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Design of a 240' through span railroad bridge: Including analysis of stresses due to concentrated wheel loads, design of individual members, and drawings showing stresses, and details

L. C. Torrence

Department: Civil, Architectural and Environmental Engineering

THESIS.

DESIGN

of

A 240′ THROUGH SPAN RAILROAD BRIDGE.

by

L. C. Torrence.

May 1897.

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For the Degree

of

Bachelor of Science

in

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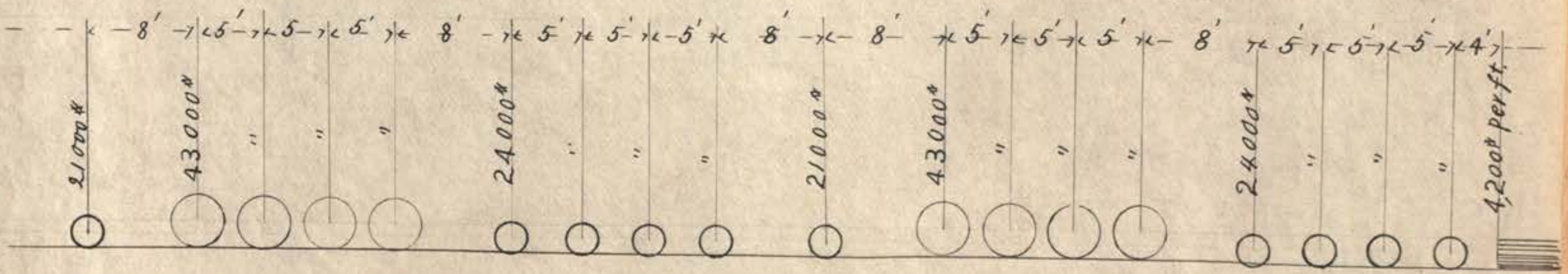
The Span length will be 24o' center to center of end pins. Truss to be sqaure ended, Track straight. Live load to consist of two engines, concentrating 289 tons over a length of 1o4' followed by a uniform train of 2.1 tons per linear foot.



Style and dimension of truss. The truss will be of the Baltimore type; and consist of eight full panels, each 3o' center to center of pins and sixteen semi-panels each 15' center to center.

The inclined end posts will be 5o' center to center of end pins. The seven main verticals will be 4o' center to center of pins, and the eight semiverticals will be 2o' center to center. The length of the upper chord will be increased $\frac{1}{8}$" for each 1o' for camber.

The main diagonals will be 5o' long, and consist of two sets of eye bars 25' center to center of pins, plus allowance for camber. The semidiagonals will be 25' center to center of pins, corrected for camber.

The true length of the main diagonals will be determined by adding $\frac{1}{16}$" to top chord for each 1o' solving for the hypothenuse of the right triangle formed by the main vertical and length of top chord thus increased, true length of main diagonals will be 5o' $\frac{11}{32}$ ". The lower chord will be made of eyebars 15' center to center.

DEAD LOAD.

The weight of floor will be determined by allowing 165# per linear foot for rails, guard rails, bolts, spikes,&c. and 27o# per linear foot for cross ties. The cross ties will be 8" x 1o" x 12' spaced 16" apart center to center; Total weight of floor equals 435 lbs. The weight per linear foot of the steel in the bridge will be given by the formula W equals5L Plus 35o lbs., when W equals weight per linear foot, L equals span in feet.

W equals 5 x 24o plus 35o equals 155o lbs.

Total weight per linear foot per truss equals

$\frac{155o \text{ plus } 435}{2}$ equals 992 lbs.,

Panel load per truss equals 992 x15 equals 149oolbs,

Total weight per truss equals 149oox 16 equals 238200 lbs.

DESIGN OF THE.STEEL FLOOR SYSTEM.

-------------------eOo-------------

The permissible working stress in flanges of stringers and floor beams to be determined by the following formula:-

a equals u(1 plus r)   (J.B.J. 318)

a equals permissible stress per sq.in either tension or compression.

r equals $\frac{\text{min. stress}}{\text{max. stress}}$

u equals : 7800 lbs permissible stress compression.
: 8400 " " " tension

correction for stress in top flange by column formula:-

b equals $\frac{a}{1 \text{ plus } \frac{L^2}{5000}}$ (J.B.J 320)

a equals stres found above

L equals 15

b equals allowed stress,(corrected).

The stringers are plate girders of a span length equal to panel length. The dead load on a pair of stringers consist of the weight of the stringers plus the weight of the floor.

The weight of the steel may be approximated by the formula:-

w equals 9L plus 55

Total dead load per linear foot equals

w equals 9L plus 55 plus 435 equals 625 lbs.

Maximum dead load bending moment equals

$\frac{625 \times 15 \times 15}{2 \times 8}$ equals 88oo ft. ~~lbs~~.

The maximum live load bending moment will occur when wheel (3) or (4) is at the center of the stringer.

Max. L.L. M. equals $\frac{645oo \times 7.5 \times 7.5}{15}$ - 1o75oo equals 1344oo ft.~~lbs~~.

Total bending M. equals 1432oo

Assume depth of web to be 26" o.a., 24" effective.

Max. flange stress equals (1432oo x 12) divided by 24" equals 716oo ~~lbs~~.

Allowed stress in bottom flange equals

84oo(1 plus $\frac{88oo}{1432oo}$) equals 89oo~~lbs~~. call it 9ooo ~~lbs~~.

equals (7800 lbs call it 7800 lbs.

Allowed stress in top flange ,equals

7800(1 plus $\frac{8800}{143200}$) equals 8300 lbs.

Correction of stress in top flange,

b equals $\frac{8300}{1 \text{ plus } \frac{15 \times 15}{5000}}$ equals 7900 lbs. call it 8000 lbs.

Lower flange area, equals

71600 divided by 9000 equals 7.8 sq.in., net.

The flange shall consist of 2 ∠s 6" x$3\frac{1}{2}$" x $\frac{1}{2}$" net area 8sq.in. 15.3 lbs.

Will use same ∠s for top flange. The max. end shear will occur when three wheels are on the stringer and one is just off the floor beam .

Max., shear equals 21.500 plus $\frac{2}{3}$(21500) plus $\frac{1}{3}$(21500) equals 43000 lbs.

Allowing a bearing and shearing value of 4000lbs. per $\frac{7}{8}$" rivet in single shear, 11 rivets will be required through the stringers web and end flanges; also the same number will be required to attach the stringer to the floor beam; but since the stringers must be riveted to the floor beams in the field it will probally be advisable to use 16 rivets 8 in each ∠.

The rivets in the flange shall be pitched 3" at the ends and 6" in the middle 8'of the stringers. Each stringer will consist of:-

1 web plate 26" x$\frac{5}{8}$" x 15', area9. 85 sq.in. equals 492 lbs

2 top ∠s 6" x $3\frac{1}{2}$" x $\frac{1}{2}$" gross area 9sq.in. at 15.3 equals 459lb

2 bottoms ∠s " " net " 8 " " " " " 459

4 end fillers 18" x 6" x $\frac{1}{2}$" " 60

4 " ∠s 6" x 4" $\frac{5}{8}$" at 12.3 " 108

144 $\frac{7}{8}$ rivets $\frac{62}{1640 \text{ lb}}$

There will be 32 **stringers**;

Total amount equals 1640 x 32 equals 52 480 lbs-.

Intermediate floor beams to be 17' center to center and 48" deep o.a. ,stringers to be riveted to floor beam and spaced 7' center to center.

Maximum floor beam load will occur when wheel 4 is over the floor beam

Max. load equals $\left(\frac{1333 \times 98 \times 2}{2} - 322.5\right)\frac{2}{15} \times 2$ equals 59.6x2
or $2(98 - \frac{322.5-2636}{15})$ equals 58.94 x 2 call it 60 x 2.

Max. end shear equals 60 plus 4.7(4.1) equals 64.7

Beam 48" o.a., 46" effective.

Flange stress equals $\frac{60000 \times 12 \times 5}{46}$ equals 78000 lbs
allowed bottom flange stress equals 9000 lbs

Therefore 78000 divided by 9000 equals 8.7 sq.in., net.

Each intrmediate floor beam will consist of:-

1 web plate 48" x $\frac{3}{8}$", 18 sq. in. equals		936 lbs
4 $\angle$s 4" x 5" x $\frac{5}{8}$"	18.4 sq. in.	956 "
4 end $\angle$s 4" x 6" x $\frac{1}{2}$		253 "
4 fillers 6" x $\frac{5}{8}$"		165 "
160, $\frac{7}{8}$" rivets		70 "
Total mat, equals-------------------------------		2380 "

Details of end floor beams will be shown in drawings

Load concentration on main panel joints.

Try wheel (3) at joint L_2

The length of uniform load from right end equals 210-91 equals 119';

$\frac{G}{N}$ quals $\frac{289 \text{ plus } 119 \times 2.1}{8}$ equals 67.5

$\frac{G}{1}$ equals $\frac{32}{1}$ or $\frac{53}{1}$ No Max.

Try wheel (4) at L_2

$\frac{G}{N}$ equals $\frac{289 \text{ plus}(210-86)\,2.1}{8}$ equals 68.67

$\frac{G}{1}$ equals 53 or 75 H max.

Hence the moment willbe a max. where wheel (4) is at L_2.

Moment about 19 equals 159 81

The right abutment is 124' to the right of 19:

Hence the total moment about right end equals

15981 plus 289 x 124 plus $\frac{124^2 \times 2.1}{2}$ equals 67872 ft.(1000#)

Left abutment reaction equals $\frac{67872}{8 \times 30}$

Moment of left abutment reaction about L_2 equals

$\frac{67872}{8 \times 30}$ x 30 -511 equals 7973

Wheel (9) gives a max. at L_4

Max. moment about L_4 equals 12650.

Wheel (13) gives a max. at L_6

Max. moment about L_6 equals 16497.

Wheel (16) gives the Max. at L_8

Max. moment about L_8 equals 17139.

The moment at U_0, U_1, U_2, U_3, equals

the moment at L_2 L_4 L_6 L_8 plus

the moment of the load at panel points L_3 L_5 &c about L_4 L_6 &c..

The max. panel load equals 60, and assuming it possible for the max. load and max. moment to come together we have moment about;

U_1 equals 12650 plus 60 x 15 equals 13550.

U_2 equals 16497 " " " " 17397

U_0 equals 7973 " " " " 8873.

LIVE LOAD SHEARS.

Wheel (3) at L_1 gives a max. shear in L_0-- L_1

Shear equals 29o.

The loading for max. shear in L_1 L_2 will be the same as for max. at L_0 ie. wheel (4) at L_2

$$S \text{ equals } \frac{15891 \text{ plus } 289 \times 124 \text{ plus } 2}{240} - \frac{\frac{124 \times 2.1}{511.1}}{30} \text{ Equals } 2657.$$

Wheel (4) gives max. at L_4

S equals 2o1.

Wheel (3) gives a max. at L_6

S equals 1444.

Wheel (3) gives a max. at L_8

S equals 967

Negative shears.

Wheel (3) at L_6 gives max. negative shear in L_6 L_7

S equals 57.9

Wheel (2) at L_4 gives a max. in L_4 L_5

S equals 26.1

WEB STRESS.

The max. stresses in the web members L_4 O_1 L_6 O_2 L_8 O_3 occur when max. shaer is in L_3 L_4, L_5 L_6, ----

max. stress in O_1 U_0 O_2 U_1 O_3 U_2 equals

max. stress in L_4 O_1 L_6 O_2 plus one half stress due to load on the corresponding sub-vertical at time of max shear in the panels as given above.

Wheel (5) gives max. shear in L_3 L_5 load an O_1 L_3 equals 3o.

Shear in L_3 L_5 equals 2o1.

Therefore ,vertical camponent in O_1 U_0 equals 2o1 plus 15 equals 216

Wheel (3) gives max. shear in $L_5 L_6, L_7 L_8$ the corresponding increment to be added for stress in upper half of diagonals equals 93.

While wheel (3) gives max. shears in panels last named, the Max. shear is only slightly in excess of shear for wheel(4) at the corresponding points, while the load on the sub-vertical is much greater. The Max. stress in the upper half of the diagonal will be when wheel (4) is at the corresponding panel points. We will use 15 as the increment to be added for vertical components.

S H O E   P I N .

ThE pressure on the shoe is vertical and equals the vertical component of stress in the portal post.

Pressure on shoe equals 532 x .8 equals 425.6

Bearing an area reqiured for pin equals

425.6 divided by 13.5 equals 31.52 sq.in.

Assume a 6"(pin for firsttrial), 31.52 divided by 6 equals)

5.25" bearing thickness required, or 2.62" on each side of Shoe. Each side of shoe will consist of 1 $\frac{1}{2}$" hinge plate 3 $\frac{1}{2}$" plates and 1 $\frac{3}{4}$" plate.

Each side of L_0 U_0 will consist of $\frac{11}{2}$" web plate reinforced with 4 $\frac{1}{2}$" plates and 1 $\frac{1}{2}$" hinge plate.

Horizontal forces are

L_0 L_1 equal 331.8 and L_0 U_0 equals 331.8

Vertical forces are

U_0 L_0 equals 425.6

L_0 to L_5 will consist of 4 Eye bars $\frac{11}{16}$" x 7" monment of $L_0 L_1$ on $L_0 U_0$ equals

155.9 x 2 $\frac{1}{4}$ equals 350

Momentum of $L_0 U_0$ on Shoe equals

212.8 x $\frac{3}{4}$ equals 159.6

M.(t) $(\overline{350^2 \text{ plus } 160^2})$ equals 385.

A 6" pin will be larger than needed for bending, will use

$6\frac{1}{8}$" pin to be uniform.

P I N FOR "U."

Assume $U_0 O_1$ have its Max. stress, also that $L_0 U_0$ & $U_0 U_1$. TO meet in a planned joint and have sufficient thickness to take up all bearing force, so that the pin will have to resist only the bearing and bending moment of

$U_0 L_1$ & $U_0 O_1$.

$U_0 L_0$ will consist of a $\frac{1}{2}$" web reinforced with two $\frac{1}{2}$"pin plates and one $\frac{1}{2}$" hinge plate.

$U_0 U_1$ will consist of $\frac{3}{8}$" web, one $\frac{5}{8}$" pin plate and one $\frac{1}{2}$"hinge plate. and one 1/2" pin Plate

$U_0 O_1$ will consist of 4 $1\frac{1}{8}$" x 7" Eyebars.

$U_0 L_1$ " " " 2 $1\frac{1}{16}$"x 6" " "

Vertical forces are

$U_0 O_1$ equals 372.7 x 8 equals 298.16 : equals $L_0 U_0$

$U_0 L_1$ equals 468

Horizontal forces are

$U_0 O_1$ equals 372.7 x 6 equals 223.62 equals U U

Momentum equals

$((149 \times 2 \text{ plus } 23.4 \times 3\frac{3}{4})^2 \text{ plus} (111.8 \times 2)^2)^{1/2}$ equals 445.

a 6 $\frac{1}{8}$"pin will answer for bending;

Bearing diameter equals

136.3 ÷ 13500 equals 6.11"

a 6 $\frac{1}{8}$" pin will answer.

PIN FOR U_1.

Assume same conditions for this point as for U_0 we have the forces U_1 L_4 compression and U_1 O_2 tension for the vertical forces, and U_1 O_1 & U_1 U_2 tension and compression for the horizontal forces.

U_1 L_4 will consist of 13" [reinforced to have a bearing thickness of $1\frac{1}{2}$"

U_1 O_2 will consist of two $1\frac{7}{16}$" x 7" eye bars.

Vertical forces are U_1 L_4 equals plus 195.7 equals $-U_1$ O_2

Horizontal forces are U_1 O_2 equals -146.6 equals plus U_1 U_2

bearing diameter required equals

$122.1 \div 13.5 \times 1\frac{7}{16}$ equals 6"

Moment equals $\left(\overline{93 \times 1\frac{1}{2}}^2 \text{ plus } \overline{74 \times 3^2}\right)^{\frac{1}{2}}$ equals 280 270

there the diameter of the pin will be determined by the bearing, Will use $6\frac{1}{8}$" pin.

Pin L_6

Assume Max. chord stress, and 60 per load on O_3 L_7

Then horizintal forces are

L_6 L_7 equals 624.9

L_5 L_6 " 439.2

O_2 L_6 " 117.7

O_3 L_6 " 18.

Vertical forces are

U_2 L_6 equals 130

O_3 L_6 equals 30

O_2 L_6 equals 160

$L_6 - L_7$ will consist of 6 eyebars $1\frac{3}{16}$" x 8"

L_4-L_6 will consist of 4 eyebars $1\frac{3}{8}$" x 8".

O_2 L_6 will consist of 2 eyebars $1\frac{5}{16}$" x 7"

U_2 L_6 will consist of 2 channels 12" x 9o# reinforced to1" thick for bearing.

O_3 L_6 will consist of [s 7" x 45# with $\frac{1}{2}$"eye plates.

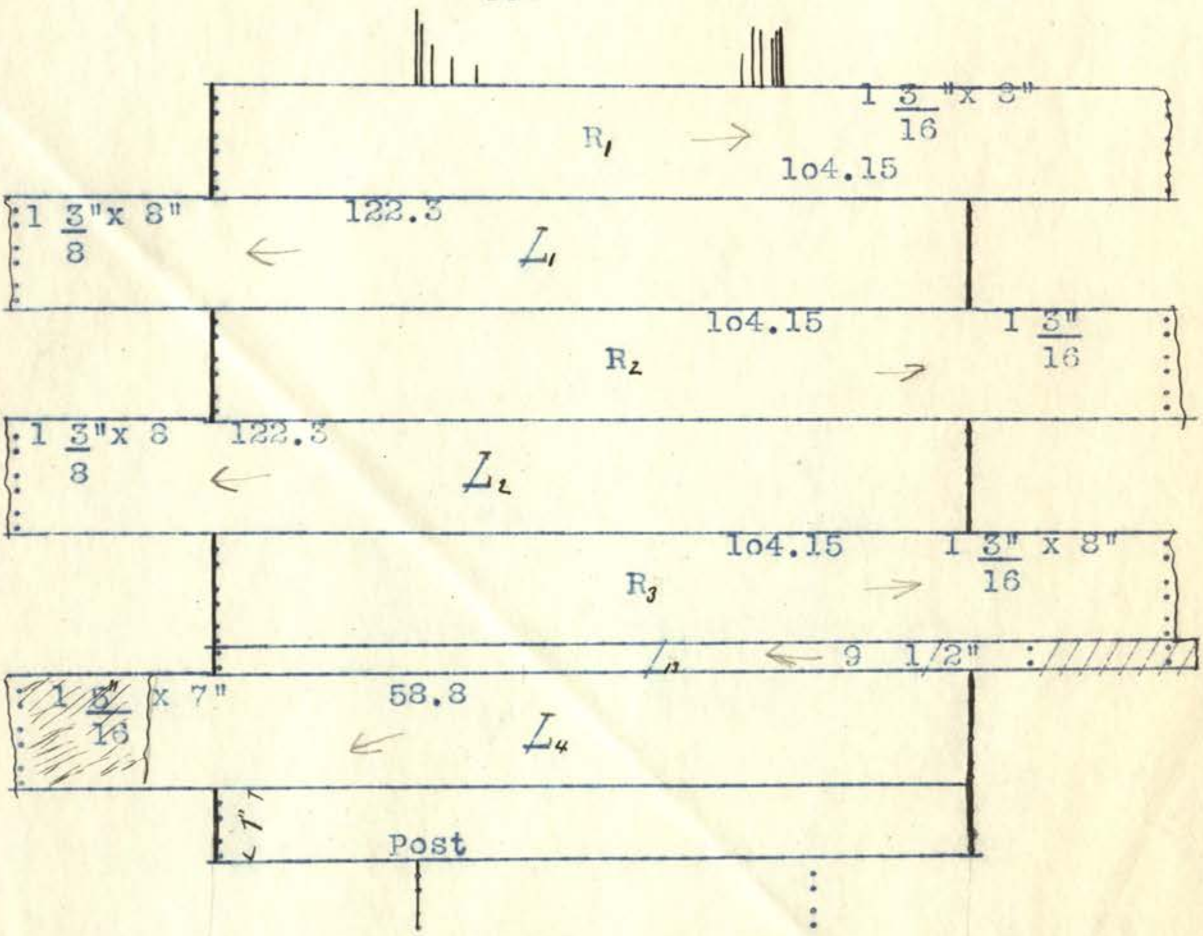
The bearing area at 15ooo# equals 41.6

" " " " 135oo# " 46. sq. in.

If we use six eyebars $1\frac{3}{16}$" thick the bearing depth will be $7\frac{1}{8}$"and the diameter of pin required fort he above cases will be 6'4" & 5.8".

PIN L_6

----oOo----



Plan of horizontal forces at joint L_6 showing method of packing half the joint. all joints to be packed as shown above. The lower chord eyebars to be placed within the post.

Horizontal bending moments on joint L_6

Member	stress	shear	arm	Bending moment Inc.	Total
R_1	plus1o415				
		+ 1o4.15	$\frac{15}{16}$	+136.7	
L_1	-122.3				+136.7
		- 18.15	$\frac{15}{16}$	-23.8	
R_2	1o4.15				+112.9
		36.	$1\frac{5}{16}$	+113.	
L_2	-122.3				+ 2259
		-36.3	$1\frac{5}{16}$	-47.6	
R_3	1o4.15				+178.3
		67.35	$1\frac{1}{2}$	1o1.8	
L_3	-9				+279.1
		000			
L_4	-58.8				

Vertical M. equals 15 xl plus 65 x $1\frac{1}{4}$ equals 95,

M.(t) equals $(\overline{95}^2$ plus $\overline{28o}^2)^{1/2}$ equals 296.

The bearing stress will determine the size of pin. For simplicity of erection and construction $6\frac{1}{8}$" pins will be used through out the structure, except at 0 where 4" pins will be used.

Member	Area	d	m	f	Af²	I	Af + I	r
a	15	23.75	356,25	10,11	1534.	.312	1534.312	
b	17.25	11.75	201,69	2,89	144.	.312 862.25	1006.25	
c	6.5	22.7	147,55	8,06	422.	4.52	462.52	
c'	9.25	8.	7,4	13,84	1772.	4.8	1776.8	
	48.		712,89				4743.882	
			14,64				99	9.1

The above is an analysis of U_0 U_1, the same "e" will be used for all members.

w equals 133.33 lbs per ft.

M.(w) equals $\frac{133.33 \times 30 \times 30 \times 12}{8}$ equals 247.500

S equals 482000

therefore e' equals $e_1 \frac{-247500}{482000}$ equals $e_1 - e_{11}$

equals 2.89 -51 equals 238.

Portal and upper chord members. using column formula:- a equals 10500-.24 $\left(\frac{l}{r}\right)^2$; r equals 9.1

L equals 50' for portal and 30' for chord members.

for portal a equals 9600 lbs.

portal area equals 532000÷9600 equals 55.4"

chord members:

a equals 10200 lbs.

U_0 U_1 equals 461200 ÷10200 equals 45.2" area required,

U_1 U_2 equals 596700 ÷ 10200 equals 58.5"

U_2 U_3 equals 629300 ÷ 10200 equals 61.7"

POSTS.

Using same formula as above.

U_1 L_1 Try 13" [assume r equals 4.9

a equals 10500-24 $\left(\frac{l}{r}\right)^2$

equals 82oo or 81oo if r equals 4.8

this last r corresponds to 13" [of about 45 per ft, area 13 "

196ooo ÷81oo equals 24.2

two of the above channels will be used

$U_2 L_6$ will use two 12" x 3o" [per ft.

$U_3 L_7$ " " " " 24" " "

Portal bracing

R e uals 15oX 9o equals 135oo"

$\frac{P}{2}$ equals 15o x 15 equals 225o" , P equals 45oo"

C equals 5o', e equals 1o'

stress in $U_o U_o$ equals$\left(\frac{R \text{ plus } P}{2}\right)\frac{c}{e}$ plus $\frac{R}{2}$ equals

$\left(\frac{13500 \text{ plus } 4500}{2}\right)\frac{50}{10}$ plus $\frac{13500}{2}$ equals 517oo#

stress in D.D', 'equals $\frac{R \text{ plus } P}{2}$ $\frac{c}{e}$ equals $\frac{13500 \text{ plus} 4500 x5}{2}$

equals 45ooo#

stress in $U_o D'$ equals (R plus P) $\frac{c}{17}$ sec.e equals

$\frac{18000}{17}$ x 5o x $\frac{1}{5}$ equals 1o6ooo#

Bending M. at D. equals $\frac{R \text{ plus } P}{2}$) 5o-1o equals 36ooooft. ~~lbs.~~

stress $L_o U_o$ equals 36oooo ÷17 equals 212oo#

This stress will be included in the live load stress on the portal chord. The above is the analysis of the stresses in a simple portal as shown in sketch, and will serve as a guide for the amount of metal needed in type of portal bracing shown in drawings, which will be used in the proposed bridge.

The Portal, Lateral and vibration bracing will consist of angles and adapted to resist compression as well as tension. The details, sizes, methods of attaching, will be shown in the drawings.

The stress in the various members of the lateral systems are shown in sketch. No attempt is made to adjust the material in the lateral systems, precisely to the stress as the loss from using the greater variety of dimensions would be likely to exceed the gain by saving material.

P I N P L A T E S-.

L_0

Portal bearing of L_0 will consist of 5 $\frac{1}{2}$"plates on each side plate of portal post making a total bearing of6" including the side plates. The two inside plates are hinge plates. Since all plates have the same thickness they will require the same number of rivets.

The second plate from web on each side outside will extend over the flanges and receive the flange rivets, number of rivets required for each plate using $\frac{7}{8}$"rivets and allowing 4000" for single shear.

U equals $\dfrac{532000 \times \frac{1}{2}}{6} \div 4000$ equals 12.

total number of rivets required will be 36, method of placing them will be shown in drawing.

P I N P L A T E S.

PortalU_0

Portal U_0 will consist of a $\frac{1}{2}$" web plates reinforce with two $\frac{1}{2}$" plates, one $\frac{1}{2}$" hinge plate. The web and reinforcing plates to be planned to make a neat bearing joint, so that the hinge plate will not bear a full 1/4" of the pressure. On this account we will take effective bearing thickness at 3 $\frac{1}{2}$" in stead of 4".

U equals $\dfrac{532 \times \frac{1}{2} \div 4}{3\frac{1}{2}}$ equals 19

The hinge plate will receive the same number,

Chord U_0 will consist of $\frac{3}{8}$" web reinforced with a $\frac{5}{8}$", a $\frac{1}{2}$" plates and one $\frac{1}{2}$" hinge plate. Hinge plate of chord U_0 to be on the outside. The bearing conditions to be the same as above and the effective bearing depth the same.

U equals $\dfrac{461.2 \times \frac{1}{2} \div 4}{3\frac{1}{2}}$ equals 18

~~all plates will receive the same number~~

all plates will receive the same number.

Upper chord splices will be made at a convenient distance from the column pins and towards the end of the truss from pin. The same plates will be used for the splices that are used for pin plates at the corresponding joints, the ends of the chord shall be neatly planned to make a close joint but enough rivets will be used through the splice plate to take all the stress so that no reliance will be placed upon the butt joint, see drawings.

The lower side of the top chord will be fitted with tie plates 36" x 30" x $\frac{3}{8}$" placed on each side of the columns. The remainder of the chord will be latticed with 2½ x ~~4~~" x $\frac{3}{8}$" bars set at 45°. Double laced,

SHOE

Each shoe will consist of one 1" bed plate, one $\frac{3}{8}$" plate to be placed on top of bed plate and extend beyond bed plate, and inside. sufficiently far to attach the end members of the lower lateral system. The pin bearing members will be made of one $\frac{1}{2}$" hinge plate, three $\frac{1}{2}$" and one $\frac{3}{4}$" plates, the members to be attached to bed plates by four 6" x 6" x $\frac{3}{4}$" ∠s

End reaction equals 425600"

allow 250 " per sq.in. on the masonry

1700" required or 41" x 41"

allowed pressure on rollers equals 500 $\sqrt{d}$

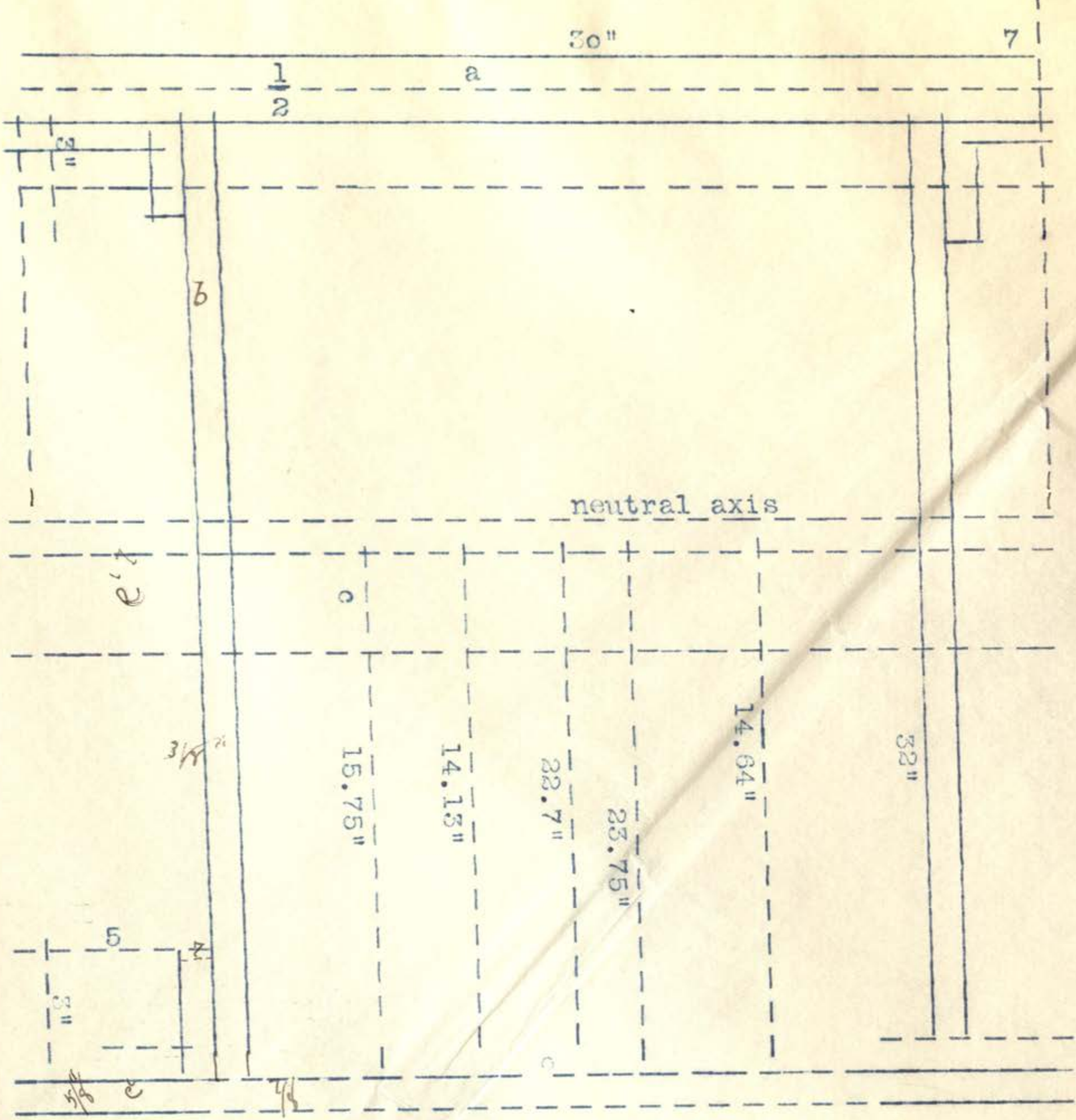
Let d equal 3

then p equals 500$\sqrt{3}$ equals 865"

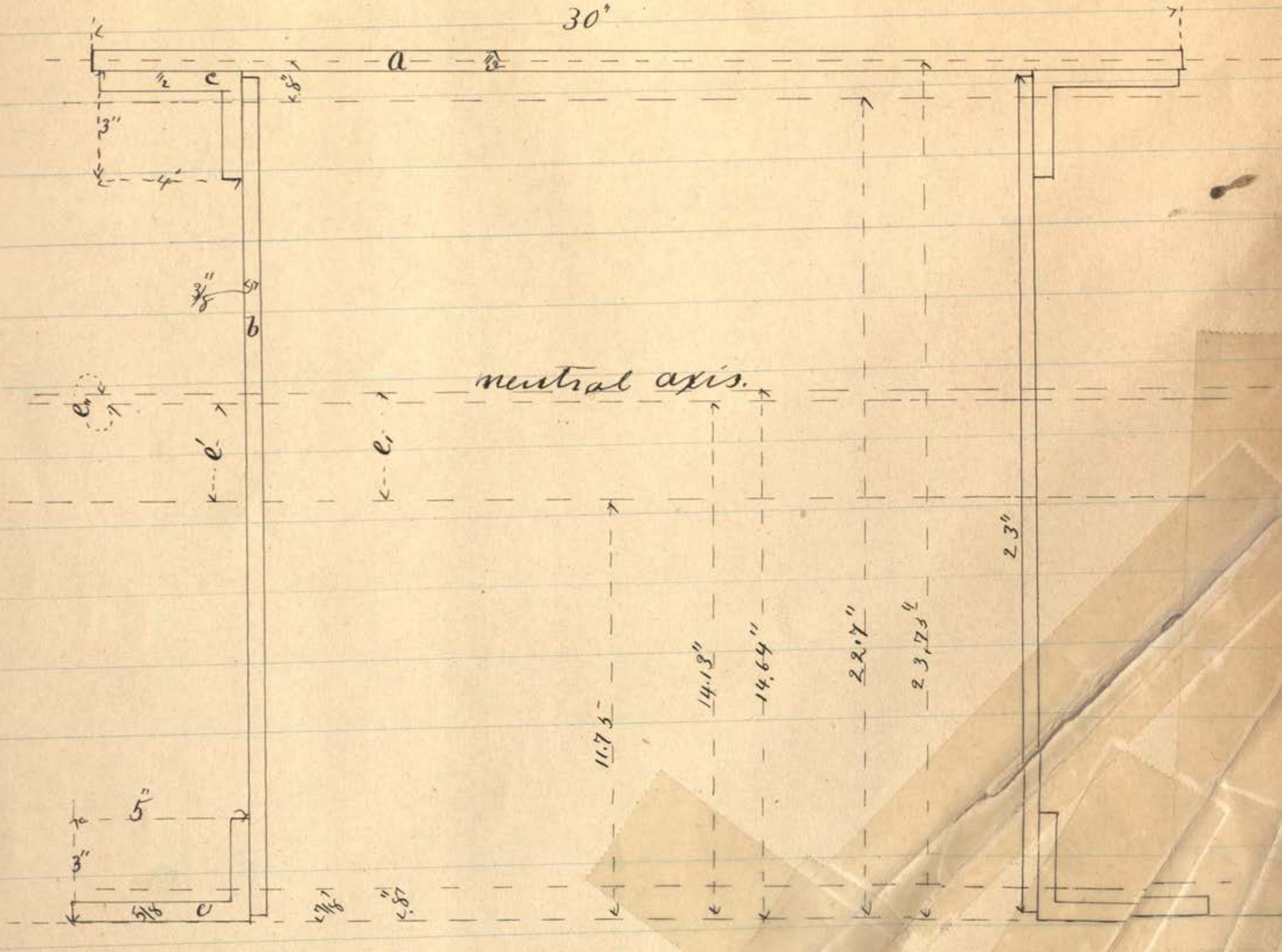
Then 492" of3" rollers will be required or 12.3 rollers

each 40" long, will use 13 and, to allow for expansion

and spacing of roller will use a bed plate 40" x 46".



30"
7
1
a
2
3"
b
neutral axis
e'
c
15.75"
14.13"
22.7"
23.75"
14.64"
32"
5
3"
e



Cross section and dimensions of

U. U.

Estimated weight of Material used in the structure.

Floor Beams	38000#
Stringers	52500
End Posts	18000
Upper chords	33800
Posts	17000
Semiverticals	6700
Hip verticals	2000
Main Diagonals	20800
Semidiagonals	6200
Lower Chords	31600
Lower lateral Bracing	3180
Upper " "	1960
Portal " "	1200
Pin Plates Stay Plates etc	9000
anchor Plates for lateral Bracing, Wts etc	400
Pins	4000
Total wt of metal in one truss =	290700#