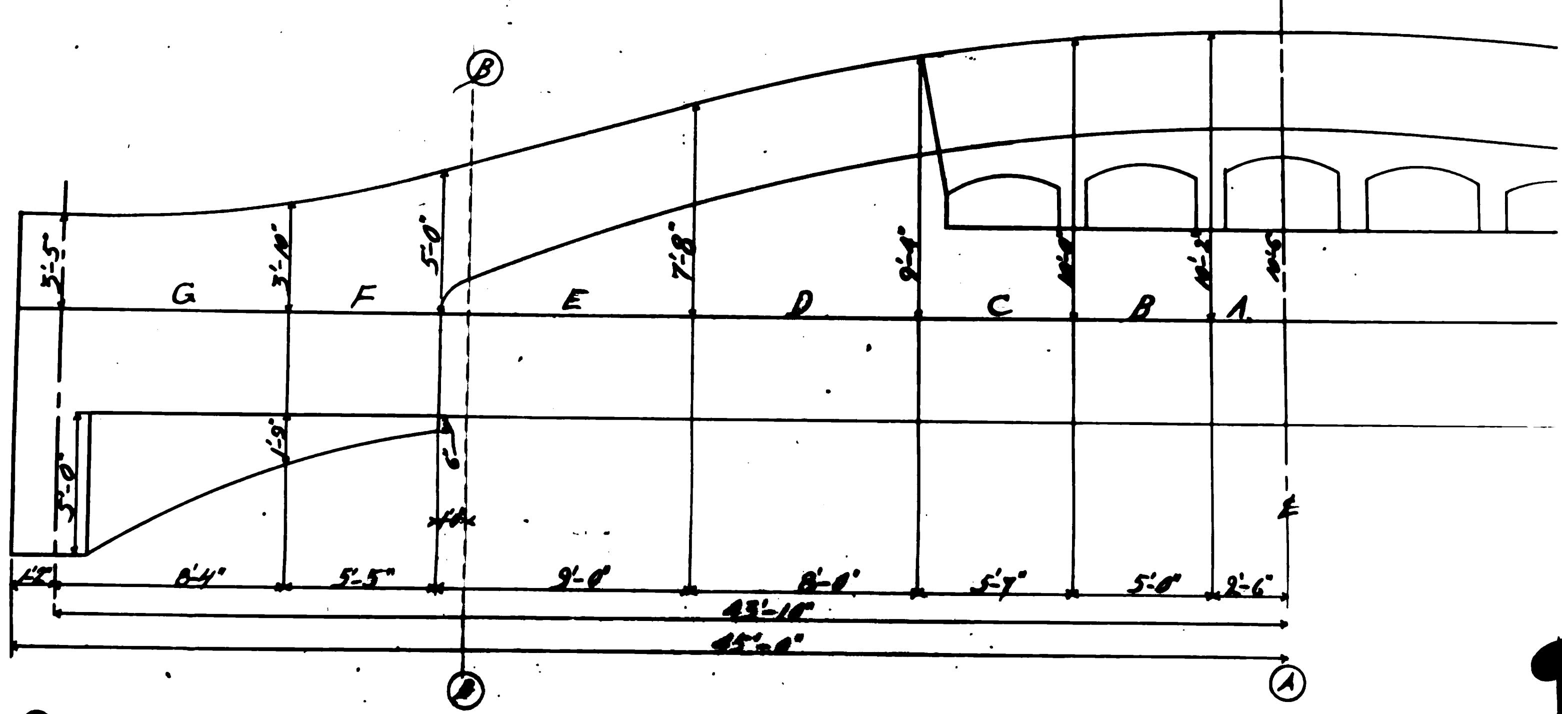


w + wL = 4441 lbs per lin. ft.

a	= 5112 "	at	1'-3"
b	= 10,500 "	"	5'-0"
c	= 11595 "	"	10'-4"
d	= 15600 "	"	17'-1"
e	= 11880 "	"	25'-7"
f	= 9015 "	"	32'-9"
g	= 16185 "	"	39'-8"

Scheme for Load Determination.

Scale, 3/8" = 1'-0"



At center of Girder

$d = 14'\ 0" - 8\frac{1}{2}" = 159.5"$

$$k = \frac{1}{1 + \frac{fs}{nfc}} = \frac{1}{1 + \frac{16000}{12 \times 813}} = .379$$

kd = depth of neutral axis = .379 X 159.5 = 59.8"

No.	Area	Unit Stress	Total Stress	Lever Arm	M of total stress About the top
1	54" X 16" = 864 sq in	.087fc	75.2fc	37"	2030.4 fc
1	864 sq in	.457fc	394.8fc	18"	7106.4 fc
2	4x2x42 = 336	.298fc	100.1fc	31"	3103.1fc
2	336 sq in	.351fc	135.9fc	14"	1902.6 fc
			706.0fc		12941.5fc

z x P = Summation P'x

z 706 fc = 12941.5 fc

$$z = 18.3 \frac{fc}{fc} = 18.3$$

159.5" - 18.3 = 141.2" = jd

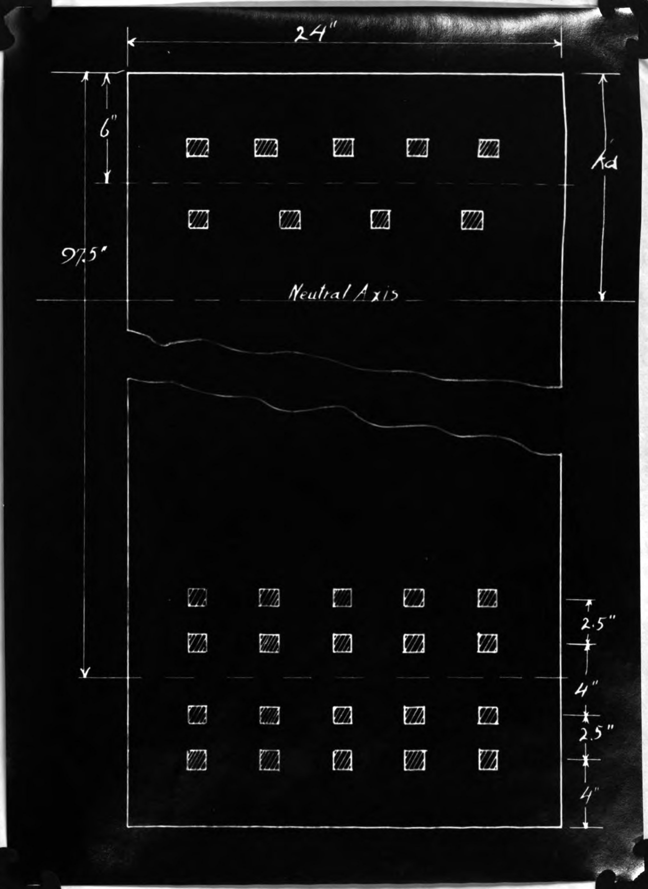
$$j = \frac{141.2}{159.5} = .885$$

The stresses at the center of the girder were then solved by the formulae of the straight line theory."d","k" and "kd" are first found in order. Then on the theory that the total stress in the concrete multiplied by a distance will balance the moment of total stress about the top,a method was found for determining the distance "z". The area of certain sections was taken and multiplied by the unit stress for the section. This gave a total stress and when multiplied by its lever arm about the top, produced the moment of the total stress about the top. Then when this was completed for all the sections,the summation of total stresses times "z" was equated to the summation of the moments of total stresses. "z" was then found abd then d - z = jd

The solution follows:

$$fc = \frac{73,403,960}{705 \times 141.3} = 727$$

$$fs = \frac{73,403,960}{31.35 \times 141.8} = 18,400$$


24"
6"
kd
97.5"
Neutral Axis
2.5"
4"
2.5"
4"

Computation for Girder at Critical Section.

At the critical section, the area of steel in both tensile and compression face was taken into account and hence As and A's were obtained first. Then by entertaining the factor "kd," an equation was obtained balancing the stresses in the tensile face. Solving the resulting quadratic equation gave a value for "kd" and the use of the straight line formulae brought the rest of the results.

A's = 31.25 sq.in.
A's = 14.06
One "n" of concrete taken by steel in compression face.
As to concrete = 12 X 31.25 = 375
A's " " = 11 X 14.06 = 154.66

$$375\,(97.5 - kd) = 154.66\,(kd - 6) + kd \times 24 \times \frac{kd}{2}$$

$$12\,kd^2 + 530.66\,kd - 37490 = 0$$

$$kd = \frac{530.66 \pm \sqrt{530.66^2 + 48 \times 37490}}{24}$$

$$kd = \frac{913.1}{24} = 37.9''$$

$$k = \frac{37.9''}{97.5} = .389$$

$$j = 1 - \frac{k}{3} = .871$$

$$jd = 84.9 \text{ sq in}$$

For Bending Moment at Critical Section

273380 X 14!75 = 4,032,355

Minus

4,441 lbs. X 14'75 X 7' 43	=		486,700
16,185 lbs. X 10'7"	=		171,237
9,015 lbs. X 3'-9"			33,806
			691,743

4,032,355 - 691,743 = 3,340,612 ft.lbs.
or
40,087,344 in.lbs.

$$fs = \frac{M}{As\ jd} = \frac{40,087,344}{31.25 \times 84.9} = 15,100$$

$$fc = \frac{fs\ k}{12(1-k)} = \frac{15100 \times .389}{12 \times .611} = 805$$

Max.vertical shear at the support = 273380 lbs.

$$v = \frac{V}{bjd} = \frac{273380}{24 \times 70} = 164 \text{ lbs.}$$

v(M.S.H.Sped) = 12% of compressive strength of concrete, = 12% of 2500 lbs. = 300 lbs.

In this case "jd" is purely a matter of experience, but consultation with the designer of this bridge disclosed the fact that "jd" taken equal to 70 inches was considered very conservative indeed.

Conclusion

Extensive study and consultation with the designer, computer, construction engineer, inspector, and constructor of the bridge mentioned as constructed near Tecumseh, has convinced the author of the entire applicability of the structure. Comparison with other concrete designs for the same span and clearance has proven conclusively the economy of the design. At no point in the structure are the stresses in the concrete exceeded. The stress in the steel never exceeds 16,400 and it has become common practice in many cases to permit the stress of 18,000 and 20,000 pounds for steel properly bedded in concrete. Hence under the assumption of a satisfactory inspector in charge, it is a very satisfactory bridge. And last but not to be disregarded, is the strong appeal to the esthetic sense derived from the gentle curve of the top of the girder. None can deny the supreme beauty of the well designed arch and a near approach is here made to that curve.

It stands the test of analysis, it has an appeal to the senses, and above all it has been built, and stands the test of utility.

GENERAL SPECIFICATIONS

for

STEEL AND CONCRETE HIGHWAY BRIDGES

and

SPECIFICATIONS FOR MOVABLE BRIDGES

FOURTH EDITION

1920

MICHIGAN STATE HIGHWAY DEPARTMENT

LANSING, MICHIGAN

Contract No................

CONTRACTORS FOR BRIDGE CROSSING

SECTION...................... TOWN......................N/S RANGE..................E/W

..................................TOWNSHIP

..................................COUNTY

GENERAL SPECIFICATIONS

for

STEEL AND CONCRETE HIGHWAY BRIDGES

and

SPECIFICATIONS FOR MOVABLE BRIDGES

FOURTH EDITION
1920

MICHIGAN STATE HIGHWAY DEPARTMENT
LANSING, MICHIGAN

FRANK F. ROGERS, C. E., State Highway Commissioner.
C. V. DEWART, Bridge Engineer.
C. A. MELICK, Consulting Bridge Engineer.

General Clauses.

1. Blank Forms.—All contracts, proposals, bonds, etc., must be made out on blanks furnished by the State Highway Department. Additional blanks or blue prints may be had by Contractors upon request.

2. Familiarity with Conditions.—The Contractor shall make himself familiar with all details shown on the plans and conditions at the site, and shall refigure all bills of material or estimates of quantities shown thereon before submitting his proposal.

3. Concrete Bridges.—All concrete work will be designed and detailed by the Michigan State Highway Department.

4. Stress Diagram for Steel Bridges.—Bidders on steel bridges will submit proposals accompanied by stress diagrams and general drawings, showing live and dead loads and other forces used in calculations, material, shape, size and all other characteristics of the structure; the make up and gross and net cross sectional area of each member, and the maximum stress therein, total, and due to each class of load separately, being careful to show lateral and sway systems and the stresses therein, floor beams and stringers and their connections, make up, gross and net flange and web areas and the stresses therein due to each class of load separately. The stress diagram shall also show enough details to indicate the general intent of the work.

5. Engineer's Drawings.—When stress sheets and general drawings are furnished by the Michigan State Highway Department, they shall be followed in detail except in so far as the details governing method of erection are concerned. Any substitutions of details shall be subject to the approval of the State Highway Commissioner.

6. Drawings for Steel Bridges.—Upon the acceptance of the proposal and the signing of the contract for steel bridges, the Contractor shall submit two (2) complete sets of blueprints of working drawings for the approval of the State Highway Commissioner and no work shall be commenced or material ordered until the working drawings are thus approved. If the State Highway Commissioner retains such drawings more than one (1) week from date of their receipt it shall entitle the Contractor to an equivalent extension of time for completing the work, provided the Contractor notifies the State Highway Commissioner of the delay. The Contractor will be expected to furnish free of cost to the State Highway Commissioner complete sets of approved working drawings and stress sheets as the State Highway Commissioner may require. In addition, the Contractor shall, upon the fulfillment of the contract furnish the State Highway Department with a complete set of all tracings pertaining to their contract.

7. Name Plates.—For concrete bridges the Contractor will be furnished with a plate to be set in the concrete in two conspicuous places as he may be directed. The Contractor's name will appear on this plate and the use of any other name plate or advertisement is forbidden.

8. For steel bridges one or more cast iron name plates of an approved design shall be furnished by the Contractor and bolted to the superstructure at the point or points specified. For trunk line bridges these shall bear the inscription "Trunk Line Bridge, built by State Highway Department, Frank F. Rogers, Commissioner," also the number of the bridge, the date of construction and the name and address of the Contractor. Details of Reward Bridge" name plates will be furnished by the State Highway Commissioner.

9. Liabilities of Contractors.—The Contractor shall maintain sufficient guards by day and night to prevent accidents from travel or by any other cause incident to the performance of the contract and shall be liable for any damage which may arise from his neglect to do so, or from any omission on his part or on the part of his agents.

10. The Contractor must construct barricades and guards to prevent accidents to travel as he may be directed, provide proper detour signs, and also hang out red lights by night all of which must be left in place or maintained until permission is given to remove. Barricades and lights shall be placed not less than 50 ft. away from points of imminent danger to vehicular traffic. In addition to red lights the premises shall be kept illuminated by carbide lights so disposed as to cover the entire work from barricade to barricade or such danger zone limits as the Engineer may designate.

11. Patterns.—It is understood that all patterns shall become the property of the State Highway Department upon request of the State Highway Commissioner.

12. Special Erection.—Special permission shall be secured from the State Highway Commissioner in writing when it is proposed to erect a structure in such a manner as to bring upon it concentrated loads other than those for which it has been designed—such as might be due to floating to position, or erection by cantilever method. This is particularly to insure against applying load to a structure in such a manner as to reverse tension members.

13. Commencing Work.—He is to commence and prosecute work on the bridge as he may be directed to by the State Highway Commissioner within ten days from and after signing the contract, and shall prosecute the work rapidly and continuously in accordance with the best modern practice unless delayed by orders from the State Highway Commissioner.

14. Time of Completion.—He further agrees to complete the work on or before the date specified in the contract and to allow the liquidated damages to be deducted from moneys which may be due him. Provided' however, that the State Highway Commissioner may extend the time limit for the completion of this contract upon the recommendation of the Engineer in charge, giving satisfactory reasons for such extension.

15. Force.—The Contractor shall begin work as specified in the contract, and he shall at all times thereafter employ such force and outfit as will, in the opinion of the Engineer, be necessary to complete the work within the contract time; and if he fails to begin work at the proper time or to furnish materials or execute the work in accordance with the plans and specifications, or fails to proceed with the same as rapidly or in as workmanlike a manner as the State Highway Commissioner shall deeem necessary in order to complete the same within the time limit; then in any such case, upon ten days' written notice to Contractor, the State Highway Commissioner shall have the right to annul and determine such contract and enter upon and take possession of the work and complete the same either by reletting or directly under the charge of the State Highway Commissioner, and if the cost of completing the work in such manner shall exceed what it would have cost under the contract, such increased cost shall be paid from any money on hand for work under this contract, and if that be not sufficient then such increased cost shall be met by the Contractor and the sureties on his bond given to guarantee the faithful performance of this contract.

16. Stakes and Monuments.—The Contactor shall be required to preserve all stakes and monuments established on the line of the work until duly authorized by the Engineer to remove the same. If any monuments or stakes marking the boundaries of property along the line of work have to be removed in the process of the work, the Contractor will promptly notify the Engineer in charge so that he can properly locate and reset the same after the grading is complete.

17. Maintaining Travel.—The Contractor shall preserve the roadway on which he is working from needless obstructions, and also in case of a bridge crossing a stream or thoroughfare of any kind he shall conduct his operations in a manner which will not in any way interfere with or jeopardize the safety of the travel. He shall have the right, however, to close that part of the road on which he is working to travel whenever other roads can be traveled without serious inconvenience to the public if given the written permission by the State Highway Commissioner.

18. For temporary traffic the contractor shall provide a width of roadway not less than 10 ft. in the clear. In the case of embankments or stream crossings, said roadway shall be protected by an exceptionally strong railing or hub guard. The roadway is to be maintained in good traveling condition at all times for as long as the need exists.

19. All designs or schemes for maintaining travel must be submitted to the State Highway Commissioner for alterations or approval.

20. Accidents.—The Contractor shall so conduct his operations as not to interfere with the work of other Contractors working on the same or adjacent work. The Contractor shall assume all risks of accident to men, material, or structure in place prior to the acceptance of the finished structure.

21. Payments.—Payments will be made once a month on the basis of 80 per cent of the Engineer's estimate for work done and material delivered. For steel bridges a payment of 75 per cent will be made on delivery and the balance paid when bridge is erected and accepted.

22. Proposals.—All proposals which contain bids not asked for or that other-wise are not in conformity with the specifications will be rejected. Each proposal must be accompanied by a certified check drawn to the order of Frank F. Rogers, The State Highway Commissioner, in the amount of the specified lump sum or in the sum of five per cent of the proposal, conditioned, that if the bidder or bidders to whom the contract is awarded should refuse or neglect to execute the contract or furnish security the adequacy and sufficiency of which shall be approved by the State Highway Commissioner within ten days, then in either such case all or that portion of said check which shall be necessary to compensate for the liquidated damages caused by such refusal or neglect shall be retained by the State Highway Commissioner and become the property of the State of Michigan.

23. Checks Returned.—Checks shall be returned to the unsuccessful bidders after the award of the contract, and to the successful bidder after the execution of the contract.

24. Right of Rejection.—The State Highway Commissioner reserves the right to reject any or all proposals or award the contract as he deems advisable for the best interests of the State of Michigan.

25. Bonds.—Two bonds furnished by a surety company doing business in Michigan shall be required of of the Contractor. One in a sum equal to the consideration to be paid under this contract, guaranteeing the faithful performance of the work in accordance with the terms herein, and the other in a sum equal to the consideration to be paid under this contract, provided that said bond shall be for a minimum sum of $5,000, guaranteeing the payment of indebtedness incurred for labor, materials, or any cause whatsoever in fulfilling this contract, it being expressly understood that the latter bond is to include any liability of the Contractor, through the execution of this contract, arising from the provisions of Act No. 10 of the Public Acts of 1912 (extra session), as passed or thereafter amended.

26. Subletting.—The Contractor agrees to give his personal attention to this contract and not to sublet the same or any portion thereo', without the written consent of, and subject to the conditions stipulated by the State Highway Commissioner.

27. Instructions to Foremen.—The superintendent or foreman of any particular portion of the work shall receive and obey the instructions of the Engineer referring to that particular part of the work in case the Contractor himself is not present.

28. Incompetent or Disorderly Workmen.—Any foreman or workman employed by the Contractor or by any sub-contractor who, in the opinion of the Engineer or his authorized assistant, should not perform his work in a skillful manner, or should be disrespectful, intemperate, disorderly or otherwise objectionable, shall at the written request of the Engineer, be forthwith discharged by the Contractor or sub-contractor employing such foreman or workman, and shall not be employed again on any portion of the work provided for by these plans and specifications without the written consent of the Engineer.

29. Imperfect Work or Material.—All insufficient, imperfect or damaged work or material when pointed out at any time to the Contractor by the Engineer, or his authorized assistant, shall be remedied immediately and made good, or removed and rebuilt, or placed to conform to the plans and specifications, and any omission by the Engineer or his authorized assistant to disapprove of or reject any such defective work or material during construction shall not be deemed an acceptance of such work or material, nor shall such omission on the part of the Engineer be construed as in any way releasing the Contractor from remedying, replacing or making good any defective work or material so as to conform to the plans and specifications.

30. Changes in Plans.—The right is reserved to make such minor changes in the plans and specifications as are not otherwise herein provided for, as may from time to time appear necessary or desirable, and such changes shall in no wise invalidate this contract and shall be paid for at the unit price as quoted. Should such changes or any other changes be productive of increased or decreased cost to the Contractor for which there is no price quoted in the contract, a fair and equitable sum therefore, to be agreed upon in writing before such changed work shall be started shall be added to the contract price and in like manner deductions shall be made.

31. Extras.—It should be thoroughly understood by the Contractor that extras shall be allowed for only when granted in writing by the State Highway Conmissioner.

32. Extra Foundation Work.—Should it be found necessary in the judgment of the Engineer to increase or decrease the depth of the foundation not more than three feet from that shown on the plans, the thickness of the wall, where said wall joins the footing, shall be increased or decreased the same amount per foot as the main wall increases per foot of its height as shown on the plans. This shall not be understood however to apply to arch abutments. For this latter type of construction special instructions shall be furnished by the State Highway Commissioner for modifying footing designs.

33. Lines and Grades.—Lines and grades will be given, when requested, by the State Highway Commissioner.

34. The Contractor will be held responsible for the line and grade of all bridges, elevation of bridge seats and accuracy of camber and arch curves. He shall satisfy himself, by test piles if need be, of the value and stability of his piling. Deviations from line, grade, or cambers or arch curves greater than one inch shall be deemed sufficient cause for rejection of the work.

35. Clearing Up.—The Contractor shall leave the bridge and premises in a neat and presentable condition and remove and clear up all rubbish and surplus material and leave the waterway unobstructed; and where it has been necessary to remove an old structure, the material from the same shall be neatly piled on the bank, where it may readily be loaded on wagons; it being understood that said material may be used by the Contractor in the erection of the new structure and that any material removed from the old structure and not used in the construction of the new bridge shall remain the property of the original owners unless otherwise specified.

36. Channel Changes.—Channel changes whenever shown on the plans or made necessary by the location of the new bridge must be done by the Contractor out to the full width of the right of way, but any changes extending beyond the right of way will be done by the township or county or be handled as an extra to the contract. The channel must be cleared out to the full width and depth under the new bridge.

37. Backfilling.—In all cases after the masonry is built up the remaining openings of the excavation shall be backfilled up to the original contour of the ground with good material well rammed into place. Any surplus material shall be placed in back of the abutments where it may be covered by the embankment. All new bridges must be restored to travel however, before final payment. This may be accomplished by a temporary approach span, by restoring the old bridge as approach spans for the new bridge or by making enough of the back fill to provide a 16 ft. width of shoulder and not greater than 4% grade. In arch construction the Contractor shall make the back fill, depositing same in 8-inch layers, carefully rammed according to the instructions of the Engineer. He shall place the material in such places and in such order as required by the Engineer. Said backfill to extend to full roadway grade set by Engineer for a length of roadway extending between tip of extreme widths of abutments whether of flaring or straight design. The fill may slope away from said extreme limits on a slope of 1½ horizontal to one vertical.

38. Removal of Existing Structures.—Removing existing structures, if any shall be done by the Contractor and included in the contract price.

39. In removing existing structures the Contractor shall carefully and clearly mark all members of the structures before dismantling. Upstream trusses shall be marked using symbols U, M and L for upper, middle and lower panel points respectively; Downstream trusses shall be marked T, C, and B for the top, center and bottom panel points respectively. Panel points shall be numbered consecutively from one end to the other end of the bridge. Marks shall be both painted and stamped with steel dies. All pins, nuts, fillers, pin rings etc. shall be clearly marked and all loose parts shall be either strung on wire and attached to connected parts or they shall be neatly packed in a box. All pin holes and machine parts and surfaces shall be painted with a mixture of white lead and tallow.

40. Load Tests.—Load tests on portions of finished concrete work shall be made where there is reasonable suspicion that the work has not been properly performed, or that, through influences of some kind, the strength has been impaired. Loading shall be carried to such a point that one and one-half the calculated working stresses in critical parts are reached, and such loads shall cause no permanent deformations. Load tests shall not be made until after sixty days of hardening.

41. Engineer as Referee.—It is agreed by both parties to this contract that the Engineer shall act as referee in all questions arising under the terms of this contract between the parties thereto, and that the decision of the Engineer in all such cases shall be final and binding upon both alike.

42. Definitions.—Whenever the words "State Highway Commissioner" are used in the contract it is understood to mean the party of the first part to this contract, or other authorized representative limited to the particular duties intrusted to him.

43.—Whenever the word "Contractor" is used, it is understood to mean the person or persons who have entered into this contract as party or parties of the second part or his or their heirs, executors, administrators, successors or assignees.

44. Whenever the word "Engineer" is used, it is understood to mean the Engineer for the Michigan State Highway Commissioner or his authorized representative.

45. Whenever the word "Inspector" is used, it is understood to mean the person employed to perform such duties as are herein described as duties of the Inspector.

Foundations.

46. Character of Bottom.—The material of the bottom upon which piers and abutments must be founded, may, for the purpose of these specifications, be divided into the following classes:

a. Rock.

b. Hard ground; as hard-pan, gravel, compact sand held laterally, or hard dry clay.

c. Soft ground; as soft or wet clay, silt or mud whose sustaining power must largely depend upon the frictional resistance of piles or upon piles driven through the soft material to an underlying material of a harder character.

47. Rock.—Where the site of the foundation is on rock, it shall be cleared of all overlying soil or other material, all the loose and distintegrated portions of the rock removed and the resulting surface roughened to a depth of six inches. When the surface is inclined it shall be levelled in steps to prevent any tendency of the foundation to slip.

48. Hard Bottom.—In hard ground the material shall be excavated to a depth below the action of frost or scour by surface currents, with a minimum depth of 4 ft., if above the water. For foundations in the water the excavation shall extend a sufficient depth below any possible scour by the river currents to give the piers sufficient foothold to resist displacement by the shoving action of floods, ice or floating material. In no case, however, shall the foundation extend less than three feet below the bed of the stream.

49. Where the foundatons are on or near the banks of streams or on sloping strata they shall be carried deep enough to insure them from slippng by the sliding of this underlying material.

50. Where the material is liable to be softened, scoured or undermined by water, or where foundations cannot be carried deep enough to be beyond any possibility of beng affected by scour the bottom shall be piled.

51. Soft Ground.—Where the foundation is in soft ground, the material shall be excavated to a stratum of hard material or else it must be excavated to a depth where the soil is permanentlv wet, if on land, and below possible scour, if in the water, piles may then be driven as shown on the plans.

52. Timber Work.—No piles or timber shall be used as an essential part of any foundation above the water line or in ground which is not permanently wet.

53. When the Contractor, in order to faciliate construction, uses timber in such a way that it can not be removed, it shall not be paid for nor shall it be allowed to be so placed as to occupy space for which concrete is shown on the plans—nor shall it be considered as concrete.

54. Steel Work.—No iron or steel work shall be used as an essential part of any foundation in direct contact with any kind of earth or soil or in any position inaccessible for painting and cleaning except where imbedded in concrete.

55. Piers.—The tops of trestle or viaduct piers on land must be at least 18 inches above the surface of the ground.

56. Pedestals.—Pedestal tops shall not be less than 18 inches square.

57. Anchors.—When sepcified on the plans all anchor blots and anchors shall be properly placed and built in by the masonry Contractor, the material for the same being furnished by the Contractor for the metal work.

58. Piles.—Piles shall be of any sound hard timber that will stand driving, free from loose or rotten knots or other defects which would impair their strength or durability. They shall be at least 6 inches in diameter at the point and not less than 10 inches at the butt.

59. Driving Piles.—Piles shall be of sufficient strength to allow being driven until the penetration under 1,500 lb. hammer falling freely twelve (12) feet is not more than three-fourths (¾) of an inch, or its equivalent for the last three blows. No hammer weighing less than 1,500 lb. will be permitted. The piles in no case, shall be driven less than ten (10) feet. The heads of the piles, while driving, shall be protected by iron rings to prevent brooming.

60. Test Piles.—If requested by the Engineer, the Contractor shall test loadings of one or more piles as he may select to verify the capacity of piles as stipulated on the plans. In case such a test is required, it will be paid for as an extra at the cost value of the labor involved plus ten per cent (10%).

61. Cut Off.—After the piles are driven they shall be sawed off square at a level not more than one foot above the bottom of the footing.

62. Drainage.—Provision shall be made in abutment and retaining walls and in the fills between spandrels of earth-filled arches, for the drainage of water behind the walls, by weep holes or other means as may be shown on the plans or called for by the Engineer.

63. Adherence to Plans.—The Contractor shall, during construction, adhere strictly to the plans and the inspector shall not be allowed to make any change therein without the written authority of the State Highway Commissioner or his Engineer of Bridges.

64. The Contractor shall check all leading dimensions and clearances as a whole and in detail, and become responsible for the exact position and elevation of all parts of the work.

65. Surface Treatment of Concrete Roadway.—The surface of the concrete roadways shall be thoroughly cleaned and coal tar, heated to from 250° to 350° Fahr., shall be evenly spread over the surface, using not less than ⅛ gallon per square yard of surface. Immediately after application of tar, and while tar is still hot, the surface shall be evenly covered with ½″ of clean, coarse, sharp sand. The application of tar must not be made when the surface of the concrete is damp.

66. Bridge Camber.—Bridges consisting of more than one (1) span shall be built with their bearings at such an elevation that ponts over each bearing on a nominally straight grade from abutment to abutment shall be raised so as to lie on a vertical circular curve having a ratio of chord, from abutment to abutment, to the middle ordinate equal to the ratio of span to camber allowances for the type of structure under consideration. For all practical purposes the said curve may be considered as a parabola. See 341, 347, 351.

Concrete Materials.

67. Cement.—A standard brand of Portland cement shall be used. No cement shall be used which the State Highway Commissioner deems unfit for the work. The Contractor shall notify the State Highway Commissioner in writing what brand or brands he intends to use and before ordering the cement shall receive the written approval of the State Highway Commissioner as to the selection of the brand, but the cement itself may be rejected if it fails to meet the requirements herein specified.

68. Chemical Limits.—The following limits shall not be exceeded:

Loss on ignition, %	4.00
Insoluble residue, %	.85
Sulphuric Anhydride, (SO_3), %	2.00
Magnesia (MgO), %	5.00

69. Specific Gravity.—The specific gravity of Cement shall be not less than 3.10. Should the test of cement as received fall below this requirement a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

70. Fineness.—The residue on a standard No. 200 sieve shall not exced 22% by weight.

71. Soundness.—A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking or disintegration in the steam test for soundness.

72. Time of Setting.—The cement shall not develop initial set in less than 45 minutes when the Vicat needle is used or 60 minutes when the Gillmore needle is used. Final set shall be attained in not more than ten hours.

73. Tensile Strength.—The average tensile strength in pounds per square inch of not less than three standard mortar briquettes composed of one part cement and three parts standard sand, by weight, shall be equal to or higher than the following:

Age at test, days.	Storage of briquettes.	Tensible strength, lbs. per sq. inch.
7	1 day in moist air, 6 days in water	200
28	1 day in moist air, 27 days in water	300

The average tensile strength of standard mortar at 28 days shall be higher than the strength at seven days.

74. Packages and marking.—The cement shall be delivered in suitable bags or barrels with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94 pounds net. A barrel shall contain 376 pounds net.

75. Storage.—In order to allow ample time for inspection and testing, the cement shall be stored in a suitable weather-tight building having the floors properly blocked or raised from the ground. The cement shall be stored in such a manner as to provide easy access for proper identification and inspection of each shipment.

76. Inspection and Tests.—All cement shall be inspected. Every facility shall be provided by the Contractor and when cement is to be tested after delivery a period of at least twelve days shall be allowed for the inspection and necessary tests. Cement failing to meet the seven day requirements may be held awaiting the results of the twenty eight day tests before rejection. All sampling and tests shall be made in accordance with the methods proposed by the American Society for Testing Materials as adopted September first, 1916, and with all subsequent amendments thereto.

77. Rejection of Cement.—No cement shall be used until tested, except by special permit in writing from the State Highway Commissioner, and all lumpy, caked, dirty or damaged cement shall be rejected. All rejected cement shall at once be removed from the site of work.

78. Fine Aggregate.—Fine aggregate shall consist of hard silicious material, clean, free from dust, soft particles, vegetable loam or other deleterious matter. The run of the pit shall be fairly uniform and in all cases shall meet the following requirements:

Passing one quarter (¼) inch screen	100%
Passing twenty (20)mesh sieve, between the limits	40% and 80%
Passing fifty (50) mesh sieve, not more than	20%
Passing one hundred (100) mesh sieve, not more than	4%
Clay or Silt adhering to the grains, not over	2%

79. Fine aggregate shall be of such quality that mortar composed of one part Portland cement and three parts fine aggregate by weight, when made into briquettes, shall show a tensile strength at least equal to the strength of 1:3 mortar of the same consistency made with the same cement and standard Ottawa sand.

80. Coarse Aggregate.—Coarse aggregate shall consist of hard, sound, durable particles of stone, clean, free from dust, soft particles, vegetable loam or other deleterious matter. The stone shall be fairly spherical in shape, being practically free from elongated or flat particles. The run of the pit shall be fairly uniform and shall meet the following requirements:

a. For one and one-half (1½) inch aggregate	
Passing one and one-half (1½) inch screen	100%
Passing one (1) inch screen, between the limits	36% and 84%
Passing three-quarter (¾) inch screen, between the limits	16% and 64%
Passing one-half (½) inch screen, between the limits	4% and 36%
Passing three-eighths (⅜) inch screen, between the limits	0% and 19%
Retained on one-fourth (¼) inch screen	95%
b. For one (1) inch aggregate	
Passing one (1) inch screen	100%
Passing three-quarters (¾) inch screen, between the limits	45% and 89%
Passing one-half (½) inch screen, between the limits	16% and 64%
Passing three-eighths (⅜) inch screen, between the limits	3% and 31%
Retained on one-fourth (¼) inch screen	95%
c. For three-quarter (¾) inch aggregate	
Passing three-quarter (¾) inch screen	100%
Passing one-half (½) inch screen, between the limits	36% and 84%
Passing three-eighths (⅜) inch screen, between the limits	16% and 64%
Retained on one-fourth (¼) inch screen	95%
d. For one-half (½) inch aggregate	
Passing one-half (½) inch screen	100%
Passing three-eighths (⅜) inch screen, between the limits	45% and 89%
Retained on one-fourth (¼) inch screen	95%

81. Aggregate passing any of the preceding gradation tests may be used and will be considered as "Acceptable Aggregates" provided however, that the following requirements are met:

a. For spindles, rails, pilasters and in reinforced concrete sections not thicker than eight (8) inches, the aggregate shall not exceed three-quarter (¾) inch.

b. For all other reinforced concrete work the aggregate shall not exceed one (1) inch.

c. For plain concrete, the aggregate shall not exceed one and one-half (1½) inch except as hereinafter provided for under the heading "Plums". 143.

82. Inferior Aggregates.—When aggregates are submitted for use which in any way do not come up to these specifications they may be either rejected entirely or used with a sufficient increase of cement to give the requisite strength as hereinafter provided for in 105. It should be understood that an increase of cement will not be allowed for as an extra to the contract price.

83. Bank-run Gravel.—Concrete made of cement and unscreened gravel shall not in any case be used for reinforced concrete. In case of a well graded gravel, however, an unscreened mixture may be permitted for plain concrete in large masses upon receiving written permission of the State Highway Commissioner after examination of a sample sent in by the inspector.

84. Rubble Concrete.—When the concrete is to be deposited in massive work, clean stones may be used, thoroughly imbedded and entirely surrounded by at least three inches of concrete. Stones to be acceptable must be as hard in themselves as the resultant concrete. Rubble concrete shall not be deposited in water. This concrete shall be further governed by the requirements of 143.

85. Water.—The water used in mixing concrete shall be free from acid, oil, strong alkalies, vegetable matter or other materials detrimental to the strength of concrete.

86. Concrete Reinforcement Bars.—All reinforcement bars shall be designed for a stress not greater than 16,000 pounds per square inch, shall be of the structural steel grade and shall conform to "Standard Specifications for Billet Steel Concrete Reinforcement Bars" as adopted by the American Society for Testing Materials in 1914 or any subsequent revisions therein with exceptions as may be hereinafter specified.

87. Manufacture.—Steel may be made by either the open-hearth or Bessemer process. Bars shall be rolled from standard new billets and no rerolled material will be accepted. The use of twisted bars will not be permitted except in heavy concrete sections involving little or no bending and relatively free from impact or vibration and in no case shall they be used without written permission from the State Highway Commissioner.

88. Chemical and Physical Properties.—The chemical and physical properties shall conform to the following units:

	Structural Steel Grade	
Properties considered	Plain Bars	Deformed Bars
Phosphorus, maximum:		
Bessemer	.10	.10
Open-hearth	.05	.05
Ultimate tensile strength, lbs. per sq. inch	55/70,000	55/70,000
Yield point, minimum lbs. per sq. inch	33,000	33,000
Elongation, per cent in 8 inches, minimum	1,400,000 / T. S.	1,250,000 / T. S.
Cold bend without fracture:		
Bars under ¾ inch in diameter or thickness	180° d=t	180° d=t
Bars ¾ inch in diameter or thickness and over	180° d=t	180° d=2t

89. Chemical Determinations.—In order to determine if the material conforms to the chemical limitations prescribed in 88 herein, analysis shall be made by the manufacturer from a test ingot taken at the time of the pouring of each melt or blow of steel, and a correct copy of such analysis shall be furnished to the Engineer or his inspector.

90. Yield Point.—For the purposes of these specifications, the yield point shall be determined by careful observation of the drop of the beam of the testing machine, or by other equally accurate method.

91. Form of Specimens.—Tensile and bending test specimens may be cut from the bars as rolled, but tensile and bending test specimens of deformed bars may be planed or turned for a length of at least 9 inches if deemed necessary by the manufacturer in order to obtain uniform cross-section.

92. Number of Tests.—At least one tensile and one bending test shall be made from each melt of open-hearth steel rolled, and from each blow or lot of ten tons of Bessemer steel rolled. In case bars differing ⅜ inch and more in diameter or thickness are rolled from one melt or blow, a test shall be made from the thickest and thinnest material rolled. Should either of these test specimens develop flaws, or should the tensile test specimen break outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor. In case a tensile test specimen does not meet the specifications, an additional test may be made.

93. The bending test may be made by pressure or by light blows.

94. Modifications in Elongation for Thin and Thick Material.—For bars less than $\frac{7}{16}$ inch and more than ¾ inch nominal diameter or thickness, the following modifications shall be made in the requirements for elongation:

95. For each increase of ⅛ inch in diameter or thickness above ¾ inch, a deduction of 1 shall be made from the specified percentage of elongation.

96. For each decrease of $\frac{1}{16}$ inch in diameter or thickness below $\frac{7}{16}$ inch, a deduction of 1 shall be made from the specified percentage of elongation.

97. Finish.—Material must be free from injurious seams, flaws or cracks, and have a workmanlike finish.

98. Variation in Weight.—Bars for reinforcement are subject to rejection if the actual weight of any lot varies more than 5% over or under the theoretical weight of that lot.

99. **Unit of Measure.**—The unit of measure shall be the cubic foot; a bag of cement containing ninety-four (94) pounds shall be considered as the equivalent of one cubic foot by loose volume.

100. **Measure of Fine and Coarse Aggregates.**—The measurement of fine and coarse aggregates shall be by loose volume.

101. **Proportioning Acceptable Aggregates.**—The fine and coarse aggregates shall be used in such relative proportion as will insure the maximum density. The inspector shall, as soon as convenient, mix five (5) specimens of concrete using twenty-three and one-half (23.5) pounds of cement in each sample (¼ bag) and the corresponding total aggregate as called for on the plans, but using ratios of fine to coarse aggregate of 30, 40, 50, 60, and 70% respectively, all of the consistency prescribed for reinforced concrete mixtures. These specimens of concrete shall in turn then be carefully placed and puddled with a three-fourths (¾) inch diameter bar in a box, one foot square by two feet deep and the height of the resulting solid content carefully noted. The inspector shall then send to the Testing Laboratory of the State Highway Depament, one sack of cement, one (1) cement sack of fine aggregate, and one (1) cement sack of coarse aggregate, all of accepted materials, these materials to be used by the laboratory primarily in making two (2) standard eight (8) inch by (16) inch cylinders of each ratio of fine to coarse aggregate above mentioned. Accompanying this shipment will be a statement of the recorded heights of the field specimens with proper identification. The inspector may permit the use of that ratio of fine to coarse aggregate which resulted in the smallest solid content subject to acceptance of the cement and the fine and coarse aggregates themselves, until he shall receive from the laboratory the results of a seven (7) day crushing test on one (1) of the two (2) sets of standard cylinders. He shall then, if necessary, modify the ratio to agree with the strongest compression test until he shall receive the results of the twenty eight (28) day crushing test on the other set of standard cylinders at which time further revision based on strength shall be made if necessary. In no case shall less than one (1) volume of fine aggregate be used for one (1) volume cement.

102. **Proportioning for Poor Aggregates.**—In case either fine or coarse aggregates or both, fail to meet the requirements of these specifications, they may, on the recommendation of the Engineer, be used providing the units of total aggregate be reduced one and one-half units below that called for on the plans and the ratio of fine to coarse aggregates be determined as described for acceptable aggregates. In no case however shall less than one volume of fine aggregate be used for one volume of cement.

103. **Relation of Cement to Aggregate.**—The amount of cement to be used shall be expressed as the ratio of the number of bags of cement to the sums of the corresponding number of cubic feet of fine and coarse aggregate required. A 1:9 ratio of cement to total aggregate shall in general be used for footings. When footings are reinforced with steel, however, a 1:7½ ratio shall be used. A 1:7½ ratio of cement to total aggregate shall in general be used for all plain concrete above footings unless otherwise specified. A 1:6 ratio of cement to total aggregate shall in general be used for all reinforced concrete sections, excepting those requiring a relatively large amount of surface detail. A 1:4½ ratio of cement to total aggregate shall be used for precast railing posts, and in general for sections of less thickness than eight (8) inches and in all sections where waterproof construction is required. Exception to the above shall be made when specifically called for on the plans.

104. The above proportions shall, however, be subject to the condition that the strengths of the 8″ cylinder at twenty-eight days shall not be less than the following; for 1:4½ use 2,500, for 1:6 use 2,000, for 1:7½ use 1,600, for 1:9 use 1,300 pounds per square inch. The corresponding values for seven day tests shall not be less than 50% of the above. In case the given proportions will not furnish the above compressive strength the relative amount of aggregate shall be decreased until the strength conditions are guaranteed.

105. **Mixing.**—The ingredients shall be thoroughly mixed and the mixing continue until the cement is uniformily distributed and the mass is uniform in color and homogeneous.

106. **Measuring Ingredients.**—Methods of measurement of the proportions of the various ingredients shall be used, which will insure separate and uniform measurements of the cement, fine aggregate, coarse aggregate and water at all times.

107. **Mixer.**—A batch mixer shall be used unless written permission is given to the contrary.

108. **Machine Mixing.**—When conditions will permit, a machine mixer shall be used of a type which insures the uniform proportioning of the material throughout the mass.

109. The mixing shall continue for a minimum time of at least one minute after all the ingredients are assembled in the mixer.

110. **Hand Mixing.**—Mixing by hand will only be permitted on small jobs when necessary and the following directions carefully followed:

(a) Water tight platforms shall be provided of sufficient size to accommodate men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches shall not exceed one-half cubic yard each, and smaller batches are preferable.

(b) Spread the sand evenly upon the platform, then the cement upon the sand (which must be dry enough to be granular and mix readily), make a thin mortar and spread again; add the gravel if used (which must be free from sand), and finally the broken stone, both of which, if dry, should be thoroughly wet down. Turn the mass with shovels or hoes until thoroughly incorporated, and all the gravel and stone is covered with mortar; this will probably require the mass to be turned four times.

111. Consistency.—The materials should be mixed wet enough to produce a concrete of such consistency as will flow into the forms and about the metal reinforcement when used, and which at the same time can be conveyed from the mixer to the forms without separation of the coarse aggregate from the mortar. Under no circumstances, however, shall water be permitted to stand in the forms, such surplus, as soon as apparent being immediately taken up by a dry batch thoroughly rehandled in the forms. It is important that the amount of water used be the very minimum consistent with the above requirements.

112. Retempering.—Mortar or concrete shall not be remixed with water after it has partly set.

113. Water-Proof Concrete.—The use of water-proofing compounds or other foreign material added for the purpose of making the concrete water-proof will not be permitted. Sole reliance for water-proofing shall be placed upon the use of a 1″ thickness of a water side facing mixture, composed of one unit of cement to one unit of fine aggregate, deposited in 8″ layers and immediately backed by a 1:4.5 mixture of maximum density mixed of driest possible consistency and well puddled. The use of a vibrator for compacting the concrete shall not be permitted but careful puddling with a 1″ diameter bar shall be relied on for securing a dense mixture. The facing mixture shall at all times be kept at least 3″ above the concrete backing. All water-proof concrete shall be reinforced and the reinforcement shall be designed so as to interfere with puddling operations as little as possible.

114. Placing Concrete.—Concrete, after the completion of the mixing shall be handled rapidly, and in as small masses as is practical from the place of mixing to the place of final deposit, and under no circumstances shall concrete be used that has partly set.

115. The use of spouting systems for placing concrete is not to be permitted without special permission in writing from the State Highway Commissioner. When this system is used great care shall be taken to avoid too wet a mix, with consequent weakening of concrete and danger of laitance. The slope of spouting shall be such as to avoid the separation of materials. Under no condition shall this system be used with any but smooth gravel aggregates.

116. Compacting.—Concrete shall be deposited in such a manner as will permit the most thorough compactness, such as can be obtained by working with a straight shovel or slicing tool kept moving up and down until all the ingredients have settled in their proper places by gravity and the surplus water forced to the surface.

117. Laitance.—Special care shall be exercised to prevent the formation of laitance. To fulfill this condition it is important that the amount of water used shall be as small as is consistent with the requirements of 111. In case laitance has formed despite these precautions, it shall be removed in a manner satisfactory to the Engineer.

118. Securing Reinforcement.—Before depositing concrete the reinforcement shall be carefully placed in accordance with the plans, and adequate means provided to hold it in its proper position until the concrete has been deposited and compacted.

119. Design of Forms and Surface Finish.—Forms shall be substantial and unyielding so that the concrete shall conform to the design, dimemsions and contours shown on plans, and they shall be tight in order to prevent the leakage of water.

120. All knot holes, cracks and irregularities on the inside of forms for exposed surface of concrete shall be stopped up with clay or other suitable material.

121. All exposed edges of concrete including grooved panels shall be beveled with a ¾″ triangular molding.

122. Bracing for forms shall be arranged with wedges so that any notion may be corrected by means of the wedges.

123. In order to detect this motion plumb lines shall be hung at suitable points and observed during the time the concrete is being placed.

124. For all important work, the lumber used for face work shall be one and one-half (1½) inch matched tongue and groove, dressed to a uniform thickness, sound and free from knots and secured to the studdings or uprights in horizontal lines.

125. If approved in writing by the State Highway Commissioner, the Contractor may use some other type of form if supplemented by an acceptable carborundum brick treatment. The greatest of care must however, be exercised to prevent the warping of timbers, forms must be absolutely tight to prevent loss and separation of cement, and the formation of "lap siding" effect entirely eliminated.

126. In case a carborundum brick treatment is permitted, the surfaces to be rubbed shall receive the treatment not later than three (3) days in warm weather nor six (6) days in cold weather after the placing of the oldest concrete in the section. All holes and imperfections in the surface shall first be thoroughly wet, scrubbed with a wire brush, and compactly filled with a mortar composed of one (1) unit of cement to two (2) of sand. The entire surface is then to be thoroughly wet down and kept moist and a grout composed of one (1) unit of cement to two (2) of sand is to be swabbed on the surface in small patches and ground in vigorously with a carborundum brick or similar abrasive block until all hollows, lines, markings, and surplus material have been removed from the surface. The surface is then to be washed clean with clean water and thereafter no further surface treatment is to be permitted.

127. Cleaning Forms.—Immediately before placing concrete, the forms shall be thoroughly cleaned of all foreign accumulation. The stability of the forms shall be inspected, wedges tightened up and dimensions checked throughout.

128. **Wetting Forms.**—Care shall be taken to see that the forms are substantial and thoroughly wetted (except in freezing weather), or oiled, and that the space to be occupied by the concrete is free from debris.

129. When oil or other form surface treatment is used, care shall be taken to see that the material used is of such a nature as will not discolor or otherwise injuriously affect the concrete surface. Preference shall be given to the use of Paraffine Oils or a soap treatment.

130. When the placing of concrete is suspended, all necessary grooves for joining future work shall be made before the concrete has had time to set.

131. **Resuming Work.**—When work is resumed, concrete previously placed shall be roughened, thoroughly cleansed of all foreign material and laitance, thoroughly wetted and then slushed with a mortar consisting of one part Portland Cement and not more than two parts of fine aggregate.

132. **Freezing Weather.**—Concrete for reinforced structures or for plain concrete to be left above the surface of the ground shall not be constructed in freezing weather except by the written consent of the State Highway Commissioner, and it shall be protected in the manner in which the State Highway Commissioner directs. In this case the water and the fine and coarse aggregate shall be heated; and in severe cold, salt shall be added in the proportion of about two pounds per cubic yard but no salt shall be used for reinforced concrete. Effective means shall be provided to protect the concrete from freezing until it has thoroughly hardened. It is understood, however, that any concrete laid during freezing weather shall be entirely at the risk of the Contractor and concrete showing injury by frost shall be removed and replaced at expense of Contractor.

133. **Placing Under Water.**—No concrete shall be placed under water without the written consent of the Engineer in charge. In placing concrete under water a tremie of an approved design shall be used.

134. The concrete shall be mixed very wet (more so than is ordinarily permissible) so that it will flow readily through the tremie and into place with practically a level surface.

135. The coarse aggregate shall be smaller than usual and never more than 1" in diameter.

136. The mouth of the tremie shall be buried in the concrete so far that it is at all times entirely sealed, and the surrounding water prevented from forcing itself into the tremie.

137. The tremie shall be suspended so that it can be lowered quickly when necessary, either to choke off or to prevent too rapid flow.

138. Rubble concrete shall not be permissible under water.

139. All concrete placed through the water shall be not leaner than 1:6 or as stipulated by the Engineer and the extra cement added at the expense of the Contractor.

140. **Top Finish.**—Where a top finish is called for on the plans, it shall be "struck" with a straight edge until all coarse aggregates have been forced below the surface and then troweled down to a smooth surface. This finish work shall be done immediately after the concrete is poured.

141. **Protecting Concrete While Curing.**—Concrete floors on steel bridges and reinforced bridge tops of all descriptions and all other surfaces exposed to premature drying shall be protected from the direct rays of the sun, by means of canvas, straw, sand or other means and shall be kept continually wet for a period of at least seven days, after placing.

142. **Plain Concrete.**—For plain concrete abutments, retaining walls, etc., the following instructions shall be followed:

(a) Each layer shall be left somewhat rough to insure bonding with next layer, above; and if it be already set, shall be thoroughly cleaned and scrubbed with coarse brushes and water before the next layer is placed upon it.

(b) Concrete shall be deposited in the forms in layers of such thickness and position as shall be specified by the Engineer in charge.

(c) Temporary planking shall be placed at ends of partial layers so that none shall run out to a thin edge. In general, except in arch work, all plain concrete must be deposited in horizontal layers throughout.

(d) The work shall be carried up in sections of convenient length and each section completed without intermission.

(e) In no case shall work on a section stop within 18 inches of the top.

143. **Plums.**—Plums shall be permitted in plain concrete structures provided that their size is not greater than one-quarter of the least width of the concrete section. The concrete shall not be poured in around the plum. Plums shall be clean, hard and dense and shall be deposited by hoist into a bed of fresh concrete of such consistency as to envelop the plum to one-half its depth.

144. **Arch Construction.**—In arch construction the prevention of high stresses in the spandrel walls due to the distortion of the arch ring under dead load shall be taken care of by providing a one-half inch tar felt keyed joint at about one-third span intervals. The lowering of wedges shall be forbidden inside of a 28 day interval since the placing of the last batch of concrete in the arch ring. In addition to the above joints one-half inch tar felt keyed expansion joints shall be provided in the spandrel walls over the springing points of the arch. The arch ring shall be poured in longitudinal strips each strip being poured in one continuous operation. When necessary to prevent distortion of the arch ring while pouring concrete the forms shall be weighted down at the crown. When convenient to do so splices in the reinforcement shall be at the quarter span points.

145. **Gravity Spandrels.**—Spandrel walls for earth filled arches shall be of gravity section in order to reduce the combined stresses in the arch ring.

146. **Thickness of Gravity Walls.**—Gravity walls retaining earth fills with or without highway loading shall have a thickness not less than 0.45 of the superimposed height of wall. If the fill back of the wall is surcharged or if it carries an electric or steam railway loading this thickness shall not be less than 0.5 of said height and in case of railways carrying E50 loadings or heavier the factor shall be increased to 0.55 as a minimum.
147. **Cantilevered Wings.**—The wings of abutments shall extend not less than 2′ into the natural soil even when partially covered by a fill flowing around the outside. No reliance is to be placed on this outside fill. The cantilevering of wings from arch spandrels is not to be permitted.
148. **Reinforced Concrete.**—For reinforced concrete it is desirable to cast the structure at one operation. Whenever this is not possible on account of the size of the structure, points shall be selected in such a manner as to have the least possible effect on the strength of the structure. See 153-160 inclusive. Sections which are to be water tight shall either be poured in one continuous operation or shall be joined by a continuous waterproof membrane at all points of discontinuity in pouring operations. In this latter type of construction waterproof membrane shall always be kept available so that a complete ring of water proofing may be placed in case of tie up or discontinuity of pouring operations. Not over forty-five minutes shall elapse between placing of successive layers of concrete at any portion of a structure which is to be waterproof.
149. **Finishing.**—After the forms are removed, which should generally be as soon as possible after the concrete is sufficiently set, any small cavities or openings in the face shall be neatly filled with mortar. Any ridges due to cracks or points in the lumber may be rubbed down with a chisel or composition brick. The sooner the above operations are performed, the better will be the result.
150. **Removal of Forms.**—Forms for reinforced concrete shall remain in place longer than for plain or massive concrete, and forms for floors, beams and similar horizontal structures shall remain in place much longer than for vertical walls.
151. The following minimum time for the removal of forms (not the supporting shores) shall be as follows:
a. For bottom of slab four days for spans 4 ft. or less plus 1 day extra for each additional foot of span.
b. For sides of beams and girders 7 days.
c. For columns and piers 4 days.
d. For bridge arches 28 days.
e. For monolithic piers and abutments 36 hours.
f. The minimum time for the removal of shores shall be as follows:
g. For bottoms of beams and girders 21 days for spans of 10 ft. or less plus 1½ days for each additional foot of span.
h. The original shores must in no case be taken down, replaced or disturbed until permitted by the Engineer in charge.
i. When frosty weather occurs during the above periods an extension of time shall be made equal to its duration.
j. In special cases written permission may be given by the State Highway Commissioner to decrease the above duration of time for removal of forms.
152. **Travel on Concrete Floors.**—Travel shall not be allowed on concrete bridge floors until at least ten days have elapsed after pouring the last batch of concrete.

Details of Concrete Construction.

153. **Joints.**—Concrete construction shall, when possible, be cast in one operation.
154. When joints are necessary, they shall be so located as to have the least possible effect on the strength of the structure.
155. Joints in columns shall be made flush with the lower side of the girders.
156. Joints in girders shall be made at a point midway between supports, but should a beam intersect a girder at this point the joint shall be offset a distance equal to twice the width of the beam.
157. Joints in the members of a floor system shall in general be made at or near the center of the span.
158. Joints in columns shall be perpendicular to the axis of the column and in girders, beams and floor slabs perpendicular to the plane of their surfaces.
159. Girders shall not be constructed over freshly formed columns without permitting a period of at least two hours to elapse, thus providing for settlement or shrinkage in the columns.
160. All construction joints shall however be formed with a key of sufficient strength to take the entire maximum possible shear that may come upon the section.
161. **Contraction Joints.**—In massive work such as retaining walls, abutments, etc., built without reinforcement keyed contraction joints shall be provided at intervals of from 25 to 50 feet, and with reinforcement from 50 to 80 feet (the smaller the height and thickness, the closer the spacing) throughout the length of the structure.
162. Contraction joints shall be lubricated by an application of petroleum residuum oil or a similar material, so as to permit a free movement at the joints when the concrete expands or contracts.
163. **Splices in Reinforcement.** Whenever it is necessary to splice tension reinforcement the length of lap shall be determined on the basis of the safe working bond stress, the working strength of the bar, and the

shearing resistance of the concrete at the point of splice; or a connection shall be made between the bars of sufficient strength to develop the full strength of the bar. All laps shall be wired for their full length with No. 12 wire or equivalent and in addition all lapping bars shall be finished with standard hooks.

164. Splices at points of maximum stress shall be avoided.

165. In columns, bars more than ¾″ diameter, not subject to tension shall be properly squared and butted in a suitable sleeve, smaller bars may be treated as indicated for tension reinforcement or the stress may be cared for by embedment in large masses of concrete.

166. At foundations, bearing plates shall be provided for supporting the bars, or the bars shall be carried into the footing a sufficient distance to transmit the stress of the steel to the concrete by means of the bearing and bond resistance; in no case shall the ends of the bars be permitted merely to rest on the concrete.

167. Lengths of Beams and Columns.—The span lengths for beams and slabs simply supported should be taken as the distance from center to center of supports, but need not be taken to exceed the clear span plus the depth of beam or slab. For continuous beams the span shall be considered as the distance from center to center of supports. In no case shall any reduction of span be allowed for the effect of brackets.

168. The length of columns shall be taken as the clear, unsupported length.

169. Calculations.—Calculations shall be made with reference to working stresses and safe loads, rather than with reference to ultimate strength and ultimate loads.

170. Initial Stress.—Initial stress in reinforcement due to contraction or expansion shall be neglected.

171. Tee Beams.—In beam and slab construction an effective bond shall be provided at the juncture of the beam and slab.

172. When the principal slab reinforcement is parallel to the beam, transverse reinforcement shall be used, extending over the beam and well into the slab.

173. Where adequate bond and shearing resistance between slab and web of beam is provided, this slab may be considered as an integral part of the beam, but its width shall be determined by the following rules:

a. It shall not exceed one-fourth of the span length of the beam.

b. Its overhanging width on either side of the web shall not exceed six times the thickness of the slab.

174. Proportions of Tee Beams.—Beams in which the tee form is used only for the purpose of providing additional area of concrete shall have a width of flange not more than three times the width of the stem, and a thickness of flange not less than one-third of the depth of the beam.

175. Continuous Tee Beams.—In the design of tee beams acting as continuous beams, due consideration shall be given to the tensile and compressive stresses at the supports.

176. Floor Slabs.—Floor slabs shall, in general, be designed and reinforced as continuous over the supports and shall be designed for a bending moment equal to eight-tenths of the maximum value when considered as simply supported. A sufficient amount of steel at supports shall be placed at both upper and lower fibres to keep the bond stress within allowable limits should the slab action be either continuous or simply supported. If the length of the slab exceeds 1.5 times its width, the entire load shall be carried by the transverse reinforcement.

177. Concrete for Bridge Floors.—Concrete for bridge floors shall be mixed in the proportions of one part of cement to four and one-half parts total aggregate. When a concrete wearing surface is called for it shall be of the same proportion as the floor and shall have carefully embedded in it at mid depth the metal fabric specified to insure toughness, prevent temperature and contraction cracks and insure the supporting slab against wear by traffic. The top surface of the supporting slab shall receive a coat of hot tar before the pouring of the wearing surface is undertaken.

178. Square Slabs.—Square slabs supported on all four sides shall be reinforced in both directions.

179. Continuous Beams and Slabs.—When the beam or slab is continuous over its supports, reinforcement shall be fully provided at points of negative moment, and the stresses given in 238 shall not be exceeded.

180. In computing the positive and negative moments in beams and slabs continuous over several supports due to uniformly distributed loads, the following rules shall be followed:

a. That for floor slabs the bending moments at center and at supports shall be taken as $\frac{w\,l^2}{12}$ for both dead and live loads, where w represents the load per lineal foot and l the span length.

b. That for beams the bending moment at the center and at supports for interior spans, shall be taken as $\frac{w\,l^2}{12}$ and for end span $\frac{w\,l^2}{10}$ for center and adjoining supports, for both dead and live loads.

c. In case of beams and slabs continuous for two spans only, the bending moment at the central support shall be taken as $\frac{w\,l^2}{8}$ and near the middle of span as $\frac{w\,l^2}{10}$.

d. At the end of continuous beams the amount of negative bending moment will be left to the judgment of the designer, but it must be provided for.

e. Continuous beams and slabs designed for concentrated loads shall have their moments calculated as if they were simply supported and the resulting moment shall then be multiplied by the factor eight-twelfths or eight-tenths to give the designing moment; the factor eight-twelfths shall be used where the coefficient of $w\,l^2$ for uniform loading is one-twelfth, and the factor eight-tenths shall be used where the coefficient of $w\,l^2$ for uniform loading is one-tenth.

181. Unusual Span Lengths.—For spans of unusual lengths more exact calculations shall be made, and special consideration shall be given to concentrated loads.

182. Compression Reinforcement.—Where beams are reinforced on the compressive side, the steel shall be assumed to carry its proportion of stress in accordance with the provisions of 243.

183. Cantilever Beams.—In the case of cantilever and continuous beams tensile and compressive reinforcement must extend sufficiently beyond the support and beyond the point of inflection to develop the requisite bond strength.

184. Bond Strength and Spacing of Reinforcement.—Adequate bond strength shall be provided. The formula herein-after given for bond stresses in beams is for straight longitudinal bars. Care shall be taken to provide sufficient bars at supports in both top and bottom fibres of beams and slabs to provide for the greatest bond stresses under possible extreme conditions of loading and continuity.

185. Restrained Beams.—In restrained and cantilever beams full tensile stress exists in the reinforcing bars at the point of support, and the bars must be anchored in the support sufficiently to develop this stress. All such bars shall have hooked ends. See 192.

186. Anchorage of Bars.—Bars ending theoretically at a point where the shearing stresses are high and the bars are in tension, but the tensile stress is small, may be simply extended into the concrete 50 diameters beyond the theoretical point of ending of said bar. Bars ending theoretically at a point where the tension in the bar is large or a maximum shall be extended into the concrete 50 diameters and in addition shall be finished with a standard hook. See 192. Bars in Compression may transfer their stress by a 50 diameter embedment, and in case of a small member transferring to a large member, the compressive steel shall be flared or splayed so as to distribute the stress rapidly. No sharp bends in compressive steel shall be permitted inside of the 50 diameter limit. When stress is to be transferred by lapping of bars, the bar shall be tightly wired by not less than No. 12 wire wound spirally for a length of lap of not less than 50 diameters.

187. High Bond Resistance.—Where a high bond resistance is required the deformed bar shall be used.

188. Minimum Slab Thickness.—The total thickness of a slab shall be not less than one-thirtieth of the slab span in the direction of the principal reinforcement nor less than 4 inches.

189. Minimum Width of Beams and Girders.—The minimum width of web, in beams or girders, shall not be less than one-twenty-fourth (1/24) of the span.

190. Internal Stresses.—The internal stresses shall be calculated upon the basis of the following assumptions:

a. A plane section before bending remains plane after bending.

b. The distribution of compressive stresses in members subject to bending is rectilinear.

c. The tensile stresses in the concrete are neglected in calculating the moment of resistance of beams.

d. The depth of a beam is the distance from the compressive face to the centroid of the tension reinforcement.

e. The effective depth of a beam at any section is the distance from the centroid of the compressive stresses to the centroid of the tension reinforcement

f. The maximum shearing unit stress in beams is the total shear at the section divided by the product of the width of the section and the effective depth at the section considered. This maximum shearing unit stress is to be used in place of the diagonal tension stress in calculations for web stresses.

g. The bond unit stress is equal to the vertical shear divided by the product of the total perimeter of the reinforcement in the tension side of the beam and the effective depth at the section considered.

191. Reinforcement for Shrinkage and Temperature Stresses.—When areas of concrete too large to expand or contract freely as a whole are exposed to atmospheric conditions, the concrete shall be reinforced with not less than one-fourth of one per cent of steel. When the concrete is required to be water tight this shall be increased to one-third of one per cent. This reinforcement shall be placed near the exposed surface and be of a high bond resistance.

192. Standard Hooks.—Standard hooks on reinforcing bars shall be formed by bending 180° on a radius of three diameters of the bar and a final tangent length of four diameters of the bar.

193. Anchorage of Deformed Bars.—The length of embedment for deformed bars may be taken as forty diameters instead of fifty. Otherwise deformed bar anchorages are to be subject to the same specifications as for plain bars above.

194. Lateral Spacing.—The lateral spacing of parallel bars shall not be less than three diameters from center to center, nor shall the distance from side of beam to nearest bar be less than two diameters.

195. Spacing Between Layers of Bars.—The clear spacing between two layers of bars shall not be less than 1″ and the distance center to center of layers shall be not less than 3d, where d is the diameter of the bar.

196. Number of Layers Permitted.—The use of more than two layers will not be allowed, unless the layers are tied together by adequate metal connections, particularly at or near points where bars are bent up or down. In no case will more than three layers be permitted.

197. Spacing of Small Bars.—The spacing of small bars shall not be so close as to prevent the passing of the concrete between the bars. Bars in slabs shall not be placed closer than three inches center to center.

198. Crossing Layers.—Two layers of bars crossing each other may be in contact, and in this case the bars forming the main reinforcement shall be placed outermost.

Shear in Concrete Construction.

199. Maximum Vertical Shear.—The maximum vertical shearing stress in any section shall be used as a means of comparison of the resistance to diagonal tensile stress developed in the concrete in beams not having web reinforcement.

200. Reinforced Webs.—For reinforced webs five-sixths of the average vertical shear shall be considered as being taken by the stirrups, diagonal web pieces and bent up bars.

201. Vertical Web Reinforcement.—Web reinforcement, if vertical, shall be looped around the horizontal reinforcement.

202. Inclined Web Reinforcement.—If the reinforcement is inclined it shall be securely attached to the longitudinal rods to prevent slipping.

203. Free Ends of Stirrups.—The free ends of stirrups at points where the beam has no top reinforcement shall be turned closely through 360° to give additional bond.

204. At points where top reinforcement exists the free ends of stirrups shall be wound around the bars approximately 1½ times.

205. Shear Allowance on Web.—Properly reinforced webs will be allowed an average shearing stress from vertical shear three times as high as a plain, unreinforced web.

206. Distribution of Points of Bend.—Where the longitudinal bars are bent up, the points of bending of the several bars shall when possible without detriment to the bond or flexural strength of the beams, be distributed along the length of beam in such a way as to give as effective a web reinforcement as possible over the portion of the length of the beam in which it is most needed.

207. In connection with the bent up rods, and in addition to them, vertical stirrups shall be used to act in combination with the bent up rods.

208. Spacing of Stirrups.—The longitudinal spacing of stirrups or diagonal members, or the distribution of the points of bending of adjacent bent up bars when considered as web reinforcement, shall not exceed three-fourths of the depth of the beam.

209. Stirrups at Points of Negative Moment.—Where negative moment exists as in the case of a continuous beam at the supports, web reinforcement shall be looped over or wrapped around or be connected with the longitudinal reinforcing bars at the top of the beam. In all cases stirrups shall be looped around the tension steel.

210. Straight Shearing, and Punching Shear.—Where pure shearing stress occurs, or shearing stress combined with but a small amount of tensile stress in the concrete, as when a concentrated load rests upon a slab, or other forms of punching shear are produced, or, as in the case of such compression pieces as arch rings or arch ribs, the element of tension will not need consideration, the permissible limit of the shearing stress will be higher than the allowable limit where this stress is used as a means of comparing the diagonal tensile stress.

211.—The allowable unit stress for the above condition is given under the heading "Punching Shear" in 239g.

212. Maximum footing Projection.—When plain concrete footings are used, they shall not project farther than one-half of the height of the projecting step.

Concrete Columns.

213. Definition of Columns.—By columns are meant compression members of which the ratio of unsupported lengths to least width exceeds six, and which are provided with reinforcement of one of the forms hereinafter described.

214. Slenderness Ratio.—The ratio of unsupported length of column to its least core width shall not exceed fifteen.

215. Effective Area.—The effective area of a column shall be taken as the area within the protective covering. This shall be known as the core area.

216. Pedestal Proportions.—No plain concrete pedestals shall have a less area under coping than twice the area of the corresponding masonry plate.

217. Composite Columns.—Composite columns of structural steel and concrete in which the steel forms a column by itself shall not be classified as a reinforced concrete column.

218.—When this type of column is used the concrete shall not be relied upon to tie the steel units together, or to transmit stresses from one unit to another.

219. Working Stresses.—The following working stresses shall be used for the different types of columns:

a. Columns with longitudinal reinforcement only, to the extent of not less than one per cent, and not more than four per cent, the unit of stress for axial compression shall be as given in 235.

b. Columns with reinforcement of bands, hoops or spirals as hereinafter specified, 20% higher than given for "a," provided the ratio of the unsupported length of the column to diameter of the hooped core is not more than ten.

c. Columns reinforced with not less than 1% and not more than 4% of longitudinal bars, and with bands, hoops or spirals, as hereinafter specified; stresses 45% higher than given for *a*, provided the ratio of the unsupported length of the column to the diameter of the hooped core is not more than 8.

d. The values of the above working stresses for various classes of concrete are shown in the diagram of 245.

220. Working Stresses for Arch Rings and Ribs.—For earth filled arches the arch rings are to have a longitudinal reinforcement of not less than one per cent of the crown section. At the springing points this steel shall be increased if necessary in order to provide not less than one-fourth per cent of reinforcement in each face of the rib. Continuous radial stirrups are to be provided between the skew backs and the one quarter points. For arch ribs carrying the roadway loadings through the spandrels the above specifications for reinforcement shall hold with the exception that the radial stirrups are to be radial bands extending around all longitudianl steel and spaced at intervals not greater than one-half the smallest core dimension of the rib, said bands being used throughout the entire length of arch rib. For such arch rings or ribs the allowable unit stress shall not exceed 25% of the compressive strength of the concrete when temperature and rib shortening stresses are neglected, nor shall they exceed 32.5% when such stresses are included.

221. Longitudinal Reinforcement.—In all cases longitudinal reinforcement shall be assumed to carry its proportion of stress in accordance with 243, 244 and 222.

222. The hoops or bands shall not be counted on directly as adding to the strength of the column.

223. Fastening of Reinforcement.—Bars composing longitudinal reinforcement shall be straight and shall have sufficient lateral support to be securely held in place until the concrete has set.

224. Amount of Hooping.—Where hooping is used the total amount of such reinforcement shall be not less than 1% of the volume of the column so enclosed.

225. Spacing of Hooping.—The clear spacing of such hoops shall not be greater than 1/10 of the diameter of enclosed column with a maximum of not more than 2½".

226. Shape and Splicing of Hooping.—Hooping shall be circular and the ends of bands united in such a way as to develop their full strength.

227. Securing of Hooping.—Adequate means must be provided to hold bands or hoops in place so as to form a column, the core of which will be straight and well centered.

228. Eccentric Loads.—Bending stresses due to eccentric loads and lateral forces must be provided for by increasing the section until the maximum stress does not exceed the values given in 219-220 and where tension is possible in the longitudinal bars adequate connection between the bars must be provided to take this tension.

229. Stirrups and Bands in Arch Rings and Ribs.—No stirrups or bands shall have a smaller diameter than one-fourth inch and the volume of the steel in stirrups shall not be less than one-half per cent of the volume of the corresponding core concrete.

Unit Stresses for Concrete Bridges.

230. Allowable working Stresses.—The allowable working stresses are given as a percentage of the ultimate compressive strength of the concrete.

231. The ultimate compressive strength is to be considered as that developed by the laboratory cylinders described in 104 at an age of 28 days.

232. For the purposes of design, in general five such ultimate units will be used as given in 106 and 107. Special values may, however, be used when the character of the materials to be used warrant, providing complete data on this material is in the hands of designer before preparing plans.

233. The values of permissible unit stresses for various strengths of concrete are given in the diagram of 245.

234. Bearing.—When compression is applied to a surface of concrete of at least twice the loaded area, a stress of 32.5% of the compressive strength will be allowed.

235. Axial Compression.—For concentric compression on a plain concrete column or pier the length of which does not exceed 12 diameters, 22.5% of the compressive strength will be allowed.

236. For other forms of columns the stresses obtained from the ratios given in 219 will be allowed.

237. Compression on Extreme Fiber.—The extreme fiber stress of a beam calculated on the assumption of a constant modulus of elasticity for concrete under working stresses will be allowed to reach 32.5% of the compressive strength.

238. Adjacent to the support of continuous beams, stresses 15% higher may be used.

239. Shear and Diagonal Tension.—In calculations on beams in which a maximum shearing stress in a section is used as a means of measuring the resistance to diagonal tension stress, the following allowable values for the maximum vertical shearing stress will be allowed:

a. For beams with longitudinal rods only, and without web reinforcement 2% of the compressive strength.

b. The shearing stress per square inch to be calculated by dividing the total shear at the section by the product of the breath of beam and the lever arm of the resisting couple.

c. For beams thoroughly reinforced with web reinforcement with value of the shearing stress calculated as in b, the maximum vertical shearing stress must not exceed 12% of the compressive stress.

d. The web reinforcement exclusive of bent up bars in this case shall be proportioned to resist 5/6 of the external vertical shear, this amount to be obtained by multiplying total vertical shears by the distance center to center of stirrups, and dividing this product by the lever arm of the resisting couple.

e. If the stirrups are inclined at 45 degrees the above amount given for f, shall be multiplied by 0.7.

f. For beams in which parts of the longitudinal reinforcement is used in the form of bent up bars distributed over a portion of the beam in a way covering the requirements for this type of web reinforcement, the limit of maximum vertical shearing stress, calculated as for b, shall not exceed 3% of the compressive strength.

g. Where punching shear occurs, that is, shearing stress uncombined with compression normal to the shearing surface, and with all tension normal to the shearing plane provided for by reinforcement, a shearing stress of 12% of the compressive strength will be allowed.

240. Bond.—A bond stress between concrete and plain reinforcing bars shall not exceed 4% of the compressive strength.

241. The bond stress between concrete and drawn wire shall not exceed 2% of the compressive strength.

242. The bond stress between concrete and deformed bars of high carbon steel shall not exceed 5% of the compressive strength.

243. Stress in Reinforcing Steel.—The tensile stress in reinforcing steel shall not exceed 16,000 lbs. persquare inch. The compressive stress in reinforcing steel shall not be considered greater than the stress in the immediately surrounding concrete times the ratio of the moduli of the elasticity of steel to concrete. The values of this ratio to be used for concretes of various strength is given in 244.

244. Modulus of Elasticity of Concrete.—The value of the modulus of elasticity shall be taken as follows:

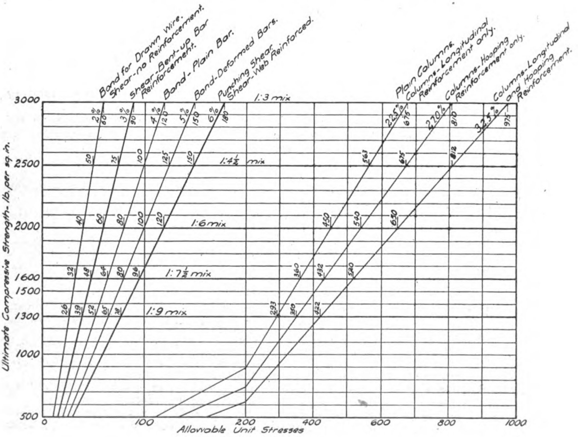
a. 1/15 of that of steel when the strength of the concrete is taken as 2,200 lbs. per square inch or less.

b. 1/12 of that of steel when the strength of the concrete is taken as greater than 2,200 and less than 2,900 lbs. per square inch.

c. 1/10 of that of steel when the strength of the concrete is taken as greater than 2,900 lbs. per square inch.

d. For deflections of beams which are free to move longitudinally at the supports, in using formulas for deflections which do not take into account the tensile strength developed in the concrete, a modulus of 1/8 of that steel may be used.

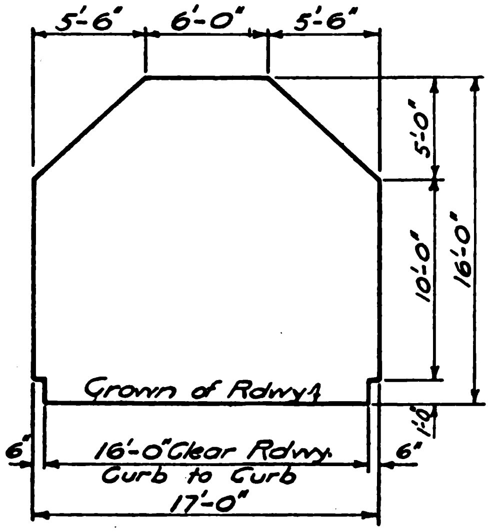
245. Diagram of Permissible Unit Stresses.—For convenience in design the following diagram has been prepared showing the allowable unit stresses in concretes of various strengths when considered for the various purposes heretofore mentioned. The common compressive values used in designare shown by heavy lines and the corresponding numerical values of permissible unit stresses are given.



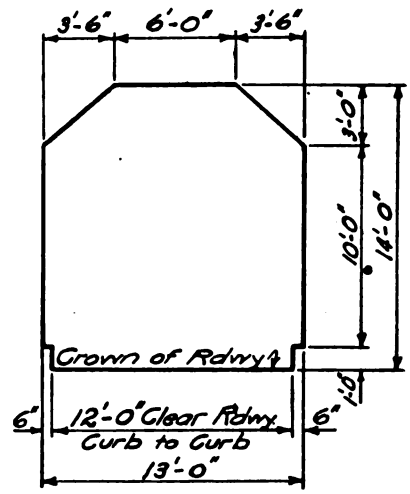
Clearances and General Proportions for Bridges.

246. Clearance.—For bridges no part of the structure shall encroach on the space indicated by the clearance diagram following and labelled "Clearance for Bridges".

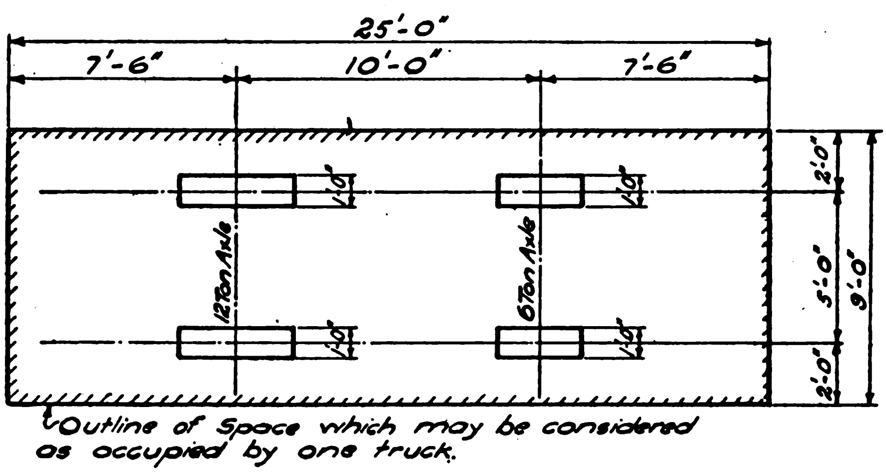
247. For under-crossings no part of the structure shall encroach on the space indicated by the clearance diagram following and labelled "Clearance for Under-Crossings."



CLEARANCE FOR BRIDGES



CLEARANCE FOR UNDER CROSSINGS



18 TON TRUCK LOADING

Note:- For 12 Ton Truck consider space and spacings as shown, and concentrations as proportional.

248. General Proportions.—The width center to center of girders or trusses shall in no case be less than one-twentieth of the effective span, nor less than is necessary to prevent overturning under the assumed lateral loading. The depth of trusses or girders shall preferably be not less than the following:

a. For rolled beams, use for I-beam spans, one-twentieth the span.
b. For plate girders, one-twelfth the span.
c. For riveted trusses, one-tenth the span.
d. For rolled beams, used as stringers or floor beams, one-fifteenth the span.
e. For pin-connected trusses, one-eighth the span.

f. For truss bridges the inclination of the diagonals with the vertical shall be preferably 45 degrees or less.

g. If shallower trusses, girders or beams are used, the section shall be increased so that the maximum deflection will not be greater than if the above limiting ratios had not been exceeded.

249. Standard Depths.—The distance from top of masonry to crown of road shall be three feet for all spans under eighty feet and five feet for all spans eighty feet or more, allowing six inches from the crown of road to top of stringers for spans under eighty feet, and eight inches for spans over eighty feet except in special cases as may be called for on plans.

Loads for Steel and Concrete Bridges.

250. Dead Load.—The dead load shall be estimated as clearly as possible and properly proportioned to the panel points.

251. When closed gutters are used an additional allowance of ten pounds per square foot shall be made for dirt or ice covering the entire roadway.

252. Live Load.—The live loads, whether uniform or concentrated, shall be considered as moving and shall be placed in position which will give the maximum stresses for each member considered.

253. The loading for the floor system and its supports shall consist of 18 ton trucks concentrated as shown in sketch and distributed to the various parts of the structure as described in 258.

254. The loading for the chord members of trusses shall consist of a floor load of 100 pounds per square foot. For spans greater than 130 feet the uniform live load may be reduced one pound for each additional 5 feet of span with a minimum of 80 pounds per square foot for spans of, or more than 230 feet. For the web members of trusses, a floor load of 115 lbs. per square foot shall be used. This may be reduced as described above.

255. The loading for sidewalks shall consist of a floor load of 100 ponds per square foot. This may be reduced as described above.

256. When electric railway loading is called for and not otherwise prescribed, the load shall consist of a series of 60 ton cars evenly distributed on two trucks with axles spaced 6.5 ft. center to center and trucks spaced 35.5 ft. center to center, the cars being assumed to occupy a space 58′x10′ each.

257. In figuring moments the effective span of floor beams shall be considered as the distance center to center of trusses and the effective spans of stringers as the distance center to center of floor beams.

258. Distribution of Live Loads.—Concentrated loadings shall be considered as distributed in the following manner:

a. **Floor slabs with main reinforcement transverse to direction of traffic.**

One or more rear truck axles, as the slab span may permit, shall be placed in such a position as to give the maximum moment in the slab, considered as a simple span. An equivalent concentrated load at the center of the span producing the same maximum moment shall then be calculated. This equivalent load shall then be considered as concentrated transverse to the direction of traffic but as distributed uniformly in the direction of traffic over a length equal to one and half feet plus sixty per cent (60%) of the span. The resulting equivalent concentrated load per inch width of slab shall be used in calculating the live load bending moment and shall also be considered as moving load which shall be placed so as to produce the maximum live load shear. The resulting live load moments are to be reduced by the factor eight tenths (8/10) if the slab is continuous over three or more supports.

b. **Floor slabs with main reinforcement parallel to direction of traffic.**

The single tread loadings for one or more trucks, as the slab span may permit, are to be placed in such a position as to give the maximum moment in the slab considered as a simple span. An equivalent concentrated load at the center of the span, producing the same maximum moment shall then be calculated. This equivalent concentrated load shall then be considered as concentrated in the direction of traffic, but as distributed uniformly transverse to the traffic over a width equal to one and one-half feet plus sixty per cent (60%) of the span. The resulting equivalent concentrated load per inch width of slab shall be used in calculating the live load bending moment and shall also be considered as a moving load which shall be placed so as to produce the maximum live load shear. The resulting live load moments are to be reduced by the factor eight-tenths (8/10) if the slab is continuous over supports but when expansion joints are placed over the floor beams no such reduction shall be made. Such expansion joints shall consist of tar paper planes of separation extending to a depth of not less than three inches below the top of the reinforced concrete slab. In all cases the edge of roadway parallel to traffic shall be reinforced by a beam forming with the edge of roadway a T beam. This beam shall be designed to carry fifty per cent (50%) of single tread traffic with an addition of twenty-five per cent (25%) for impact. The flange of this T shall have ample lateral reinforcement.

c. **For stringers parallel to traffic.**

A series of 18 ton trucks so placed as to give maximum moments or shear, treated as concentrated moving loads of a value equal to 1/10th of the axle concentration times the transverse spacing of stringers when concrete slabs are used. When a timber floor is used, the fraction of the axle concentration shall be taken as 1/6th, instead of 1/10th. All stringers are to be designed as simply supported beams. When reinforced concrete stringers are poured monolithic, however proper allowance shall be made for negative reinforcement over supports.

d. **Floor beams, floor beam hangers and stringers transverse to direction of traffic.**

For roadways over 22′ wide and under, floor beams and hangers shall be designed for two lines of 18 ton trucks to pass in such positions as to cause the maximum stresses, and in the direction of traffic, the trucks shall be so placed as to produce the greatest floor beam concentration.

When cantilevered sidewalks are used the effect of the negative moment at supports in reducing the positive bending moment in the roadway floor beams shall be neglected.

For roadways over 22′ wide and under 32′ with no electrc car track, floor beams shall be designed for one line of 18 ton trucks on center line of roadway and one line of similar 12 ton trucks on each side and as close thereto as permissible.

When a bridge is to carry electric car traffic the floor beams shall be designed for such 18 ton truck traffic as may be placed thereon in addition to a continuous line of street car traffic, all to be placed in such a manner as to produce the maximum stresses in the floor beam.

e. **Arch Rings.**

Earth filled arches with pavement shall have not less than 18″ of earth fill over the crown. When there is no pavement, there shall be not less than 2′ of fill over the crown.

For electric or steam railway loading, there shall be not less than 3′ of fill over the crown to base of low rail.

All concentrated loads may be considerd as distributed laterally through fills at the rate of ¾ horizontally to 1 vertically, extending from the edge of the wheel tread in case of a truck wheel or from the end of the tie in case of rail traffic. This distribution of loading laterally shall be considered as extending only to the depth of the crown extrados.

Longitudinally truck and electric car loadings shall be considered as uniformly distributed and in case of truck loading shall be taken as 1,500 pounds per lineal foot of truck and for electric car loading, unless otherwise specified, shall be considered as 2,500 pounds per lineal foot of car.

In additional an impact allowance of 25% shall be added to the above values for the purpose of arch analysis, but may be omitted in an analysis of the abutments and footings.

For railroad loadings, the longitudinal loadings shall be considered as made up of a 20′ length at 14,000 pounds per lineal foot of track followed by a 40′ length at 7,000 pounds per foot of track, followed by another 20′ length at 14,000 pounds per lineal foot of track, followed by an indefinite length of loading at 7,000 pounds per lineal foot of track.

To this loading shall be added an impact allowance of 50%.

f. **Formulae for Design.**

For convenience in design the following formulae are given:

1. For Max. Stringer Moment

Dead............1.5 w. b. p.^{2}

Live + Impact...0.375 C. b. p. for Panel Lengths up to 18 ft.

$$0.375\ \text{C. b. p.}\left(1.225-\frac{4.08}{p}\right)^2 \text{ for Panel Lengths over 18 ft.}$$

2. For Max. Stringer Reaction

Dead............0.5 w. b. p.

Live + Impact...0.125 C. b. up to 10 ft. panels.

$$0.187\ \text{C. b.}\left(1-\frac{3.33}{p}\right) \text{ for panels from 10 to 25 ft.}$$

3. For Max. Floor Beam Moment—22 ft. Roadway and Under.

$$\text{Dead............}\ 3\ \text{w. B. p. L.}\left(1-\frac{B}{2L}\right)$$

$$\text{Live + Impact...}11.25\ \text{C. L.}\left(1-\frac{9}{L}\right)\left(1-\frac{3.33}{p}\right) \text{ for panels from 10 ft. to 15 ft. (2 Lines of 18 Ton Trucks)}$$

$$5.62\ \text{C. L.}\left(1-\frac{3}{L}\right)\left(1-\frac{2}{L}\right)\left(1-\frac{3.33}{p}\right) \text{ for panels from 10 ft. to 15ft. (1 Line of 18 Ton Trucks).}$$

$$15.0\ \text{C. L.}\left(1-\frac{9}{L}\right)\left(1-\frac{6.26}{p}\right) \text{ for panels from 15ft. to 25 ft. (2 Lines of 18 Ton Trucks).}$$

$$7.50\ \text{C. L.}\left(1-\frac{3}{L}\right)\left(1-\frac{2}{L}\right)\left(1-\frac{6.26}{p}\right) \text{ for panels from 15 ft. to 25 ft. (1 Line of 18 Ton trucks).}$$

4. **For Max. Floor Beam Reaction.** 22 ft. Roadway and Under.

Dead............0.50 w. B. p.

Live + Impact...1.875 $\left\{1-\frac{B-15}{L}\right\}\left\{1-\frac{3.33}{p}\right\}$ C. for panels from 10 ft. to 15 ft. (2 **Lines of** 18 Ton Trucks).

2.50 $\left\{1-\frac{B-15}{L}\right\}\left\{1-\frac{6.26}{p}\right\}$ C. for panels from 15 ft. to 25 ft. (2 **Lines** of 18 Ton Trucks).

5. **For Max. Floor Beam Moment**—Roadways over 22 ft.

Dead............3. w. B. p. L. $\left\{1-\frac{B}{2L}\right\}$

Live + Impact...13.14 C. L. $\left\{1-\frac{12.44}{L}\right\}\left\{1-\frac{3.33}{p}\right\}$ for panels from 10 ft. to 15 ft. (1 **Line** of 18 Ton Trucks)—(2 Lines of 12 Ton Trucks).

17.50 C. L. $\left\{1-\frac{12.44}{L}\right\}\left\{1-\frac{6.26}{p}\right\}$ for panels from 15 ft. to 25 ft. (1 **Line** of 18 Ton Trucks)—(2 Lines of 12 Ton Trucks).

11.25 C. L. $\left\{1-\frac{9}{L}\right\}\left\{1-\frac{3.33}{p}\right\}$ for panels from 10 ft. to 15 ft. (2 **Lines** of 18 Ton Trucks).

15.0 C. L. $\left\{1-\frac{9}{L}\right\}\left\{1-\frac{6.26}{p}\right\}$ for panels from 15 ft. to 25 ft. (2 **Lines** of 18 Ton Trucks).

The following notation applies to the above formulae:

b = Stringer Spacing in feet.
p = Panel Length in feet.
B = Clear Roadway width in feet.
L = Distance c. c. Trusses in feet.

w. = Dead Load in pounds per sq. ft. of Roadway.
C = Weight of Rear Truck Axle of 18 Ton Truck = 24,000 lbs. in all Cases.
An Impact allowance of 25% is included in all Live Load Formulae.

259. **Number of Stringers Required.**—Unless otherwise specified, the srtingers or floor joists shall be composed of 5 lines of I-beams for all bridges having a 16′ roadway, 6 lines for 18′ roadway, and 7 lines for 20′ roadway.

When a plank floor is used, the stringers shall not be over 2′, center to center.

When a concrete slab floor is used, the roadway stringers shall not, in general, be over 4½′ center to center.

260. Alternate Stresses.—Members subject to alternate stresses of tension and compression shall be proprotioned for the stresses giving the larger section. If the alternate stresses occur in succession during the passing of a load each stress shall be increased by 50 per cent of the smaller. The connections shall in all cases be proportioned for the sum of the stresses.

261. Whenever the live and dead load stresses are of opposite character, only two-thirds of the dead load stresses shall be considered as effective in counteracting the live load stress.

262. Wind Force.—In trestle towers the bracing and columns shall be proportioned to resist whether loaded or unloaded, a lateral load of 100 pounds for each vertical foot of the tower in addition to the dead and live loads and the assumed lateral forces on the spans.

263. Trestle towers shall be braced in a longitudinal direction for forces not less than those assumed above for lateral bracing.

264. Lateral Forces.—A lateral force shall be assumed of 150 lbs. per linear foot of unloaded chord and 300 lbs. per linear foot of loaded chord. All lateral loads shall be treated as moving.

265. Impact.—An impact load of 25% of the specified concentrated loading shall be added to said concentrated loads for the design of all slabs, stringers, floor beams and hangers. For truss members, this impact loading is already included in the specified uniform loads per square foot.

266. An impact load of 50% of the specified electric railway loading shall be added to said loading for the design of all stringers, floor beams and hangers. For the design of truss members, an impact load of 25% shall be used.

267. Impact loads for the design of arch rings are specified in article 258e. No impact, however, is to be considered for the design of arch ribs carrying on spandrel walls a reinforced concrete roadway.

Unit Stresses and Proportion of Parts for Steel Bridges.

268. Unit Stresses.—All parts of structures shall be so proportioned that the sum of the maximum stresses produced by the foregoing loads shall not exceed the following amounts in pounds per sq. in., except as modified in 260, 278 and 279.

269. Tension.—Axial tension on net section 16,000

270. Compression.—Axial compression on gross section of columns .... $16{,}000-70\frac{l}{r}$

with a maximum of 14,000

where "l" is the length of the member in inches, and "r" is the least radius of gyration in inches.

Direct compression on steel castings 16,000

271. Bending.—Bending: on extreme fibers of rolled shapes, built sections, girders and steel castings, net section 16,000

On extreme fibres of pins 24,000

272. Shearing.—shop driven rivets and pins 12,000

Field driven rivets and turned bolts 10,000

Plate girder webs; gross section 10,000

273. Bearing.—Bearings: shop driven rivets and pins 24,000

Field driven rivets and turned bolts 20,000

Expansion rollers; per linear inch 600d

where "d" is the diameter of the roller in inches.

On masonry 400

274. Unit Stresses for Timber.—Timber beams shall in general be desinged for a fibre stress of 1,200 pounds per square inch, omitting in the design all impact loads mentioned in these specifications. For more detailed design data for timber the values of The American Railway Engineering Association as quoted for railway work shall be used. These values will be found in table V of the "Structural Engineers Handbook" by Ketchum.

275. Allowable Loads on Piling.—The allowable loads for pil ng shall be determined by the "Engineering News Formula"

For a pile driven by drop hammer $P = \frac{2Wh}{s + 1}$

For a pile driven by steam hammer $P = \frac{2Wh}{s + 0.1}$

in which P is the safe load in pounds, and W the weight of the hammer in pounds, h the height of the fall of the hammer in feet, and s the penetration or sinking in inches under the last blow assumed to be sensible and at an approximately uniform rate. When advance information in regard to foundation is lacking or indefinite, the assumed load per pile shall not exceed 15 tons and preferably not over 10 tons. In all cases, the assumed value per pile shall be plainly shown on the plans.

276. Limiting Length of Members.—The lengths of main compression members shall not exceed 100 times their least radius of gyration, and those for wind and sway bracing 120 times their least radius of gyration.

277.—The lengths of riveted tension members in horizontal or inclined positions shall not exceed 200 times their radius of gyration about the horizontal axis. The horizontal projection of the unsupported portion of the members is to be considered as the effective length.

278. Combined Stresses.—Members subject to both axial and bending stresses shall be proportioned so that the combined fiber stresses will not exceed the allowed axial stress.

279.—For stresses produced by longitudinal and lateral or wind forces combined with those for live and dead loads and centrifugal force, the unit stress may be increased 25% over those given above; but the section shall not be less than required for live and dead loads and centrifugal force at the above units.

280. Net Section.—In proportioning tension members the diameter of the rivet holes shall be taken ⅛ in. larger than the nominal diameter of the rivet.

281.—Holes shall be deducted whenever a zigzag line joining adjacent rivet holes makes an angle with the axis of the member having a cotangent less than ½.

282. Rivets.—In proportioning rivets the nominal diameter of the rivet shall be used.

283. Net Section at Pins.—Pin-connected riveted tension members shall have a net section through pin-hole at least 25 per cent in excess of the net section of the body of the member, and the net section back of the pin-hole, parallel with the axis of the member, shall be not less than the net section of the body of the member.

284. Plate Girders.—Plate girders shall be proportioned either by the moment of inertia of their net section; or by assuming that the flangers are concentrated at their centers of gravity; in which case one-eighth of the gross section of the web, if properly spliced, may be used as flange section. The thickness of web plates shall be not less than 1/160 of the unsupported distance between flange angles.

285. Compression Flange.—The gross section of the compression flanges of plate girders shall not be less than the gross section of the tension flanges; nor shall the stress per sq. in. in the compression flange of any beam or girder exceed $16{,}000-200\frac{l}{b}$, when flange consists of angles only or if cover consists of flat plates, Or $16{,}000-150\frac{l}{b}$ if cover consists of a channel section, where l = unsupported distance and b = width of flange; with a maximum of 16,000 for stringers carrying a concrete slab having their top flange supported thereby.

286. Flange Rivets.—The flanges of plate girders shall be connected to the web with a sufficient number of rivets to transfer the total shear at any point in a distance equal to the effective depth of the girder at that point combined with any load that is applied directly on the flange.

287. Web Splices.—Web splices in plate girders shall be made with two plates whose combined vertical section shall be at least one and one-half times the sectional area of the thickest web plate spliced thereby. The width of the splice plates shall be sufficient to admit not less than two rows of rivets on each side of the joint and to receive the stiffeners.

288. All web splices shall be covered by a pair of stiffeners. In addition to the web splice plates mentioned, longitudinal splice plates shall be placed over the vertical legs of the flange angles to develop the unspliced portions of the web underneath flange angles.

Details of Design for Steel Bridges.

289. Open Sections.—Structures shall be so designed that all parts will be accessible for inspection, cleaning and painting.

290. Pockets.—Pockets or depression which would hold water shall have drain holes, or be filled with waterproof material, the surface of which shall be sloped to drain.

291. Symmetrical Sections.—Main members shall be so designed that the neutral axis will be as nearly as parcticable in the center of section, and the neutral axis of intersecting main members of trusses shall meet at a common point.

292. Counters.—In panels where the main diagonals would under certain conditions of loading undergo a reversal of stress, these diagonals shall consist of stiff shapes and they shall be riveted to the chords and posts. No counters will be permitted except in the case of the middle panel of a span having an odd number of panels. In this case both diagonals shall consist of stiff shapes and each shall be designed for one-half the maximum panel shear in compression. They shall be properly connected at their intersections.

293. Strength of Connections.—The strength of connections shall be sufficient to develop the full strength of the member, even though the computed stress is less, the kind of stress to which the member is subjected being considered.

294. Minimum Thickness.—The minimum thickness of metal shall be three-eighths inch, except for fillers and lattice bars, and for the following items.

a. Five-sixteenths inch metal will be allowed for buckled plates with concrete filling.

b. Five-sixteenths inch metal will be allowed for top laterals, portal webs and brackets, if situated entirely above floor.

c. For the bars of latticed handrailings one-fourth inch metal will be allowed.

295. Pitch of Rivets.—The minimum distance between centers of rivet holes shall be three diameters of the rivet; but the distance shall preferably be not less than 3 inches for ⅞ inch rivets and 2½ inches for ¾ inch rivets. The maximum pitch in the line of stress for members composed of plates and shapes shall be 6 inches for ⅞ inch rivets and 5 inches for ¾ inch rivets. For angles with two gage lines and rivets staggered, the minimum shall be twice the above in each line. Where two of more plates are used in contact, rivets not more than 12 inches apart in either direction shall be used to hold the plates well together. In tension members, composed of two angles in contact, a pitch of 12 inches will be allowed for riveting the angles together.

296. Edge Distance.—The minimum distance from the center of any rivet hole to a sheared edge shall be 1½ inches for ⅞ inch rivets and 1¼ inches for ¾ inch rivets, and to a rolled edge 1¼ inches and 1⅛ inches respectively. The maximum distance from any edge shall be eight times the thickness of the plate, but shall not exceed 6 inches.

297. Maximum Diameter.—The diameter of the rivets in any angle carrying calculated stress shall not exceed one-quarter the width of the leg in which they are driven. In minor parts ⅞ inch rivets may be used in 3 inch angles, and ¾ inch rivets in 2½ inch angles.

298. Long Rivets.—Rivets carrying calculated stress and whose grip exceeds four diameters shall be increased in number at least one per cent for each additional 1/16 inch of grip.

299. Pitch at Ends.—The pitch of rivets at the ends of built compression members shall not exceed four diameters of the rivets, for a length equal to one and one-half times the maximum width of member.

300. Compression Members.—In compression members the metal shall be concentrated as much as possible in webs and flanges. The thickness of each web shall be not less than one-thirtieth of the distance between its connections to the flanges. Cover plates shall have a thickness not less than one-fortieth of the distance between rivet lines. For low trusses it shall be preferable to use two rivet double lacing instead of a cover plate.

301. Minimum Angles.—Flanges of girders and built members without cover plates shall have a minimum thickness of one-twelfth of the width of the outstanding leg. No angle less than 3½" x 3" x ⅜" shall be used in any main truss member or in any part of the roadway floor system or bottom lateral system.

302. Tie Plates.—The open sides of compression members shall be provided with double lacing and shall have battens as near each end as parcticable and at all intermediate points of concentrated loading or when lacing is interrupted. End batten plates shall have a length not less than one and one-half times the distance between the lines of rivets connecting them to the flanges and intermediate battens shall have a length not less than the distance between said lines of rivets.

303. Tension members may have either single or double lacing, and shall be provided with tie plates at the ends and at all points of interrupted lacing. End tie plates shall have a length not less than the distance between rivet lines connecting the plates to the flanges and no intermediate tie plates shall have a length less than one-half of this distance. When the component parts to be connected are separated by a clear distance less than five inches, the lacing for tension members may be replaced by minimum tie plates, spaced at intervals not exceeding three times the width of the face being laced.

304. The thickness of batten and tie plates shall not be less than one-fiftieth of the distance between rivet lines connecting the plates to the flanges.

305. Lacing.—The latticing of compression members shall be proportioned to resist the shearing stresses corresponding to the allowance for flexure for uniform load provided in the column formula in paragraph 187 by the term $70\frac{l}{b}$. The minimum width of lattice bars shall be 2½ inches for ⅞ inch rivets, 2¼ inches for ¾ inch rivets and 2 inches for ⅝ inch rivets. The thickness shall not be less than one-fortieth of the distance between end rivets for single lattice, and one-sixtieth for double lattice. Shapes of equivalent strength may be used.

306. Five-eighths inch rivets shall be used for latticing flanges less than 2½ inches wide, and ¾-inch rivets for flanges fron 2½ to 3½ inches wide; ⅞ inch rivets shall be used in flanges 3½ inches and over, and lattice bars with at least two rivets shall be used for flanges over 5 inches wide.

307. The inclination of lacing bars with the axis of the member shall be not less than sixty degrees for single lacing nor less than forty-five degrees for double lacing, and when the distance between rivet lines in the flanges is more than twelve inches, the lattice shall be double and riveted at the intersection.

308. The lattice bars shall be so spaced that the portion of the flange included between their connections shall be as strong as the member as a whole. In single lacing the bars may or may not overlap each other.

309. Faced Joints.—Abutting joints in compression members shall be faced for bearing and in addition shall be spliced to develop the full strength of the abutting members. All other joints in riveted work whether in tension or compression shall be fully spliced.

310. Pin Plates.—Pin-holes shall be reinforced by plates where necessary, and at least one plate shall be as wide as the flanges will allow and be on the same side as the angles. They shall contain sufficient rivets to distrubute their portion of the pin pressure to the full cross-section of the member.

311. Forked Ends.—Forked ends on compression members will be permitted only where unavoidable; where used, a sufficient number of pin plates shall be provided to make the jaws of twice the sectional area of the member. At least one of these plates shall extend to the far edge of the farthest tie-plate, and the balance to the far edge of the nearest tie-plate, but not less than six inches beyond the near edge of the farthest plate. Batten or tie-plates at the ends of members connecting to gusset plates and at right angles to the plane of the truss shall extend not less than one foot inside of said gussets.

312. Pins.—Pins shall be long enough to insure a full bearing of all the parts connected upon the turned body of the pin. They shall be secured by chambered nuts or be provided with washers if solid nuts are used. The screw ends shall be long enough to admit of burring of threads. No pin less than four inches in diameter shall be used.

313. Members packed on pins shall be held against lateral movement.

314. Field Connections.—All field connections shall be made with rivets unless otherwise specified.

315. Bolts.—Where members are connected by bolts, the turned body of these bolts shall be long enough to extend through the metal. A washer at least ¼ in. thick shall be used under the nut. Bolts shall not be used in place of rivets except by special permission. Heads and nuts shall be hexagonal.

316. Indirect Splices.—Where splice plates are not in direct contact with the parts which they connect, rivets shall be used on each side of the joint in excess of the number theoretically required to the extent of one-third of the number for each intervening plate.

317. Fillers.—Rivets carrying stress and passing through fillers shall be increased 50 per cent in number; and the excess rivets, when possible, shall be outside of the connected member.

318. Expansion.—Provision for expansion to the extent of ⅛ in. for each 10 ft. shall be made for all bridge structures. Efficient means shall be provided to prevent excessive motion at any one point.

319. Expansion Bearing.—Spans of 80 ft. and over resting on masonry shall have turned rollers or rockers at one end; and those of less length shall be arranged to slide on smooth surfaces. These expansion bearings shall be designed to permit motion in one direction only.

320. Fixed Bearings.—Fixed bearings shall be firmly anchored to the masonry.

321. Rollers.—Rollers shall be segmental and, whenever possible, be 6 inches in diameter. They shall be protected by substantial side bars arranged so that rollers may be readily cleaned and shall be geared to the upper and lower plates.

322. Bolsters.—Bolsters or shoes shall be so constructed that the load will be distributed over the entire bearing. Spans of fifty feet or over shall have hinged bolsters at each end. Both upper and lower sections of end shoes shall preferably be of cast steel—annealed.

323. Wall Plates.—Wall plates shall preferably be of cast steel—annealed; and shall be so designed as to distribute the load uniformly over the entire bearing. They shall be secured against displacement.

324. Anchorage.—Anchor bolts for viaduct towers and similar structures shall be long enough to engage a mass of masonry the weight of which is at least one and one-half times the uplift.

325.—Anchor bolts shall have a total area of cross-section sufficient to resist in shear two-tenths of the maximum reaction. They shall have a net embedment in masonry not less than twelve inches. No anchor bolts for bridge spans shall be less than one and one-fourth inches in diameter.

326. Inclined Bearings.—Bridges on an inclined grade without pin shoes shall have the sole plates beveled so that the masonry and expansion surfaces may be level.

327. Dragging Grades.—For bridges built on grades, the expansion abutment shoe shall always be placed on the upgrade abutment. This is to prevent the tendency of traffic to pull in the upgrade abutment.

328. Sheet Lead.—A sheet of lead ¼″ thick shall be placed between the castings or pedestals and the masonry.

329. Continuous Bearing Plates.—When two spans rest on the same masonry surface, they shall have a continuous masonry plate extending under both pedestals. This plate shall in general, be three-fourth inches thick.

Floor System for Steel Bridges.

330. Floor Beams.—Floor beams shall preferably be square to the trusses or girders. They shall be riveted directly to the girders or trusses or may be placed on top of deck bridges. They shall preferably be of Standard or Bethlehem rolled I-beam shapes. All trusses shall have end floor beams. The use of end shoe struts shall not be permitted.

331. Stringers.—Stringers shall be riveted to the webs of all intermediate floor beams by means of connection angles not less than 1½″ in thickness. Shelf angles or other supports provided to support the stringer during erection shall not be considered as carrying any of the reaction.

Bracing for Steel Bridges.

332. Rigid Bracing.—Lateral, longitudinal and trasverse bracing in all structures shall be composed of rigid members.

333. Portals.—The portal bracing of through bridges shall be of sufficient strength to transmit the accumulated wind stress from the upper lateral system to the end shoes.

334. Style of Portal.—Portals shall preferably be of the A type, or modification of same and shall lie in the central plane of the end posts.

335. Portal Connections.—At knee connections to the end posts, the end posts shall be provided with battens if a double plane portal is used or with a plate and angle diaphragm if a single plane portal is used.

336. Transverse Bracing.–Intermediate transverse frames shall be used at each panel of through spans having vertical truss members where the clearance will permit.

337. Brackets.—All transverse bracing shall be provided with either knees or corner brackets extending downward and outward as far as the clearance will permit.

338. End Bracing.—Deck spans shall have transverse bracing at each end proportioned to carry the lateral load to the support.

339. Laterals.—The minimum sized angle to be used in lateral bracing shall be 3½ x 3 x ⅜ in. for bottom laterals, and 3½ x 3 x 5/16 in. for top laterals. Not less than three rivets through each end of the angles shall be used at the connection. Bottom laterals shall have sufficient rivets to develop the strength of the member.

340. Tower Struts.—The struts at the foot of viaduct towers shall be strong enough to slide the movable shoes when the track is unloaded.

Plate Girders.

341. Camber.—All plate girders shall be cambered an amount equal to one-twelve hundredth (1/1200) of the span.

342. Top Flange Cover.—Where flange plates are used, one cover plate of top flange shall extend the entire length of the girder for deck plate girders and full length of ends for through plate girders with rounded corners.

343. Web Stiffeners.—There shall be web stiffeners, generally in pairs, over bearings, at points of concentrated loading, and at other points where the thickness of the web is less than 1/60 of the unsupported distance between flange angles. The distance between stiffeners shall not exceed that given by the following formula, with a maximum limit of six feet (and not greater than the clear depth of the web):

$$d = \frac{t}{40}(12{,}000-s),$$

Where d = clear distance, between stiffeners or flange angles.
t = thickness of web.
s = shear per sq. in.

344. The stiffeners at ends and at points of concentrated loads shall be proportioned by the formula of 270, the effective length being assumed as one-half the depth of girders. End stiffeners and those under concentrated loads shall be on fillers and have their outstanding legs as wide as the flange angles will allow and shall fit tightly against them. Intermediate stiffeners may be offset or on fillers, and their outstanding legs shall be not less than one-thirtieth of the depth of girder plus 2 in.

345. The size of intermediate stiffeners shall preferably be as follows:
When horizontal leg of flange angle is 8 inches use stiffener angle 6 x 3½ x ⅜.
When horizontal leg of flange angle is 6 inches use stiffener angle 5 x 3½ x ⅜.
When horizontal leg of flange angle is 5 inches use stiffener angle 4 x 3½ x ⅜.
When horizontal leg of flange angle is 4 inches use stiffener angle 3½ x 3 x ⅜.

346. Stays for Top Flange.—Through plate girders shall have their top flanges stayed at each end of every floor beam, or in case of solid floors at distances not exceeding 16 ft., by knee braces or gusset plates.

Low Trusses without Overhead Bracing.

347. Camber.—All low trusses shall be cambered an amount equal to one-nine hundredths (1/900) of the span.

348. Top Chord Bracing.—Top chords shall be stayed by inside knee braces or gusset plates which extend the full depth of the truss and rivet directly to the web of the floor beam. These stays shall be placed over both ends of every floor beam and shall be designed to carry the entire assumed lateral loading of the top chord.

349.—The top chord of low trusses without overhead bracing shall have a ratio of length of top chord, including end posts to the radius of gyration about a vertical axis of symmetry not less than two hundred. The vertical posts of the truss shall extend well up inside the top chord.

350. Style of Truss.—All low trusses shall be riveted structures, with double webbed chords and shall have all web members laced or otherwise effectively stiffened. They shall preferably be of the Pratt type of bracing with comparatively short panels.

High Trusses with Overhead Bracing.

351. Camber.—All trusses shall be cambered an amount equal to one-six hundredths (1/600) of the span.

352. Rigid Members.—Hip verticals and similar members, and the two end panels of the bottom chords of pin-connected trusses shall be rigid.

353. Eye-Bars.—The eye-bars composing a member shall be so arranged that adjacent bars shall not have their surfaces in contact; they shall be as nearly parallel to the axis of the truss as possible, the maximum inclination of any bar being limited to one inch in 16 ft.

Material for Steel Bridges.

354. Specifications.—All material shall conform to the "Standard Specifications for Structural Steel for Bridges" adopted by The American Society for Testing Material 1916 or any later revision thereof. Partial abstracts from these specifications follow.

355. Grade of Steel.—The material of steel superstructures shall be of structural grade, except rivets, and as may be otherwise specified.

356. Manufacture.—All steel shall be made by the open-hearth process.

357. Chemical Composition.—The steel shall conform to the following requirements as to chemical composition:

Elements Considered.	Structural Steel	Rivet Steel
Phosphorus, max., per cent:		
Basic open hearth	0.04	0.04
Acid open hearth	0.06	0.04
Sulphur, max., per cent	0.05	0.040

358. Ladle Analyses.—To determine whether the material conforms to the requirements specified, an analysis shall be made by the manufacturer from a test ingot taken during the pouring of each melt. A copy of this analysis shall be given to the purchaser or his representative, if requested.

359. Check Analyses.—A check analysis of steel may be made by the purchaser from finished material representing each melt, in which case an excess of 25 per cent above the requirements specified shall be allowed.

360. Physical Properties and Tests.—The steel shall conform to the following requirements as to tensile properties:

Properties Considered	Structural Steel	Rivet Steel
Tensile strength, lb. per sq. in.	55,000 — 65,000	48,000 — 58,000
Yield point, minimum lb. per sq. in.	0.5 tens. str.	0.5 tens. str.
Elongation in 8 in., min. per cent	$\frac{1,500,000}{\text{Tens. str.}}$	$\frac{1,500,000}{\text{Tens. str.}}$
Elongation in 2 in., min. per cent	22	

361. Yield Point.—The yield point shall be determined by the drop of the beam of the testing machine.

362. Modifications in Elongation.—For material over ¾ in. in thickness, a deduction of 1 from the percentage of elongation in 8 in. specified for structural steel shall be made for each increase of ⅛ in. in thickness above ¾ in.

363.—For material under 5/16 in. in thickness, a deduction of 2.5 from the percentage of elongation in 8 in. specified for structural steel shall be made for each decrease of 1/16 in. in thickness below 5/16 in.

364. Character of Fracture.—All broken tension test specimens shall show a silky fracture.

365. Bend Tests—Character of Fracture.—The test specimen for plates, shapes and bars shall bend cold through 180 deg. without fracture on the outside of the bent portion, as follows: For material ¾ in. and under in thickness, flat on itself; for material over ¾ in. up to 1¼ in. in thickness, around a pin the diameter of which is equal to 1½ times the thickness of the specimen; and for material over 1¼ in. in thickness, around a pin the diameter of which is equal to twice the thickness of the specimen.

366. The test specimen for pins and rollers shall bend cold through 180 deg. around a 1-in. pin without fracture on the outside of the bent portion.

367. A rivet rod shall bend cold through 180 deg. flat on itself without fracture on the outside of the bent portion.

368. Bend tests may be made by pressure or by blows.

369. Test Specimens.—Tension and bend test specimens shall be taken from the finished rolled or forged product, and shall not be annealed or otherwise treated, except as specified for annealed specimens.

370. Annealed Specimens.—Test specimens for material which is to be annealed or otherwise treated before use, shall be cut from properly annealed or similarly treated short lengths of the full section of the piece.

371. Number of Tests.—At least one tension test and one bend test shall be made from each melt. If material from one melt differs ⅜ in. or more in thickness, tests shall be made from both the thickest and the thinnest material rolled.

372. If any test specimen develops flaws, or if an 8-in. tension test specimen breaks outside the middle third of the gage length, or if a 2-in. tension test specimen breaks outside the gage length, it may be discarded and another specimen substituted therefor.

373. Material intended for fillers or ornamental purposes will not be subject to test.

374. Permissible Variations in Weight and Gage.—The cross-section or weight of each piece of steel shall not vary more than two and five tenths per cent from that specified; except in the case of sheared plates, which shall be covered by the following permissible variations to apply to single plates.

375. When Ordered to Weight.—For plates twelve and one-half pounds per square foot or over:

Under 100 inches in width, two and five-tenths per cent above or below the specified weight;

100 inches in width or over, five per cent above or below the specified weight.

For plates under twelve and one-half pounds per square foot:

Under 75 inches in width, two and five-tenths per cent above or below the specified weight;

75 to 100 inches, inclusive, in width, five per cent above or three per cent below the specified weight;

100 inches in width or over, ten per cent above or three per cent below the specified weight.

376. When Ordered to Gage.—The thickness of each plate shall not vary more than one one-hundreths inches 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 the following table, one cubic inch of rolled steel being assumed to weigh 0.2833 pounds. (Not copied here.)

377. Finish.—The finished material shall be free from injurious defects, and shall have a workmanlike finish.

378. Marking.—The name of the manufacturer and the melt number shall be legibly marked, stamped or rolled upon all finished material, except that each pin and roller shall be stamped on the end. Rivet and lattice steel and other small pieces may be shipped in securely fastened bundles, with the above marks legibly stamped on attached metal tags. Test specimens shall have their melt numbers plainly marked or stamped.

379. Inspection.—The inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests except check analyses and inspection shall be made at the place of manufacture prior to shipment, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

380. Rejection and Rehearing.—Unless otherwise specified, any rejection based on tests made in accordance with these specifications shall be reported within five working days from the receipt of samples.

a. The material which shows injurious defects subsequent to its acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

b. Rehearing. Samples, tested in accordance with these specifications which represent rejected material, shall be preserved for two weeks from the date of the test report. In case of dissatisfaction with the results of the tests, the manufacturer may make claim for a rehearing within that time.

381. Castings.—All castings shall be of steel and shall conform to the "Standard Specifications for Steel Castings" of the American Society for Testing materials as adopted in 1916, and with all subsequent revisions.

382. Timber.—All timber in the permanent structure shall be of first grade quality, containing only sound wood of high density, containing no sound knots larger in diameter than one-fourth of the width of the timber face in which knot appears, and no loose knots larger than one-twelfth of said face. Checks and shakes at ends of beams shall be restricted to not more than one-third the face of the timber.

383. Bituminous Material.—All bituminous materials shall conform to the requirements specified in "Specifications for Road Construction" of the Michigan State Highway Department, 1919.

384. Paving.—Excepting as otherwise specified, all paving and paving materials shall conform to "Specifications for Road Construction" of the Michigan State Highway Department, 1919.

Workmanship for Steel Bridges.

385. General.—All parts forming a structure shall be built in accordance with approved drawings. The workmanship and finish shall be equal to the best practice in modern bridge works.

386. Straightening Material.—Material shall be thoroughly straightened in the shop, by methods that will not injure it, before being laid off or worked in any way.

387. Finish.—Shearing and chipping shall be neatly and accurately done and all portions of the work exposed to view neatly finished. This shall also apply to the edges of all curved gussets.

388. Size of Rivets.—The size of rivets, called for on the plans, shall be understood to mean the actual size of the cold rivet before heating.

389. Rivet Holes.—When general reaming is not required, the diameter of the punch shall not be more than 1/16-in. greater than the diameter of the rivet; nor the diameter of the die more than ⅛-in. greater than the diameter of the punch. Material more than ¾-in. thick shall be sub-punched and reamed or drilled from the solid.

390. Punching.—Punching shall be accurately done. Drifting to enlarge unfair holes will not be allowed. If the holes must be enlarged to admit the rivet, they shall be reamed. Poor matching of holes will be cause for rejection.

391. Reaming.—Where sub-punching and reaming are required, the punch used shall have a diameter not less than 3/16-in. smaller than the nominal diameter of the rivet. Holes shall then be reamed to a diameter not more than 1/16-in. larger than the nominal diameter of the rivet. See 405.

392. Reaming.—All field splices and connections in main trusses and girders shall be subpunched, the work assembled in the shop, and while so assembled, reamed to correct cambered fits.

393. Reaming After Assembling.—When general reaming is required it shall be done after the pieces forming one built member are assembled and so firmly bolted together that the surfaces shall be in close contact. If necessary to take the pieces apart for shipping and handling, the respective pieces reamed together shall be so marked that they may be reassembled in the same position in the final setting up. No interchange of reamed parts will be permitted.

394. Removing Burrs.—The outside burrs on reamed holes shall be removed to the extent of making a 1/16-in. fillet.

395. Assembling.—Riveted members shall have all parts well pinned up and firmly drawn together with bolts before riveting is commenced. Contact surfaces are to be painted. See 427.

396. Lacing Bars.—Lacing bars shall have neatly rounded ends, unless otherwise shown or called for.

397. Web Stiffeners.—Stiffeners shall fit neatly between flanges of girders. Where tight fits are called for, the ends of the stiffeners shall be faced and shall be brought to a true contact bearing with the flange angles.

398. Splice Plates and Fillers.—Web splice plates and fillers under stiffeners shall be cut to fit within ⅛-in. of flange angles.

399. Web Plates.—Web plates of girders, which have no cover plates, shall be flush with the backs of angles or project above the same not more than ⅛-in. unless otherwise called for. When web plates are spliced, not more than ¼-in. clearance between ends of plates shall be allowed.

400. Riveting.—Rivets shall be uniformly heated to a light cherry red heat in a gas or oil furnace so constructed that it can be adjusted to the proper temperature. They shall be driven by pressure tools. Pneumatic hammers shall preferably be used and in no case will hand driving be permitted.

401.—Rivets shall look neat and finished, with heads of approved shape full and of equal size. They shall be central on shank and grip the assembled pieces firmly. Recupping and calking will not be allowed. Loose, burned or otherwise defective rivets shall be cut out and replaced. In cutting out rivets, great care shall be taken not to injure the adjacent metal. If necessary, they shall be drilled out.

402. Turned Bolts.—Wherever bolts are used in place of rivets which transmit shear, the holes shall be reamed parallel and the bolts shall be made a driving fit, with the threads entirely outside of the holes. A washer not less than ¼-in. thick shall be used under nut.

403. Members to be Straight.—The several pieces forming one built member shall be staight and fit closely together, and finished members shall be free from twists, bends or open joints.

404. Finish of Joints.—Abutting joints shall be cut or dressed true and straight and fitted closely together, especially where open to view. In compression joints, depending on contact bearing, the surfaces shall be truly faced, so as to have even bearings after they are riveted up complete and when perfectly aligned. The riveting requirements of 309 shall not be considered as a waiver of this clause.

405. Field Connections.—Holes for floor beam and stringer connections shall be subpunched and reamed according to 391, to a steel templet not less than one inch thick.

406. Eye-Bars.—Eye-bars shall be straight and true to size, and shall be free from twists, folds in the neck or head, or any other defect. Heads shall be made by upsetting, rolling or forging. Welding will not be allowed. The forms of heads will be determined by the dies in use at the works where the eye-bars are made, if satisfactory to the engineer, but the manufacturer shall guarantee the bars to break in the body when tested to ruptured. The thickness of head and neck shall not vary more than 1/16-in. from that specified.

407. Boring Eye-Bars.—Before boring, each eye-bar shall be properly annealed and carefully straightened. Pin-holes shall be in the center line of bars and in the center of heads. Bars of the same length shall be bored so accurately that, when placed together, pins 1/32-in. smaller in diameter than the pin-holes can be passed through the holes at both ends of the bars at the same time without forcing.

408. Pin Holes.—Pin-holes shall be bored true to gages, smooth and straight; at right angles to the axis of the member and parallel to each other unless otherwise called for. The boring shall be done after the member is riveted up.

409. The distance center to center of pin-holes shall be correct within 1/32-in. and the diameter of the holes not more than 1/50-in. larger than that of the pin, for pins up to 5-in. diameter, and 1/32-in. for larger pins.

410. Pins and Rollers.—Pins and rollers shall be accurately turned to gages and shall be straight and smooth and entirely free from flaws.

411. Screw Threads.—Screw threads shall make tight fits in the nuts and shall be U. S. standard, except above the diameter of 1⅜ in., when they shall be made with six threads per inch.

412. Annealing.—Steel, except in minor details, which has been partially heated, shall be properly annealed.

413. Steel Castings.—Steel castings shall be free from large or injurious blow-holes and shall be annealed.

414. Welds.—Welds in steel shall not be allowed.

415. Bed Plates.—Expansion bed plates shall be planed true and smooth. Cast wall plates shall be planed top and bottom. The finishing cut of the planing tool shall be fine and correspond with the direction of expansion.

416. Pilot Nuts.—Pilot and driving nuts shall be furnished for each size of pin, in such numbers as may be ordered.

417. Field Rivets.—Field rivets shall be furnished to the amount of 15 per cent plus ten rivets in excess of the nominal number required for each size.

418. Shipping Details.—Pins, nuts, bolts, rivets and other small details shall be boxed or crated and properly marked for identification.

419. Weight.—The scale weight of every piece and box shall be marked on it in plain figures.

420. Finished Weight.—Payment for pound price contracts shall be by scale weight. No allowance over 2 per cent of the total weight of the structure as computed from the plans will be allowed for excess weight.

Preservation of Materials.

421. Preservation of Timbers.—Where preservation of timbers is specified, it shall be creosoted by the full-cell process absorbing not less than twelve pounds of oil per cubic foot of timber.

422.—All paints for timber work shall consist of a white lead base mixed with pure linseed oil. A standard ready mixed paint may be used subject to the approval of the State Highway Commissioner.

423. Shop Painting.—Steel work, before leaving the shop, shall be thoroughly cleaned and given one good coating of painting mixture, No. 1, well worked into all joints and open spaces.

424. Field Painting.—Two field coats of paint shall be required: the first of painting mixture No. 2 and the second or final coat of painting mixture No. 3.

425. Painting Mixtures.—Paint for steel structures shall conform to the following specifications:

a. Painting mixture No. 1 shall be red in color and shall consist of red lead not less than 94% pure red lead and not more than one-half of one per cent of materials other than oxide or carbonate of lead and not less than 99 per cent shall wash through a sieve of two hundred meshes to the inch. If dry red lead is used it shall be mixed in a proportion of twenty eight pounds of pigment to one gallon of pure raw linseed oil, and if paste red lead is used, forty pounds of paste containing only pure red lead and six to seven per cent of linseed oil, with one gallon of pure linseed oil, and to a gallon of paint may be added one-third of a pint of pure turpentine and one-third of a pint of drier free from resin.

b. Painting mixtures No. 2 and No. 3 shall be light gray in color, of just sufficient distinction in shade to facilitate inspection, and the paint formulae proposed shall be submitted to State Highway Commissioner for approval.

426. Substitutions.—No substitutions shall be permitted for Painting Mixture No. 1.

427. Contact Surfaces.—In riveted work, the surfaces coming in contact shall each be painted before being riveted together.

428. Inaccessible Surfaces.—Pieces and parts which are not accessible for painitng after erection, including tops of stringers and floor beams, eye-bar heads, ends of posts and chords, etc., shall have an additional coat of paint before leaving the shop.

429. Condition of Surfaces.—Painting shall be done only when the surface of the metal is perfectly dry. It shall not be done in wet or freezing weather, unless protected under cover. No rust pitted material will be accepted. All scale and rust shall be thoroughly cleaned from the materials before painting will be permitted.

430. Machine-Finished Surfaces.—Machine-finished surfaces shall be coated with white lead and tallow before shipment or before being put out into the open air.

Inspection and Testing at the Shops.

431. Facilities for Inspection.—The manufacturer shall furnish all facilities for inspecting and testing the weight and quality of workmanship at the shop where material is manufactured. He shall furnish a suitable testing machine for testing full-sized members, if required.

432. Starting Work.—The purchaser shall be notified well in advance of the start of the work of the shop, in order that he may have an inspector on hand to inspect material and workmanship.

433. Access to Shop.—When an inspector is furnished by the purchaser, he shall have full access, at all times, to all parts of the shop where material under his inspection is being manufactured.

434. Accepting Material.—The inspector shall stamp each piece accepted with a private mark. Any piece not so marked may be rejected at any time and at any stage of the work. If the inspector, through an oversight or otherwise, has accepted material or work which is defective or contrary to the specifications, this material, no matter in what stage of completion, may be rejected by the purchaser.

435. Shipping Invoices.—Complete copies of shipping invoices shall be furnished to the purchaser with each shipment. These shall show the scale weights of individual pieces.

Full-Sized Tests.

436. Eye-Bar Tests.—Full-sized tests on eye-bars and similar members to prove the workmanship, shall be made at the manufacturer's expense, and shall be paid for by the purchaser at contract price, if the tests are satisfactory. If the tests are not satisfactory, the members represented by them will be rejected.

SPECIFICATIONS FOR MOVABLE BRIDGES

SPECIFICATIONS FOR MOVABLE BRIDGES.

General Clauses.

437. Scope.—These specifications are intended to cover single or double leaved bascule bridges of the simple trunnion type without linkages, and bridges which swing in a horizontal plane.

438. Drawings.—The Contractor shall furnish complete working drawings for all structural steel work. He shall make conplete detail drawings of the machinery so that any other shop can take them and duplicate the machinery. The electrical contractor shall submit for approval complete plans with details and specifications showing the wiring and the parts he proposes to install. Plans for electrical work shall be submitted within twenty (20) days of signing of contract. Within another ten (10) days Contractor shall submit curves and data on motor performance. In addition, the Contractor is to be governed by 5 and 6 of the general specifications.

439.—The plans furnished by the State Highway Commission shall be carefully checked by the Contractor for clearances and dimensions before beginning work. Should any errors or discrepancies be found, the attenion of the Engineer shall be called to such errors, after which the Contractor shall be responsible for all errors which may occur or have occurred.

440.—If the Contractor for Erection has any objection to any features of the machinery, as designed, he must state his objections to the State Highway Commissioner within ten days after signing his contract; otherwise his objections will be ignored, if offered later as an excuse for defective erection, adjustment, or operation.

441. Acceptance Test.—The working of the machinery and its efficiency to operate the bridge shall be tested to prove that it fulfils the specified requirements.

441a.—The Contractor for Erection shall also maintain all machinery in adjustment and shall perform all labor and operate the bridge for a period of 60 days after it has been accepted and put into service without additional payment therefor.

442. Specifications.—The General Specifications for Steel and Concrete Highway Bridges, Michigan State Highway Department, 1920, shall apply to movable bridges except for additions and modifications as contained herein.

443. Shipping Weights.—Triplicate copies of all shipping invoices containing an itemized statement of shipping weights shall be furnised by the Contractor.

444. Erection.—The method of erection will in general be left to the discretion of the Contractor, but no work shall be commenced until such method has been submitted to and approved by the Engineer; but such approval shall not relieve the Contractor of any responsibility.

445.—Particular care must be taken to secure perfect adjustment and centering of all trunnions and pins and to provide ample clearance and easy operation of all moving parts.

446.—Before starting the erection, the Contractor for erection shall check the elevation of all masonry supports and the alignment of all anchor bolts and columns, and if any error is found, he shall notify the Engineer and cause such errors to be corrected. The Contractor for erection shall be responsible for the proper alignment of all parts of the structure.

Manner of Bidding.

447. Parts Classified as Machinery.—Eccentrics, pivots, trunnions and their cast supports, shafting, gear wheels, cast racks, boxes, bearings, couplings, clutches, levers, discs, cast sheaves and wheels, worm gearing, valves, pins about whoses axis the connecting members rotate, whistles, cast machinery supports, end bridge locks, wedges, indicators, cranks, axles, hooks, wrenches, rollers, and similar parts of machinery which require machine shop work shall be classed as machinery and be paid for at a common price per pound. Electric motors or other prime movers, pumps and compressors are not classified as machinery.

448. Parts Classified as Structural Steel.—Structural steel supporting the machinery proper, or supporting concrete floor slabs, or serving as safety guards, or machinery housing, counter-weight frames and trusses, truss protections and fenders, steel ladders, anchor bolts, and structural steel railings shall be paid for at the same price per pound as the span itself. Attached machine parts shall be weighed separately and shall be classified as machinery.

449. Operator's House.—The operator's house, exclusive of that part which consists of concrete poured in forms, shall be paid for on a lump sum basis. Detailed drawings for house and contents with specifications for fixtures, hardware, etc. shall be submitted for approval within fifty (50) days after signing contract.

450. Hand Railing.—Hand railing, involving the use of gas pipes, or metal fabric, or hard wood or brass rail with necessary fixtures shall be included with the operator's house in submitting proposals.

451. Electrical Equipment.—All electrical equipment, such as wiring, switch boards, controllers lights, signals, blow-outs, cut-offs, solenoids, switches, motors, contact indicators, submarine cables, conduits, electrically operated safety gates, etc., shall be paid for on a lump sum basis.

452.—The electrical contract shall include the entire work of carrying the current from the source of power to the switch board and all mechanisms and wiring served therefrom. The electrical equipment shall also include electrically operated pumping equipment complete. Before bidding, the Contractor shall assure himself as to the nearest connections for power which will be acceptable to the State Highway Commissioner.

453. **Counter-Weights.**—Cast iron, cast steel, and scrap metal used in counter-weights, or for adjusting the balance of the movable span shall be paid for as structural steel.

454.—Concrete in counter-weight shall be paid for at a price per cubic yard in place, but shall not be considered as "Subaqueous Concrete".

455. **Extra Parts.**—It is to be understood that if any extra parts or quantities are needed, or if any question arises, all difficulties shall be settled for on the unit price basis as quoted and accepted for the parts in question.

456. **Cofferdams.**—When cofferdams are required for any part of the structure, the price therefore shall be included in the price allowed for subaqueous concrete. The cofferdam must be reasonably tight and must afford ample protection for the structure enclosed. The type and method of construction of cofferdam which Contractor proposes to use must be submitted in writing and by sketch to the Engineer for his approval before construction. This approval will not, however, relieve the Contractor from responsiblity for damage to the structure or materials from any cause.

457. **Channel.**—After the completion of the work the channel shall be restored to its original contour and condition and the existng span, piling and masonry removed from the site.

458.—When the location of a structure requires dredging to make the channel reasonably straight and of uniform cross-section, said work shall be performed after the masonry is in place and, unless otherwise specified, shall be paid for on a cubic yard basis and shall include such channel changes as the Engineer may direct.

459. **Bulkheads and Fenders.**—Fender piling and bulkheads in place, exclusive of bolts embedded in concrete shall be paid for on a unit basis. Contractor shall submit detailed sketches or plans with his proposal subject to the approval of the Engineer.

460 **Pumping Machinery.**—Pumps and accessories when electrically operated shall be included with the Electrical Equipment in submitting proposals.

Materials to be Used.

461. **Rolled or Forged Steel.**—Rolled or forged steel shall be used for bolts, nuts, keys, cotters, pins, axles, screws, worms, piston rods, trunnions and crane hooks.

462. Trunnions, pins and shafting over 4½ inch in. diameter shall be of forged structural steel. Shafting 4½ inch or less in diameter may be of cold rolled steel.

463. Pinions shall be made of forged steel and cut from the solid metal unless pinions are too large for forgings.

464. **Cast Steel.**—Forged or cast steel shall be used for levers, cranks and connecting rods.

465. Cast or forged steel shall be used for couplings, end shoes, racks, toothed wheels, brake wheels, drums, sheaves and hangers where the supported weight will cause tensile stress.

466. **Cast Iron.**—Cast iron may be used in boxes for shafts 2 inches or less in diameter and which obviously carry light loads. Other boxes shall be of cast steel. Cast iron may be used in Eccentrics, Cylinders and Pistons. Cast iron shall not be used for any trunnion or axle supports.

467. **Hardened Steel.**—Hardened steel shall be used for pivot discs, friction rollers, ball bearings, and in other similar cases for the purpose of reducing the bearing surface, abrasion, and friction.

468. **Metal for Bushings.**—Phosphor bronze, brass, and babbitt metal shall be used for the bushing or lining of journal bearings and other rotating or sliding surfaces to prevent seizing.

469. Phosphor bronze only shall be used for the trunnions of bascule bridges or in any large bearing carrying heavy loads.

470. **Physical Characteristics.**—Material not otherwise specified in General Specifications shall satisfy in every respect the "Specifications for movable Bridges" by C. C. Schneider as published in Transactions of American Society of Civil Engineers, Vol. LX.

General Features of Design.

471. **Limitation of Type.**—Single leaf bascule bridges shall be designed so that the live load reaction on the trunnion end shall be carried directly by the trunnions. Double leaf bridges shall be so designed that they will transmit through the center lock only live load shears and there shall be a live load anchor provided at heel of counter weight to take the maximum uplift from live load. The use of live load supporting shoes in front of the trunnion shall not be permitted.

472.—Swing bridges shall be center bearing and shall be so designed that the entire dead load of the bridge is carried on a center pivot when the bridge is swinging, but when the bridge is closed the trusses should rest at the center on wedges or other substantial supports proportioned to resist the reaction resulting from the live load and impact.

473.—Machinery shall be installed in duplicate including every part from motor, or hand lever, in case of hand power operations, to operating pinion.

474. Self Centering and Locking Devices.—Self-centering and seating devices shall be used on the free ends of the moving span of bascule bridges and holding and forcing down devices shall be used for the free ends of each truss.

475.—End latches shall be provided for automatically locking and centering the bridge when in the proper position for closing, the speed to be so slow that shock will do no damage. The end supports should be arranged so that they can easily be adjusted to the proper amount of lift.

476. Buffers.—Timber or babbit metal buffer blocks shall be furnished for bascule spans at the seats of the free ends of the trusses and at the contact points at the heel of the counter weight when the bridge is fully open. For double leaf bridges, a similar buffer shall also be provided at the contact points of the heel of the counter-weight with a live load anchor for bridge closing.

477. End Lifting Apparatus.—All swing bridges must be provided with an effective lifting and locking apparatus at the ends. The lifting apparatus must be strong enough to exert an uplifting force equal to the maximum negative end reaction of the live load plus fifty per cent (50%), and must have a bearing capacity for the positive maximum end reaction including impact. It shall be designed to take care of the maximum drop of the free end of span when swinging including the effect of a thirty (30) degree Fahrenheit difference in temperature of upper and lower chords.

End lifts and end latches shall be designed so that they may be operated by hand from either the ends or center of span. If, in addition, machine power is used for this purpose, separate motors, placed at the ends of the spans shall be used.

478. Counter-Weights.—Counter-weights shall be easily adjustable, the adjustment being made by add-adding or taking away iron or concrete blocks. These blocks are to be provided with proper lifting hooks. The designed of fixed structure shall be so arranged as to facilitate the removal or addition of adjustment blocks to as great an extent as possible. The fabricator of the structural steel shall check the location of the center of gravity of the moving leaf including all parts attached thereto, and also the location of the center of gravity of the counter weight, including counter-weight girders and trusses, by computations based on the accurate weights, figured from the shop plans and he shall submit duplicate copies of these computations accompanied by weight bills to the Engineer for approval. Aside from the provision for adjustments, counter-weights shall be designed to be built of concrete of a 1:6 mixture unless otherwise specified. Counter-weights shall be made five per cent (5%) lighter than the figured weight and balance blocks provided to the extent of ten per cent (10%) of said weight. The adjusting blocks shall be two (2) man blocks of about one foot (1) on edge. They shall be provided with three-fourths (¾) inch eye bolts with two (2) inch diameter eyes. Blocks shall be placed in wells, and no block shall project above tbe top of said wells. Independent adjustment shall be provided for bridge in extreme positions, open and closed.

479. Center Bearing.—The center pivot of swing bridges shall be so designed that the discs can be taken out, examined or replaced when the bridge is not in operation, without interfering with traffic. Trailing wheels running on a circular track shall be provided for the purpose of balancing the bridge and carrying the wind or unbalanced pressure to the track while swinging. The center pivot, as well as the trailing wheels, shall be adjustable as to height.

480. Rack and Track.—The rack and track segments for swing bridges shall be made in short sections, preferably not more than four (4) feet long. If a cast lower track is used, in case the track is light, as in center bearing bridges, the rack and track shall preferably be cast in one piece. The maximum pitch of the teeth in the rack shall not exceed six (6) inches, steel rail shall not be used for the track. No metal less than one and one eighth (1⅛) inches thick shall be used for rack and track work. The width of the base of the rack shall be at least two thirds (⅔) of its height and ribs bracing the vertical portion to the base shall be provided at a distance not exceeding eighteen (18) inches. Proper drainage holes shall be provided to keep the rack and track segments dry. The rack for bascule bridges shall be of the pin type operated with an external pinion.

Loads and Loading Conditions.

481. Conditions of Loading for Swing Spans.—The stresses in the trusses of swing bridges shall be computed for the following condtions:

a. Bridge open. No live load; supported entirely on center pivot.
b. Bridge closed. No reaction at ends from dead loads.
c. Bridge closed. Ends lifted until trusses are fully continuous.

482. Combinations of Loading for Swing Spans.—For purposes of design, the maximum stresses of either kind shall be determined by combining loading "a" alone with twenty-five per cent (25%) allowance for vibration of moving structure; loading "b" with no vibration allowance for dead load; or loading "c".

483. Conditions of Loading for Machinery of Swing Spans.—In designing the machinery and machinery supports for swing bridges, the frictional and inertia resistances and those due to unbalanced wind, shall be reduced to a common resistance applied at the pitch line of the rack circle and the machinery shall be designed either for accelerating the span or for holding the span in accordance with the conditions hereinafter specified. The most severe of these requirements shall govern the design.

484. For swing spans the accelerating force shall be computed on the basis of uniformly accelerating or decelerating the span in one-quarter of the time specified as the time of opening. For machine power operation, this time of opening shall, unless otherwise specified, be taken as ninety (90) seconds. For hand power operation, the time of opening shall be taken as three hundred (300) seconds, based on the assumption that two (2) men are to operate the span.

485. Loadings for Power and Machinery of Swing Spans.—In computing the power required and designing the machinery for turning, the span shall be considered as acted upon by a wind load of one twenty-fifth (1/25) of the total span in feet of both arms, expressed in pounds per lineal foot, and considered as applied over the length of one (1) arm: This loading to be considered in addition to the frictional and inertia forces. As an alternative to this loading, the machinery shall be capable of holding the span against a wind load of four-tenths (4/10) of said total span in pounds per lineal foot considered as applied over the length of one (1) arm.

486. In designing the balance wheels and all parts affected thereby, an unbalanced wind or snow load of ten (10) pounds per square foot, acting vertically on the projected horizontal surface of one entire arm of the structure. The center achorage shall be sufficient to take care of this loading.

487. Conditions of Loading for Bascule Spans.—The stresses in the trusses of bascule bridges shall be determined for the following conditions:

a. Bridge open at any angle, dead load only.

b. Bridge open at any angle, resisting the wind of twenty (20) pounds per square foot of floor surface, blowing normal thereto and in either direction.

c. Bridge closed and locked, no dead load reaction at the end most remote from the trunnion, and structure considered as a simple span for live load in case of single leaf bascules: for double leaf bascules, the structure shall be considerd as supported at the trunnions and the live load anchors and the amount of shear at the center lock for any given live loading shall be determined by the "Method of Relative Rigidities". For this purpose the "Method of Influence Lines" shall be used in which case, for any concentrated load on one leaf the center lock shear will be equal to the amount of the load times the ratio of the deflection at the lock under the lock, with lock free, to twice the deflection for a unit load on one leaf at the lock, with lock free.

488. Combinations of Loading for Bascule Spans.—For purposes of design the maximum stresses of either kind shall be determined by combining loading "a" alone with either twenty-five per cent (25%) allowance for vibration of moving structure or with the wind loading "b". However vibration and wind shall not be considered as acting simultaneouly, nor shall any additional allowance be made in the design for reversal due to the opposite signs of stress produced by wind in opposite directions. Or use loading "c" for dead and live load with no wind nor dead load vibration allowance.

489. Conditions of Loading for Machinery of Bascule Spans.—In designing the machinery and machinery supports for bascule spans, the frictional, wind, inertia, and unbalanced resistances shall be reduced to a common resistance applied at the pitch line of the rack circle and the machinery shall be designed either for accelerating the span or for holding the span in accordance with the conditions hereinafter specified. The most severe of these requirements shall govern the design.

490. For bascule bridges, the accelerating force shall be computed on the basis of uniformly accelerating or decelerating the span in one-quarter of the time specified as the normal time of opening. For machine power operation, this time of opening shall, unless otherwise specified, be taken as forty-five (45) seconds. For hand power operation, the time of opening shall be taken as one hundred and fifty (150) seconds, based on the assumption that two men are to operate the span. These times shall be considered as the normal times of operation.

491. Loadings for Power and Machinery of Bascule Spans.—For normal operation of the bridge one motor with one (1) set of machinery shall be capable of operating the bridge in normal time of opening with motor running at normal speed and no over load against uniform frictional and inertia resistances and the wind, snow or dirt load of two (2) pounds per square foot covering the entire floor surface of the moving leaf considered normal thereto.

492. In addition to the above requirments, each motor shall have a normal starting torque not less than seventy-five per cent (75%) of the torque required to start the span against a uniform wind load of ten (10) pounds per square foot of total floor surface of the moving leaf considerd normal thereto in addition to overcoming the frictional forces.

493. All machinery, exclusive of motors, machinery supports and brakes, shall be designed for strength on the assumption that one set of machinery is to hold the span against a wind or equivalent braking load of twenty (20) pounds per square foot of entire floor surface of moving leaf, considered normal thereto. In addition the brakes and machinery shall be designed to stop the span when operating at maximum normal speed in six (6) seconds.

494. Hand Power.—In designing for hand power for normal operation, one man shall be considered as capable of applying an effective load of forty (40) pounds on a lever while walking at a rate of one hundred and sixty (60) feet per minute. The strength of the machinery, however, shall be great enough to resist the force of one hundred and twenty-five (125) pounds per man.

495. Live Loads for Movable Bridges.—The live loads for movable bridges shall be as specified in the "General Specifications for Steel and Concrete Highway Bridges" preceding these specifications.

496. Impact for Structural Steel Parts.—The floor beams, stringer brackets, castings and slabs at breaks in floor for all movable bridges shall be designed for one hundred per cent (100%) impact allowance. Otherwise all structural steel parts will be subject to the same impact as prescribed in "General Specifications for Steel and Concrete Highway Bridges" preceding these specifications.

497. Impact for Machinery.—Impact allowances for machinery shall be considered as taken care of by the lowered unit stresses permitted as hereinafter specified.

Unit Stresses and Proportion of Parts.

498. Unit Stresses for Structural Parts.—All structural parts shall be proportioned for the unit stresses prescribed in "General Specifications for Steel and Concrete Highway Bridges" preceding these specifications.

499. Machinery Parts.—The unit stresses per square inch to be used for parts in which the effects of impact are taken care of by the use of low unit stresses instead of increasing main stresses are, for stresses in one direction:

Material	Tension	Compression	Fixed Bearing	Shear
Machinery Steel	9,500	$9{,}500-40\frac{L}{R}$	13,000	6,500
Forged Strutal Steel	9,000	$9{,}000-39\frac{L}{R}$	12,500	6,400
Rolled Structural Steel	8,000	$8{,}000-35\frac{L}{R}$	12,000	6,000
Steel Castings	7,000	$8{,}000-35\frac{L}{R}$	10,000	5,000
Phosphor bronze	2,500			4,500
Cast Iron	1,500	8,000		3,000
Shear on Keys				5,000
Bearing on Keys			9,000	

For stresses which are reversed at the rate of 10 or more times per minute, use one-half of the above unit stresses.

500. Gear Teeth.—The strength of gear teeth shall conform to the following formula, one tooth only taking pressure:

$P = f.\ p.\ b.\left\{0.124 - \frac{0.684}{n}\right\}\frac{600}{600+v}$ in which P = pressure on tooth in pounds; f = permissible unit stress = 17,000 pounds; p = circular pitch in inches; b = face or breadth of tooth in inches; n = number of teeth in gear; v = velocity on pitch circle, in feet per minute.

The strength of machine molded teeth shall be calculated by the foregoing formula, taking f = 15,000 pounds.

501. Rollers at Rest.—The pressure in pounds per linear inch on rollers at rest shall be for rolled and cast steel 600d, where d equals diameter of roller in inches.

502. Bearing on Rotating and Sliding Surfaces.—The following bearing units in pounds per square inch of sliding surfaces or pounds per square inch of diametral projection of rotating surfaces are permitted.

Trunnion bearing on bascule bridges—machinery or structural steel on phosphor bronze	1,500
Pivots, hardened tool steel on phosphor bronze discs	3,000
Wedges—cast steel on cast steel or structural steel	500
Screws which transmit motion, or projected area of thread	200

For ordinary cases parts moving at moderate speeds.

Hardened steel on hardened steel	2,000
Hardened steel on bronze	900
Structural steel on bronze	600
Cast iron on structural steel	400

503. In order to prevent heating and seizing at higher speeds the pressure on pivots to footstep bearings for vertical shafts and journals shall not exceed

$$\text{On pivots} - p = \frac{160{,}000}{n.\ d.}\ \text{per square inch.}$$

$$\text{On journals} - p = \frac{300{,}000}{n.\ d.}\ \text{per square inch.}$$

where n = number of revolutions per minute; d = diameter of journal or pivot in inches; p is taken in pounds.

504. Rollers in Motion.—The permissible pressure in pounds per linear inch of rollers for rollers in motion shall be:

For cast iron p = 200d; for steel castings p = 400d; for machinery steel p = 500 d; for tool steel p = 800d; for hardened tool steel p = 1,000d; where p equals pressure per linear inch of roller, and d equals diameter of roller in inches.

505. The foregoing values are for rollers and bearing surfaces of the same material; if rollers and bearing surfaces are of different materials, the lower value shall be used.

506. Shafting.—In designing circular shafting, trunnions and axles, the greatest unit fibre stress in tension or compression due to bending and twisting shall be calculated by the following formula:

$$f = \frac{32}{\pi d^3}\left\{\frac{3}{8} M + \frac{5}{8}\sqrt{M^2 + T^2}\right\}$$

The maximum unit shear shall be calculated by the following formula:

$$s = \frac{16}{\pi d^3}\sqrt{M^2 + T^2}$$

In these formulae, f = unit fibre stress in tension or compression; s = unit shear; d = diameter of shaft; M = the simple bending moment; and T = the simple twisting moment.

507. The unsupported length of shafts shall not exceed

$L = 80 \sqrt[3]{d^2}$ for shafts supporting their own weight only;

$L = 50 \sqrt[3]{d^2}$ for shafts, carrying pulleys, gearing, etc.

where L = length of shaft between center of bearings in inches, and d = diameter of shaft in inches.

In figuring the bending moment on shafts, trunnions and journals, the distance center to center of bearings shall be taken.

508. Frictional Resistances.—The friction on trunnions of bascule bridges in motion shall be assumed as 15 per cent of the trunnion load and shall be considered as acting at the circumference of the trunnion bearings

509. The friction on pivots for center bearing swing bridges shall be assumed as 15 per cent of the load on the pivot when swinging and shall be considered as acting at the circumference of the pivot.

510. An allowance of 5 per cent of the energy transmitted by any pair of gears shall be considered as dissipated by gear and bearing friction.

511. Solid cast rollers without flanges shall be assumed to have a total frictional resistance coefficient of 0.015 of the load carried by the roller.

512. Sliding friction coefficients between plane surfaces intermittently lubricated shall be assumed as 0.08.

513. An allowance of 30 per cent of the energy transmitted by any worm gear shall be considered as lost in friction.

514. Toothed Gearing.—Gear wheels shall be designed on the assumption that one tooth transmits the whole pressure. In uncut gearing, the pressure shall be assumed as coming on a corner of the tooth, but in machine cut gearing it may be assumed as distributed over the whole width of the tooth. All cast pinions shall be shrouded and no pinion shall have less than fifteen teeth. All toothed gearing in operating machinery shall have involute teeth of 14½ degrees obliquity. The roots below the clearance line shall be filleted.

515. The minimum width of the teeth shall be 1½ times the pitch; the width shall not exceed three times the pitch, except for wheels running at a very high velocity, as in motors where abrasion is to be considered.

516. For the purpose of accurately setting gear teeth in the field erection, the pitch circle shall be plainly scribed on each side of the gear.

517. Worm Gearings.—Worm gearing for transmitting power, shall have an angle of thread not less than twenty degrees (20°). The worm shall run in oil. A bronze or brass collar shall be used at the end of the worm and at the end of the wheel axle to take care of the end thrust. The wheel shall be of bronze. If a nut engages the worm, the nut shall be of bronze.

518. Worms which are to be used for actuating signals, indicators or other minor parts may have an angle of thread less than 20 degrees.

Motors.

519. Motor Requirements.—Motors, unless otherwise specified, shall be of standard railway type, three (3) phase, sixty (60) cycle, series wound, induction type, of two hundred and twenty (220) or four hundred and forty (440) voltage. The capacity of each motor shall be estimated at normal speed and at whatever voltage is available according to the specifications of the "American Institute of Electrical Engineers", and the motor shall be capable of carrying an overload of thirty-three and one-third per cent (33⅓%) for thirty (30) minutes or fifty per cent (50%) for five (5) minutes without injurious heating or sparking at the commutator.

520. Motors shall be of the enclosed weatherproof type, provided with back gears and weather proof automatic electric brakes.

521. It is preferred that the automatic electric brakes shall be motor operated rather than of the solenoid type.

522. Independent Machinery Units.—The two (2) sets of machinery shall be run without equalizing gearing or couplings of any kind, but under equal voltage and conditions of loading both motors must, by test develop very closely the same speed.

523. Characteristic Curves and Motor Performance.—The Contractor shall, as mentioned in 437 furnish curves showing the torque, speed, current used, horse power and heating conditions for the motors he proposes to use, under any degree of opening. These shall be subject to approval of the State Highway Commissioner.

524. Extra Parts.—The Contractor shall furnish free of charge the following additional parts for each size of motor furnished: one armature, one set of field coils, one set of carbon brushes, and one set of back gears, all fitted and adjusted ready for emergency use. For each type of electric brake, provide one extra spool, two extra shoes, and six extra springs.

Machinery Details.

525. Castings.—Castings which are to be attached to rough unfinished surfaces shall be provided with chipping strips. The outer unfinished edges of ribs, bases, etc., shall be rounded off and inside corners filleted.

526. Bolts and Screws.—Bolts and nuts up to 1½ inches in diameter shall have U. S. Standard V threads. Nuts and exposed bolt heads shall be hexagonal in shape and each nut shall be provided with a washer, unless otherwise called for.

527. If the nut will come on an inclined surface, a special seat, whose top surface is at right angles to the bolt shall be cast or built up to receive the nut. Bolt heads which are countersunk in castings shall be square.

528. Nuts which are subject to vibration and frequent change of load shall have locking arrangements to prevent the gradual unscrewing of the same. If double nuts are used, for that purpose, each nut shall be of the strandard thickness. Nuts subject to vibration shall be further secured by split pins through the bolt.

529. Screws which transmit motion shall have square threads.

530. Tap Bolts.—Tap bolts and stud bolts shall not be used except by special permission.

531. Set Screws.—Set screws shall not be used for transmitting torsion to shafts or axles.

532. Collars.—Collars shall be used wherever necessary to hold the shaft from moving horizontally. Each collar shall have at least two (2) set screws at an angle of one hundred and twenty degrees (120°).

533. Shaft Couplings.—Shaft couplings, unless of the flexible kind, shall be of the flange type or split muff with bolt heads and nuts countersunk.

534. For large shafts, couplings such as are used for rolling mill shafting may be used.

535. Couplings shall be keyed to shaftings.

536. Shaft couplings of the flange type shall be shrouded to cover the exposed heads of bolts.

537. Keys—Positions and Dimensions.—Two (2) keys set at angles of ninety degrees (90°) with each other shall be used in all cases where the motion is subject to change in direction.

538. If practicable. hooked and tapered keys shall be used. The taper shall be one-eighth (⅛) inch per foot. The approximate width of the key shall be one-fourth (¼) of the diameter of the shaft. The height at mid-section of tapered length shall be three-fourths (¾) of the width. The length of the hook, measured parallel to the shaft shall be equal to the width of the key.

539. If tapered keys are not practicable, parallel faced keys of about the above proportions shall be used.

540. Tapered keys shall bear on top, bottom and sides; parallel faced keys shall bear on sides only.

541. The length of a key shall be not less than that of the hub. The key, when driven into its final position shall bear on the full length of the hub.

542. The foregoing dimensions are approximate. The shape of the key must be such as to have unit stresses in shear and bearing not exceeding those allowed by 498 of these specifications.

543. If practicable, the keys and grooves shall be made so that the keys may be backed out.

544. Keys shall be sunk in grooves in both hub and shaft. The depth of a groove shall be such that the bearing will not exceed the allowable unit stress.

545. Keys shall be held by set screws or equivalent means. In vertical shafts, bands clamped about the shafts or other devices, shall be placed below the key.

546. Keys in Trunnions.—For trunnions and similar parts, which are designed chiefly for bending and bearing, the keys, key ways and bolts shall be designed to hold the trunnions from rotating. The force tending to cause rotation shall be taken at one-fifth the load on the trunnion and shall be taken as acting at the circumference of the trunnion.

547. **Hubs.**—If practicable, the length of the hub shall not be less than two diameters of the shaft; its thickness not less than one-third of the diameter of the shaft. The hub shall have a light driving fit on the shaft.

548. The keyway groove in the hub shall be made on the center line of an arm.

549. Hubs shall be bored truly at the center of the wheel.

550. **Journals.**—Journals shall be proportioned to resist, not only the various stresses to which they are subjected, without exceeding the permissible fibre and bending stresses, but also to prevent a tendency to heat and seize.

551. Divided journal and trunnion bearings shall be used and the cap shall be fastened to the base with turned bolts recessed into the base. The bolts shall be capable of resisting the maximum uplift. The nuts and heads shall bear on finished bosses cast on the bearing. There shall be ⅛ inch clearance between the lining of the base and the cap or its lining to allow for expansion.

552. The cap bolts for the main trunnion bearings shall be of such size as to be capable of taking the maximum dead load value of the bearing. This requirement is to assist in the erection adjustments.

553. **Bushings.**—Steel bearings carrying steel shafts or journals shall be lined with bronze or brass. If shafts are 3 inches or less in diameter and of slow motion, babbitt metal may be used. Bearings of steel on steel for moving surfaces will not be allowed.

554. **Bearings.**—In cast iron bearings carrying light shafts no lining is needed.

555. The bearings of shafts shall be placed as near to the points of loading as possible.

556. The footsteps of vertical shafts shall be of tool steel and run on bronze discs.

557. **Shafts.**—Line shafts, extending from the center of the bridge to the end, shall not be continuous, but shall be connected with claw couplings. Each length of shafting shall rest in not more than two bearings with the couplings close to the bearings.

558. If shaft supports are connected to the floor beam in bridges having long panels, intermediate supports shall be used. These shall be adjustable and are intended merely to prevent the shaft from sagging.

559. Line shafts connecting machinery at the center to that at the ends shall run at fairly high speed. The speed reduction shall be made in the machinery near the ends.

560. If a shaft, trunnion or axle has one keyway cut at the section where the maximum stresses occur, f and s shall be increased one-sixth; if two keyways are cut, increase by one-fourth. If the shaft is enlarged through the hub this does not apply. (See 506)

561. Shafting transmitting power for the operation of the bridge, and shafting 4 ft. or more in length, forming part of the operating machinery of the bridge locks, and wedges, shall not be less than 2½ inches in diameter.

a. In figuring the bending moment on shafts, trunnions and journals, the distance center to center of bearings shall be taken.

562. **Pivots.**—Pivots for the centers of turn tables must revolve on discs. Disc bearings shall preferably consist of three discs, one of phosphor bronze, between two discs of hardened steel, so that the steel will slide on bronze. The phosphor bronze shall be of the special kind specified in 470. Friction rollers shall not be permitted.

563. **Hand Brakes.**—In addition to the electric brakes, there shall be provided a service hand brakeand an emergency hand brake. These hand brakes shall be of the band type and shall be operated by adjacent levers in the operator's house near the controllers. The service and emergency brakes shall each have a breaking torque fifty per cent (50%) greater than the starting torque of one (1) motor. Hard maple or basswood blocks attached to steel bands shall bear on a cast steel brake wheel. The coefficient of friction between the blocks and the wheel shall be taken as twenty per cent (20%).

564. **Mechanical Indicator.**—Mechanical indicators shall, as far as possible, be constructed of structural steel shapes and shall have indicator scales painted in alternate red and white enamel. They shall be rigidly mounted and shall be graduated after the erection and adjustment of the moving span.

565. **Shims.**—All machinery shall be bolted firmly to place by bolts of sufficient capacity and anchorage to resist the maximum uplift and shear. Shims shall be provided where necessary for aligning and adjusting the machinery and they shall vary in thickness by sixteenths of an inch as required.

a. Drainage holes of appropriate sizes shall be provided in all machinery parts where it is possible for water to collect and stand.

566. **Hand Levers.**—Hand operating levers shall be located for easy access and operation. As many levers shall be provided as are required to perform the necessary operations, in no case less than two (2). These levers shall be about four and one-half (4½) feet above the floor and shall be of either timber or wrought iron pipe and shall be easily removable from the shaft. The levers shall have a square socket at the lower end to engage a square shank on the driving shaft.

567. **Floor Covers.**—The shafts for hand operating levers shall be neatly covered by convenient metal cover which can be quickly removed and yet, when in place, is securely fastened against displacement. These openings shall be as near weatherproof as possible.

568. **Seating of Motors.**—Motors shall either have the armature shaft extended and key seated for a coupling or shall be provided with back gears. In the latter case, a forged steel pinion shall be keyed and locked to the armature shaft and shall engage a cast steel gear keyed to a secondary shaft with bearings in the motor frame. When feasible this secondary shaft is to be extended and have its main bearings in the main machinery

group of bearings, thus supporting one end of the motor and at the same time connecting it rigidly with the operating machinery. The back gearing is to be properly housed and both gears are to have machine cut teeth. The rear end of the motor is to be supported on stiff brackets connected rigidly to the main machinery bases.

569. Lubrication.—Provision shall be made for the proper and effective lubrication of all journals, pivots or any other moving parts with sliding or rotating surfaces. Closed oil or screw compression grease cups shall be provided for all journal bearings. Where not otherwise accessible they shall be connected with oil pipes. Oil grooves must be provided in the surfaces of trunnions and at all other surfaces where necessary for the proper distribution of the lubricant. Grease and oil cups must hold the lubricant for any position of the moving parts and must be easy of access.

570. Dust Covers.—Dust covers shall be provided wherever necessary to protect the sliding and rotating surfaces and prevent dust from mixing with the lubricant.

571. Grease Grooves.—The grooves in large trunnions shall approximate to a U shape; the size shall be such that a wire 5/16 inch in diameter may lie wholly within the groove. The edge of the U shall be smoothly rounded to a ¼ inch radius.

572. The grooves shall be straight, running parallel to the axis of the trunnion. They shall be so located, not less than three in number, that all parts of the bearing surface of the bushing will be swept by the contained lubricant in an opening and in a closing of the bridge. The grooves must allow of being cleaned with a wire.

573. Grease Cups.—In any trunnion bearings, or similar heavy bearings strong screw compression grease cups shall be used for the grooves.

574.—Oil and grease ducts shall be so located, if practicable, that the lubricant will flow by gravity toward the bearing surface.

575. Wedges.—For center wedges of swing spans, a bevel of 1:10 shall be used. They shall be provided with ample means for adjustment. The wedges shall bear on upper castings provided with guides engaging lips on the wedge. These guides and lips shall be so arranged that the wedge will be supported by the upper casting during the swinging of the span. The wedge shall bear on a base casting substantially bolted to the pier.

576. End wedges shall move in the line of the trusses and shall bear directly under the same in the line of the end floor beams. The upper surface shall be beveled 1:5 and shall engage guides in the upper bearing casting which is directly attached to the truss so that the wedge shall be supported by the span when swinging.

The lower surface of the wedge shall be horizontal and shall bear on the base casting that is bolted directly to the masonry. The base casting shall have guides to engage the wedge, but these guides must not interfere with the span while swinging. All surfaces in contact shall be finished and polished.

577. The multiplication of power for operating end wedges shall be made at the ends of the bridge.

578. Center Bearings.—The phosphor bronze center disc shall be made convex on both faces and shall lie between two (2) hardened steel discs which have curved surfaces bearing on the center disc, but of slightly larger radius. The other surfaces of these discs shall be plane and shall bear on the upper and lower castings and be dowelled to them so as to insure that the sliding shall take place on the bronze disc. An oil tight cast steel box shall be placed around these discs and attached to the base casting. This box shall be of substantial construction with a total clearance of one-thirty-second (1/32) inch between the discs and the box. It shall be made in sections and bolted together so as to permit removal for inspection and the renewal of the center disc whenever necessary. Semicircular vertical oil grooves of one-half (½) inch radius shall be placed around the inside of the boxing and connect with an oil space around the top. Oil holes feeding into this oil space shall be provided in the top casting. The latter shall completely protect this oil space from dust. Oil grooves of three-eighths (⅜) inch radius shall be cut in diametral lines across both spaces of the center disc. A hole one (1) inch in diameter shall be drilled in all three (3) discs at the center. This hole shall feed into oil grooves cut on diametral lines across the top face of the base casting. Holes shall be drilled into this casting at the ends of these grooves and tapped for drain pipes. The sliding contact faces of the disc shall be polished, whereas all other surfaces shall be merely finished. The base casting shall be well anchored to the pier by not less than eight (8) bolts, each one and one-half (1½) inches in diameter and three (3) feet long.

579. Balance Wheels.—There shall be not less than eight (8) balance wheels. These wheels shall not be less than eighteen (18) inches in diameter and six (6) inch faces with axles not less than three (3) inches in diameter. The wheels are to be set in a radial position and are to be securely fastened. Provisions shall be made for adjusting the wheels so that they will just clear the track when the span is swinging.

Operator's House and Quarters.

580. General Provisions.—The operator's house shall furnish unobstructed view of both roadway and channel traffic, in both directions and for all angles of opening. It shall be of fireproof construction. It shall be so arranged and of sufficient size to give ample room for the operator, controllers, brake and end lock levers, switchboard, indicators, stove, chair, table, fuel storage, and convenient storage for hand operating levers, telephone, toilet and lavatory.

581. Heating and Fuel Storage.—The house shall be equipped with an electric stove, if operated electrically. If a coal stove is furnished, storage for one (1) ton of coal shall be provided and access to this storage shall be provided for, by means of a standard metal frame hopper window, so placed as to be easily reached by a chute hung from the sidewalk railing or preferably, if the design will permit, said storage bins shall be reached by a built in chute, fed from a manhole, provided in the sidewalk of the fixed structure.

582. Toilet.—The toilet and lavatory shall be first class modern fixtures of a type subject to the approval of the State Highway Commissioner. They shall be properly trapped and sewered in such a manner as to comply with all existing laws and good modern practice.

583. Windows.—All windows shall be of a single pane in each sash. The greatest practicable effective window surface shall be provided in the operator's house.

584. Eave Troughs and Down Spouts.—The eaves shall be provided with proper metal gutters and downspouts.

Machinery House.

585. General Provisions.—The machinery house shall furnish ample room for storage of spare counterweight adjustment blocks, oils, waste, span machinery and motor parts. It shall be so so arranged as to give access to the adjustable blocks on the heel of the counter-weight. The floor of the machinery room shall be depressed at least six (6) inches below the top of the concrete bases supporting the operating machinery. All openings in the bridge floor above the machinery room shall have removable aprons suspended below them in such a way as to furnish the utmost protection to machinery and machinery room contents from the weather and roadway debris. Machinery room floor shall be provided with suitable sumps and drains to permit of washing the floor clean and carrying waste into the counter-weight pit.

586. Heating.—Machinery house shall be heated in the same manner as described for the operator's house.

587. Hand Winch.—There shall be provided and stored in machinery room a light winch hand crane capable of handling a load of ten (10) tons by the use of double and triple blocking. Provisions shall be made permitting the placing of the winch in the counter-weight pit, if necessary, to assist in making any counter-weight adjustments which may be desirable. Suitable eyebolts shall be provided in bottom flanges of beams over the machinery castings to facilitate the placing of and repairs to machinery.

588. Windows.—The machinery room shall be provided with not less than thirty-six (36) square feet of window surface illuminated by direct sunlight.

589. Cabinets and Work Bench.—Machinery room shall contain a work bench for convenience in making minor repairs. There shall also be provided a complete oiling, adjustment, and repair kit for the machinery, together with proper cabinets for housing and storing the same.

590. Ladder to Counterweight Pit.—The counter-weight pit shall be provided with a steel ladder, accessible from the machinery room, of approved construction, permitting access to the bottom of the pit and the manhole to the said ladder shall be not less than four (4) feet in diameter to permit removal of wastes.

591. Outside Stairways.—All outside stairways shall be provided with two (2) hand rails properly attached.

592. Storage Batteries.—When the bridge is to be operated by hand, storage batteries shall be provided of ample capacity to operate all lights, signals, and such other apparatus as may be called for on the plans.

Electrical Equipment.

593. Switchboard.—The switchboard shall be of first quality slate, of such size that all meters, cutouts, fuses, switches, current breakers, indicator lights, and etc., may be safely and easily reached and operated by the bridge operator. The switchboard shall be mounted on a substantial iron support braced to the wall. All apparatus on the board shall be properly labelled as to its use.

594. Switches.—Switches of the quick break type and of approved design shall be provided for each supply wire and all circuits. They shall be mounted on the switchboard in the operator's house. The switches shall be desinged to carry a current of not more than nine hundred (900) amperes per square inch of cross-section. Any knife switch shall have a capacity of not less than one hundred (100) amperes. Automatic circuit breakers shall be placed on the switchboard to protect each motor circuit from excessive currents. All other currents shall be protected by enclosed fuses. A Voltmeter and an Ammeter of ample capacity and standard make shall be placed on the switchboard.

595. Controllers.—Controllers shall be of the reversing drum type with contacts protected by blow out magnets, except where the currents are too large for the ordinary controller or where remote control is necessary, in which cases there shall be magnetic switches on the swithcboard operated by master controllers. All controllers shall be of ample carrying capacity to operate the motors under all conditions without injurious sparking. They shall be capable of varying and maintaining the speed from zero (0) at the start to the maximum running speed without injurious sparking or shock due to sudden variation in speed. Sufficient steps shall be provided on the controller so that the torque of the motor will vary approximately as the torque required. The controllers shall be so wired that the electric brake will be released on the first notch and the motors started on the second. Motors shall be so connected that one (1) controller will be capable of operating both motors simultaneously or either motor alone. Separate controllers shall be used for the end locking, lifting, gate, or pump motors when operated electrically. All apparatus shall be so interlocked that all operations can be perforned only in their proper sequence.

596. Electric Brakes.—All motors shall be equipped with standard electric brakes with a braking torque that will stop operations in the required time. These brakes shall be set by springs or other mechanical means and released by solenoids or electric motors operating only when the bridge motors are drawing current, except as hereinafter provided. The solenoids shall have ample capacity for all currents passing through the motors without exhibiting injurious heating. The friction surfaces shall be of materials not affected by moisture. To make coasting possible a release shall be provided for each electric brake, allowing it to draw current when the motors are shut off at the will of the operator. All motors and solenoids shall be weatherproof.

597. Limit Switches.—For all operations performed by motive power, automatic limit switches shall to be used to cut off the current at each end of travel for the wedges, locks and gates, and at such a point near each limit of movement of the span that it will come to rest without jar. The limit switches shall be so made that they will be capable of suitable adjustment. For span operation, a spring switch normally opened shall be so arranged as to shunt around the limit switches and to allow the operator to bring the span to its fully opened or closed position, if necessary after either limit switch has opened the circuit.

Lighting and Wiring.

598. Operator's House.—The operator's house shall be lighted by three (3) sixteen (16) candle power lights arranged so as to amply illuminate all indicators, switchboards and controllers. In addition a small light shall be provided for illuminating the indicating dials on the Ammeters, Voltmeters, etc.

599. Machinery Room.—Machinery room shall be equipped with not less than ten (10) sixteen (16) candle power lights properly disposed to illuminate all parts of the room; a fifty (50) foot extension cord with protected sixteen (16) candle power light shall also be provided for this room.

600. Counter-weight Pit.—The counter-weight pit shall be provided with four (4) sixteen (16) candle power lights below the walkways so disposed as to illuminate walkways, shafting, adjustable counter-weight blocks, sumps, pump, operating pinions, ladders and bottom of pit for cleaning.

601 Store Room and Lavatory.—The basement of operator's house is to be provided with two (2) sixteen (16) candle power lights, one for fuel storage section and one for the lavatory section.

602. Roadway Lights.—The roadway shall be illuminated with two (2) fourteen (14) inch globe one one (100) watt tungsten lights at each approach and two (2) lights of the same type at the operator's house. In addition there shall be a red light of sixteen (16) candle power provided for each safety gate.

603. Outside Stairways.—The head and foot of all outside stairways shall be well lighted.

604. Channel Lights.—Bridge and pier channel lights as shown on plans shall also be furnished.

605. Weatherproof Sockets.—All lights exposed to the weather shall have weather proof sockets.

606. Wiring and Conduits.—All wiring shall be double braided, rubber covered, copper wire of ample capacity to carry the currents required by the motors for maximum loads without injurious heating and to provide satisfactory operation. No wires shall be less than No. 12 B. and S. guage. The wires shall be drawn without injuring them into loricated or equivalent conduits. These conduits shall have as few bends as possible and shall be directly connected to all apparatus so as to provide a weatherproof housing for all wires. In case alternating current is employed, all the wires of all phases (both feed and return) shall be placed in one conduit. Grounds when used, shall be made so as to cause no future damage to either substructure or superstructure.

607. Cables.—All supply cables shall be brought in under the channel and through the piers. Steel armored subaqueous cables shall be used for this purpose and there shall be separate cables for the supply and return currents. Each cable shall be composed of nineteen (19) strands of turned copper wire of not less than ninety-eight (98) per cent conductivity. The insulating wall shall be not less than five-thirty-seconds (5/32) of an inch thick and shall contain not less than thirty per cent (30%) of pure Para Rubber. There shall be one (1) winding of tape, and a lead sheath three-thirty-seconds (3/32) of an inch thick, the lead containing three per cent (3%) of tin; also a substantial jute and asphalt covering and an armor of galvanized steel wire of suitable size for the diameter of the cable. The cable shall show at sixty degrees (60°) Fahrenheit an insulating resistance of five hundred (500) megohms per mile after five (5) minutes electrification. All feed wires shall be protected by a pole switch fuse and lightning arrester mounted on a non-combustible and non-absorbent insulating base.

608. Contactors.—The contactors for making or breaking the electric circuits to operate the indicator lights or similar connections shall be of substantial design and of a type that has been operated successfully under similar conditions. They shall be protected from the weather and be easily accessible for inspection and renewal.

Indicators and Signals.

609. Electrical Indicators.—The open and closed positions of the wedges, locks, gates, and spans shall be indicated to the operator by means of electric lamps attached to the switchboard. The lamps shall show clear for closed position when the span is ready for traffic and shall show red for open positions. Each signal must be sufficiently accurate to indicate that the succeeding operation may be safely performed.

610. Mechanical Indicators.—In addition to the lamp indicators, a mechanical indicator shall be placed either in the operator's house or just outside of the house within plain vision of the operator from his normal operating position. These indicators shall be practically free from effects of temperature, stretch or play in mechanism and shall be graduated to tenths of the total movement for full opening, the first and last tenths being further subdivided into ten (10) equal parts. The mechanisms shall be sensitive to the nearest smallest division mentioned which shall be placed in such a position and so plainly marked that the operator can readily see it while operating the span. Preference will be given an indicator of the sector type without intermediate linkages, cables or gears.

611. Sirens.—An electric siren shall be provided for warning roadway and pedestrian traffic off the bridge. This shall be located outside of the operator's house.

Safety Devices.

612. Safety Gates.—The safety gates shall be electrically controlled and operated unless otherwise specified. They shall be so arranged that the gates on each side of the opening may be operated independently.

613.—The gates shall be of neat design and built of structural shapes. There shall be four (4) gates, two at each end, swinging on pivots near the trusses. The gates shall be arranged so that they may be controlled either by the bridge operator or by special gate tenders. They shall be equipped with a lock or stop to hold them in both the closed and open positions.

614. Machinery Safe Guards.—Safety guards shall be provided for all machinery.

615. Walkways and Railings.—Walks and stairs, properly lighted shall give easy access to all parts of machinery requiring frequent attention and oiling. In passing under or over machinery, shafting or levers, walkways with proper railings and overhead safety guards shall be provided.

616. Protection of Truss Opening.—The heels of bascule trusses shall be encased in a protection railing fastened to the fixed approaches and enclosing the slotted opening for the trusses in the approach. These railings shall be of solid plate for a height of not less than five (5) feet above the adjacent curb or roadway and shall extend toward the channel at least as far as the trunnion.

Flooring for Movable Spans.

617. Roadway Floors.—Roadway floors shall consist of either 2 x 6 timbers, on edge, laid close together, and dressed to an even top surface with all timbers given an all over coat of hot tar just previous to placing, or it shall consist of hexagonal wood block laid on not less than four (4) inches transverse planking, the latter laid with one-half (½) inch joints and given a top coat of hot tar just previous to placing. Before placing the wood block a one-fourth (¼) inch layer of hot tar and sand shall be spread over the subplanking. Each block shall be properly fastened to the subplanking by wire spikes. Details of this or other type of approved floor will be furnished by the State Highway Commissioner.

618. Sidewalks.—Sidewalks shall consist of 2 x 4 timbers, on edge, surfaced on four (4) sides and laid with three-eigths (⅜) inch openings on timber furring strips, not less than four (4) inches thick.

619. Creosoting.—All bridge timber shall be creosoted, absorbing not less than twelve (12) pounds of creosote per cubic foot of timber.

Fender Piling and Channel Protection.

620. Cluster Piles.—Chain bound clusters of not less than seven (7) piles each closely driven and extending not less than fifteen (15) feet below bed of stream at center of channel shall be placed at each of the four (4) corners of a single channel; for a two (2) channel swing span, the center pier shall be protected by a braced pile fender enclosing the pier with a nose upstream and downstream formed of a seven (7) pile cluster as above specified.

621. Fender Piles.—In addition, the masonry along the channel shall be protected by a row of fender piles clearing the masonry by not less than two and one-half (2½) feet, spaced not greater than four (4) feet centers and driven to not less than fifteen (15) feet below the bed of the stream at center of channel. These piles shall extend not less than three (3) feet above high water and shall be joined by three (3) horizontal belts of wales 8″ x 10″ in section and spaced at two (2) feet above high water, at two (2) feet above low water, and at two (2) feet below low water. No wales are to be spaced at a greater distance however, than four (4) feet. In case this is exceeded, additional lines of waling shall be used. No connection between fenders and masonry shall be made. All fenders shall be driven carefully to line and wales shall be fastened carefully to horizontal grade. They shall be bolted to the piling in a rigid manner.