Design
of an
Iron Warren Girder
R. R. Bridge.

May, 1874.

A. Honyuma.
of Japan

Design
of an
Iron Railroad Bridge.

Data.

The bridge is to be 192 ft. in span, 18 ft. in height, 14 ft. in width, — to have 16 panels, of 12 ft. each. Permanent load per foot is 800 lbs., — travelling load per foot is 1200 lbs.

The kind of Truss adopted is Zig-zag or Warren Truss.

Let w denote permanent load on each joint, = 9,600 lbs.
" w' " travelling " " " " = 14,400 "
Then total load " " " = 24,000 "

Let l denote the length of the bridge = 192 ft.
N " " number " panels = 16
h " " height " the bridge = 18 ft.
s " " length " diagonal braces = 21.6⅓ ft.

Total load on the truss $= W = (w+w')(N-1) = 360{,}000$

The horizontal stresses.

The supporting pressure at each end $= \frac{1}{2}W = 180{,}000$
Let this be denoted by F_0.

$\frac{l}{Nk}(w+w') = \frac{192}{16\times18}\,24000 = 16{,}000.$ $\qquad \frac{l}{Nk} = \frac{192}{16\times18} = \frac{2}{3}$

$$\frac{l}{Nk}F_0 = \tfrac{2}{3}\,180{,}000 = 120{,}000$$
$$\frac{l}{Nk}F_1 = 120000 - 16000 = 104{,}000$$
$$\frac{l}{Nk}F_2 = 104000 - 16000 = 88{,}000$$
$$\frac{l}{Nk}F_3 = 88000 - 16000 = 72{,}000$$
$$\frac{l}{Nk}F_4 = 72000 - 16000 = 56{,}000$$
$$\frac{l}{Nk}F_5 = 56000 - 16000 = 40{,}000$$
$$\frac{l}{Nk}F_6 = 40000 - 16000 = 24{,}000$$
$$\frac{l}{Nk}F_7 = 24{,}000 - 16000 = 8{,}000$$

Stresses in the chords.

$$H_1 = \frac{l}{Nk}F_0 = 120{,}000$$
$$H_2 = H_1 + \frac{l}{Nk}F_1 = 224{,}000$$
$$H_3 = H_2 + \frac{l}{Nk}F_2 = 312{,}000$$
$$H_4 = H_3 + \frac{l}{Nk}F_3 = 384{,}000$$
$$H_5 = H_4 + \frac{l}{Nk}F_4 = 440{,}000$$
$$H_6 = H_5 + \frac{l}{Nk}F_5 = 480{,}000$$
$$H_7 = H_6 + \frac{l}{Nk}F_6 = 504{,}000$$
$$H_8 = H_7 + \frac{l}{Nk}F_7 = 512{,}000$$

Diagonal stresses due to the permanent load.

$T_0 = \frac{Sw}{K}\frac{N-1}{2} = \frac{21.6\frac{1}{3}\times 800}{18}\ \frac{16-1}{2} =$ 86,533t (0,15)

$T_1 = T_0 - \frac{Sw}{K} = 86533 - 11538 =$ 74,995p (1,14)

$T_2 = T_1 -$ " $= 74995 -$ " $=$ 63,457t (2,13)

$T_3 = T_2 -$ " $= 63457 -$ " $=$ 51,919p (3,12)

$T_4 = T_3 -$ " $= 51919 -$ " $=$ 40,381t (4,11)

$T_5 = T_4 -$ " $= 40381 -$ " $=$ 28,843p (5,10)

$T_6 = T_5 -$ " $= 28843 -$ " $=$ 17,305t (6,9)

$T_7 = T_6 -$ " $= 17305 -$ " $=$ 5,767p (7,8)

Diagonal stresses due to the travelling load.

$S_0 = 0$ p.

$S_1 = \frac{Sw'}{NK} = 1082$ t

$S_2 = 3\frac{Sw'}{NK} = 3245$ p

$S_3 = 6\frac{Sw'}{NK} = 6490$ t

$S_4 = 10\frac{Sw'}{NK} = 10817$ p

$S_5 = 15\frac{Sw'}{NK} = 16225$ t

$S_6 = 21\frac{Sw'}{NK} = 22715$ p

$S_7 = 28\frac{Sw'}{NK} = 30287$ t

$S_{15} = 120\frac{Sw'}{NK} = 129800$ t

$S_{14} = 105\frac{Sw'}{NK} = 113573$ p

$S_{13} = 91\frac{Sw'}{NK} = 98432$ t

$S_{12} = 78\frac{Sw'}{NK} = 84370$ p

$S_{11} = 66\frac{Sw'}{NK} = 71390$ t

$S_{10} = 55\frac{Sw'}{NK} = 59492$ p

$S_9 = 45\frac{Sw'}{NK} = 48675$ t

$S_8 = 36\frac{Sw'}{NK} = 38940$ p

The greatest resulting stress on each diagonal brace.

Braces	T_n		S_{N-n-1}		
0, 15	86533t	+	129800t	=	216,333
1, 14	74995p	+	113575p	=	188,570
2, 13	63457t	+	98432t	=	161,889
3, 12	51919p	+	84,370p	=	136,289
4, 11	40381t	+	71,390t	=	111,771
5,10	28843p	+	59,492p	=	88,335
6, 9	17305t	+	48,675t	=	65,980
7,8	5767p	+	38,940p	=	44,707

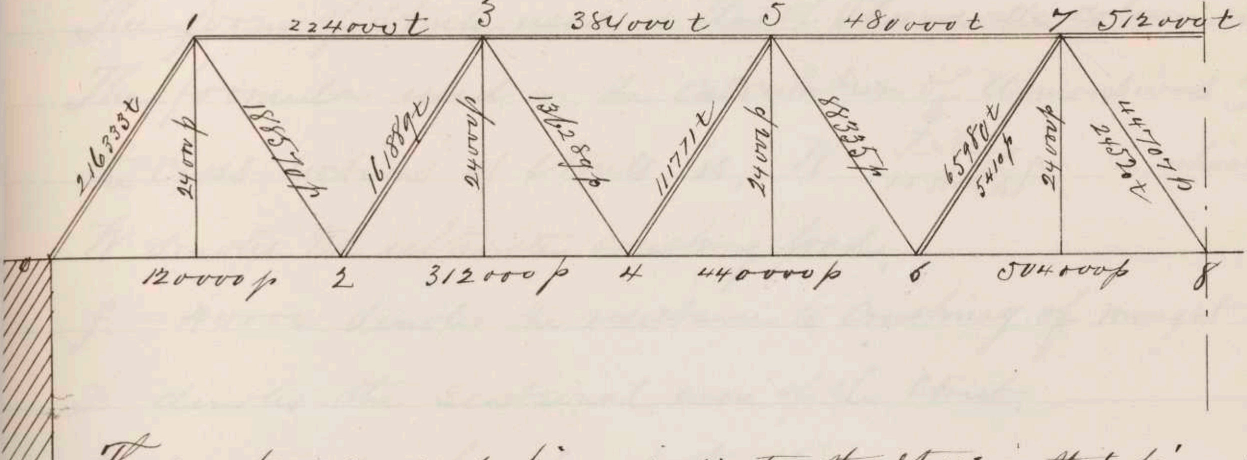
	S_n	T_n		
6,9	p = 22715	t = 17305	=	5410p
7,8	t = 30287	p = 5767	=	24520t

∴ 6 & 9 and 7 & 8 act as struts and ties.

Stresses in the vertical suspending rods.

The stresses are due to the load per joint, or 24000 lbs., and are the same for all the rods.

Diagram of a half of the bridge.



The number on each piece indicates the stress in that piece.

The struts are represented in double lines.

The strut 6 has to act as a tie with a stress of 5410 lbs.

The tie 7 " " " " strut " " " 24520 "

Calculations of Dimensions of the cross-sections of Struts.

The form of Struts used is that of Phoenixville columns.
The formula used in the calculation of dimensions of the cross-sections of Struts is, $W = \frac{fA}{1+\frac{1}{5000}\left(\frac{l}{h}\right)^2}$, in which
W denotes the ultimate crushing load,
$f = 40000$, denotes the resistance to crushing of wrought iron,
A denotes the sectional area of the Strut,
l denotes " length of the Strut,
h " " internal diameter (assumed) of the Strut.

The stresses in the Struts multiplied by a proper factor of Safety, taking into consideration both the rolling and permanent loads, will give W in the formula.
This factor of safety is obtained as follows:—

$$800 \times 3 = 2400$$
$$\frac{1200 \times 6}{2000} = \frac{7200}{9600} \div 2000 = 4.8 = \text{factor of Safety.}$$

The area A includes, besides the area of the cylindrical cell, that of flanges of the segments, and the calculation of that area is performed by means of the above formula.

$$A = \frac{W\left[1+\frac{1}{5000}\left(\frac{l}{h}\right)^2\right]}{f} = \frac{\text{Stress}\times 4.8\left[1+\frac{1}{5000}\left(\frac{l}{h}\right)^2\right]}{40000}$$

Struts in the upper chord.

Struts 1 & 13.

Stress = 224000 $\qquad l = 24' = 288''$

h is assumed, = 11"

$$\therefore A = \frac{224000\times 4.8}{40000}\left[1+\frac{1}{5000}\left(\frac{288}{11}\right)^2\right] = \frac{224\times 1.2}{10}\left[1+.1371\right] = 30.565 \square \text{ in.}$$

The number of segments is six and flanges are $\frac{1}{2}''$ by $1\frac{3}{4}''$

So that, the joint area of the flanges $= \frac{1}{2}\times 1\frac{3}{4}\times 12 = 10.5 \square$ in

$30.565 - 10.5$ gives the area of the cell, $=\pi(r^2-r'^2)$ in which r denotes the outside diameter and r', the inner, $= 5.5''$

$20.065 = \frac{22}{7}(r^2-r'^2)$ from which r is found to be $6.05''$

d = the outside diameter $= 12.10''$, which is very nearly $12\frac{1}{8}''$

The corrected area of the cell $= 20.437 \square$ in. and its thickness $= \frac{1}{2}\left[12\frac{1}{8} - 11\right] = \frac{9}{16}''$.

Struts 3 & 11. Inside $d = 11''$ $l = 24' = 288''$

$$A = \frac{384000 \times 4.8}{40000}\left[1+\left(\frac{82944}{121}\right) \div 5000\right] = \frac{384 \times 1.2}{10}(1.1371) = 52.40 \square \text{in.}$$

6 Segments; $\frac{3}{4}'' \times 1\frac{3}{4}''$ flanges, whose joint area $= 15.75 \square$ in.

$\pi(r^2 - r'^2) = 52.40 - 15.75 = 36.65 \square$ in. or $r = 6.47''$

Outside $d = 12.94''$

or $12\frac{15}{16}''$

The corrected area of the cell $= 36.479 \square$ in.

Its thickness $= (12\frac{15}{16} - 11) \div 2 = \frac{31}{32}''$

Struts 5 & 9. Inside $d = 14\frac{3}{8}''$ $l = 24' = 288''$

$$A = \frac{480000 \times 4.8}{40000}[1 + .08] = 62.21 \square \text{in.}$$

8 Segments: flanges $\frac{3}{4}'' \times 2''$, — joint area $= 24 \square$ in.

$62.21 - 24 = 38.21 = \frac{22}{7}(r^2 - r'^2)$ or $r = 7.99''$

outside $d = 15.98''$ or $16''$

The corrected area of the cell $= 38.76 \square$ in.

Its thickness $= \frac{1}{2}(16 - 14\frac{3}{8}) = \frac{13}{16}''$

Strut 7.

Inside $d = 14\frac{3}{8}''$ $l = 288''$

Area $= \frac{512000 \times 4.8}{40000}(1+.08) = 66.36$ □ in.

8 Segments; flanges $\frac{3}{4}'' \times 2''$ — Joint area $= 24$ □ in.

$66.36 - 24 = 42.36 = \frac{22}{7}(r^2 - r'^2)$. or $r = 8.07''$

Outside $d = 16.14$ or $16\frac{5}{32}$

The corrected area of the cell $= 42.79$ □ in.

Its thickness $= (16\frac{5}{32} - 14\frac{3}{8}) \div 2 = \frac{57}{64}''$

Struts for diagonal bracing.

Struts 0 & 15. Inside $d = 11''$ $l = 21.6\frac{1}{3}'$

$$Area = \frac{216333 \times 4.8}{40000}\left[1 + \left(\frac{21.6\frac{1}{3} \times 12}{11}\right)^2 \div 5000\right] = 28.85 \square in.$$

6 Segments; flanges $\frac{1}{2}'' \times 1\frac{3}{4}''$, — joint area $= 10.5 \square in.$

$28.85 - 10.5 = 18.35 = \frac{22}{7}(r^2 - r'^2)$ or $r = 6.007''$

Outside $d = 12.014$ or $12''$

The corrected area of the cell $= 18.067 \square in.$

Its thickness $= \frac{1}{2}(12 - 11) = \frac{1}{2}''$

Struts 2 & 13. Inside $d = 11''$ $l = 21.6\frac{1}{3}'$

$$A = \frac{162000 \times 4.8}{40000}\left[1 + \left(\frac{21.6\frac{1}{3} \times 12}{11}\right)^2 \div 5000\right] = 21.61 \square in.$$

6 Segments; flanges $\frac{3}{8}'' \times 1\frac{3}{4}''$, — Joint area $= 7.875 \square in.$

$21.61 - 7.875 = 13.735 \square in = \frac{22}{7}(r^2 - r'^2)$ or $r = 5.883''$

Outside $d = 11.766''$ or $11\frac{25}{32}$

The corrected area of the cell $= 14.017 \square in.$

Its thickness $= \frac{1}{2}\left(11\frac{25}{32} - 11\right) = \frac{25}{64}''$

Struts 4 & 11.

Inside $d = 11''$ $l = 21.6\frac{1}{3}'$

$$A = \frac{112000 \times 4.8}{40000}\left[1 + \left(\frac{21.6\frac{1}{3} \times 12}{11}\right)^2 \div 5000\right] = 14.94 \square \text{ in.}$$

6 Segments; flanges $\frac{1}{4}'' \times 1\frac{3}{4}''$, — joint area = 5.25

$14.94 - 5.25 = 9.69 = \frac{22}{7}(r^2 - r'^2)$ or $r = 5.77''$

Outside $d = 11.54''$ or $11\frac{18}{32}$

The corrected area of the cell = 10.007 □ in.

Its thickness $= \frac{1}{2}\left(11\frac{18}{32} - 11\right) = \frac{9}{32}''$

Struts 6 & 9. Inside $d = 7\frac{3}{16}''$ $l = 21.6\frac{1}{3}$

$$A = \frac{66000 \times 4.8}{40000}\left[1 + \left(\frac{21.6\frac{1}{3} \times 12}{7\frac{3}{16}}\right)^2 \div 5000\right] = 9.986 \square \text{ in.} = 10 \square \text{ in.}$$

4 Segments; flanges $\frac{1}{4}'' \times 1\frac{3}{4}''$, — joint area = 3.5 □ in.

$10 - 3.5 \square \text{ in} = 6.5 = \frac{22}{7}(r^2 - r'^2)$ or $r = 3.87''$

Outside $d = 7.74''$ or $7\frac{3}{4}$

The corrected area of the cell = 6.673 □ in.

Its thickness $= \frac{1}{2}\left(7\frac{3}{4} - 7\frac{3}{16}\right) = \frac{9}{32}''$

Strut and Tie 7 & 8.

Pull $= 44707$ and this requires $4.4707 \square$ in. in the tie.

Thrust $= 24520$. Inside d is assumed $= 3\frac{5}{8}''$

$$A = \frac{24520 \times 4.8}{40000}\left[1 + \left(\frac{21.6\frac{1}{3} \times 12}{3\frac{5}{8}}\right)^2 \div 5000\right] = 5.958 \square \text{ in. or } 6 \square \text{ in.}$$

4 Segments; flanges $\frac{1}{4}'' \times 1\frac{1}{2}''$, — Joint area $= 3 \square$ in.

$$6 - 3 = 3 \square \text{ in.} = \frac{22}{7}(r^2 - r'^2) \quad \text{or } r = 2.06''$$

$$\text{Outside } d = 4.12''$$

The area of the cell $= 3 \square$ in.

Its thickness $= 2.06 - \frac{1}{2}3\frac{5}{8} = 2.06 - \frac{29}{16} = 2.06 - 1.81 = .25''$

Calculation of the weight of the Bridge.

Struts, in the upper chord and diagonal.

Struts 1 & 13. Wt. of 1 cu. in. of wrought iron = 5/18 lbs.

Area = 10.5 + 20.44 = 30.94 □ in.

Length = 24' - 21" = 288" - 21" = 267"

Wt. = $267 \times 30.94 \times \frac{5}{18}$ = 2295 lbs. each.

Struts 3 & 11.

Area = 15.75 + 36.479 = 52.23 □ in.

Length = 288" - 30" = 258"

Wt. = $258 \times 52.23 \times \frac{5}{18}$ = 3743 lbs. each.

Struts 5 & 9.

Area = 24 + 38.76 = 62.76 □ in.

Length = 288" - 30" = 258"

Wt. = $258 \times 62.76 \times \frac{5}{18}$ = 4498 lbs. each.

Strut 7. Area = 24 + 42.79 = 66.79 □ in. l = 288" - 30" = 258"

Wt. = $258 \times 66.79 \times \frac{5}{18}$ = 4787 lbs.

Struts 0 & 15.

Area = $10.5 + 18.07 = 28.57$ □ in.

Length = $21.6\frac{1}{3}' - 13'' = 259.6'' - 13'' = 246.6''$

Wt. = $246.6 \times 28.57 \times \frac{5}{18} = 1957$ lbs. each.

Struts 2 & 13.

Area = $7.875 + 14.017 = 21.89$ □ in.

Length = $259.6'' - 30'' = 229.6''$ $30'' = 14'' + 16''$

Wt. = $229.6 \times 21.89 \times \frac{5}{18} = 1396$ lbs. each.

Struts 4 & 11.

Area = $5.25 + 10 = 15.25$ □ in.

Length = $259.6'' - 30'' = 229.6''$

Wt. = $229.6 \times 15.25 \times \frac{5}{18} = 973$ lbs. each.

Struts 6 & 9.

Area = $3.5 + 6.67 = 10.17$ □ in.

Length = $259.6 - 30 = 229.6''$

Wt. = $229.6 \times 10.17 \times \frac{5}{18} = 649$ lbs. each.

Struts 7 + 8.

Area = 3+3 = 6 sq in. l = 259.6 - 30 = 229.6"

Wt. = $6 \times 229.6 \times \frac{5}{18}$ = 383 lbs. each

Joint weight of all the struts.

Upper chord.

Struts 1 + 13	2295 × 2	=	4590
" 3 + 11	3743 × 2	=	7486
" 5 + 9	4498 × 2	=	8996
Strut 7	4787	=	4787
Diagonals			
Struts 0 + 15	1957 × 2	=	3914
" 2 + 13	1396 × 2	=	2792
" 4 + 11	973 × 2	=	1946
" 6 + 9	649 × 2	=	1298
" 7 + 8	383 × 2	=	766
	Total	=	36575 lbs.

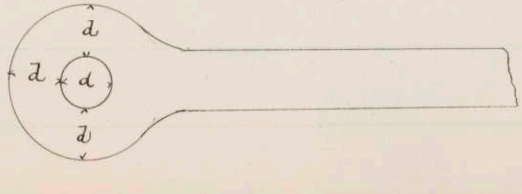
Ties.

The ties in the lower chord are divided into number of links of convenient sizes. This improves the appearance, besides serving to make the dimensions of connecting pins smaller.

The diagonal ties are ~~a~~ each divided into two equal links, and are fixed in the upper chord, to the cast iron joints by pins, — in the lower chord, they are also joined to the horizontal ties and the diagonal struts by means of pins.

The arrangement of ties or of links is shown on the accompanying drawing, — the distances from the centre line of the lower chord, to all the links being drawn to a scale.

The proportion of the heads to the pins is shown below: —



Calculation of the dimensions of Ties in the lower chord.

Ties 0 & 14. Pull = 120000. 2 links, $5'' \times 1\frac{1}{4}''$

Area required $= \frac{120000}{10000} = 12$ □ in.

" used $= 5'' \times 1\frac{1}{4}'' = 6.25$ □" for 1 tie.

or 12.5 □ in. for 2 ties.

Ties 2 & 12. Pull = 312000. 4 links, $5\frac{1}{2}'' \times 1\frac{1}{2}''$

Area required = 31.2 □ in.

" used $= 5\frac{1}{2} \times 1\frac{1}{2} = 8\frac{1}{4}$ □" for 1 tie

or $8\frac{1}{4} \times 4 = 33$ □" for 4 ties.

Ties 4 & 10.

Pull = 440000. 4 links, $6'' \times 1\frac{7}{8}''$

Area required = 44 □ in.

" used $= 6 \times 1\frac{7}{8} = 11\frac{1}{4}$ □ in. for 1 tie.

or $11\frac{1}{4} \times 4 = 45$ □ in. for 4 ties.

Ties in the lower chord.

Ties 6 & 8. Pull = 504000.

Area required = 50.4 □ in.

Area used = 51 □ in.

(a) Tie 6 is divided into 2 links $6'' \times 2\frac{1}{8}''$ and 4 links $6'' \times 1\frac{1}{16}$

(b) Tie 8 is divided into 8 links $6'' \times 1\frac{1}{16}''$

$$2(6 \times 2\tfrac{1}{8}) + 4(6 \times 1\tfrac{1}{16}) + 8(6 \times 1\tfrac{1}{16}) = 51 \text{ □ in.}$$

Diagonal Ties, — Dimensions.

Ties 1 & 14. Pull = 188570. 2 links $6'' \times 1\frac{5}{8}''$.

Area required = 18.857 □ in.

Area used = $6 \times 1\frac{5}{8} = 9\frac{3}{4}$ □" for 1 link.

or $9\frac{3}{4} \times 2 = 19.5$ □ in. for 2 links.

Ties 3 & 12. Pull = 136289. 2 links $5'' \times 1\frac{3}{8}''$

Area req. = 13.63 □ in.

Area used = $5 \times 1\frac{3}{8} = 6\frac{7}{8}$ □ in. for 1 link.

or $13\frac{3}{4}$ □ in. for 2 links.

Ties 5 & 10. Pull = 88335. 2 links $3\frac{5}{8}'' \times 1\frac{1}{4}''$

Area req. = 8.83 □ in.

Area used = $3\frac{5}{8} \times 1\frac{1}{4} = 4\frac{17}{32}$ □ in. for 1 link.

or $4\frac{17}{32} \times 2 = 9\frac{1}{16}$ □ in. 2 links.

Ties 7 & 8. Pull = 44707. 2 links $2\frac{1}{4}'' \times 1''$

Area req. = 4.47 □ in.

Area used = $2\frac{1}{4} \times 1 = 2\frac{1}{4}$ □ in. for 1 links

or $2\frac{1}{4} \times 2 = 4\frac{1}{2}$ □ in. 2 links.

Counter ties 6 & 9.

Pull = 5410. 1 link $1\frac{1}{8}'' \times \frac{1}{2}''$

Area req. = .541 □ in.

Area used = $1\frac{1}{8} \times \frac{1}{2} = \frac{9}{16}$ □ in. = .56 □ in.

Calculation of Wt. of Horizontal ties.

Call length 25', which will allow for the heads.

Ties 0 & 14.

Area = $2(5 \times 1\frac{1}{4}) = 12.5$ □ in.

Wt. = $25 \times 12 \times 12.5 \times \frac{5}{18} = 1042$ lbs. each.

Ties 2 & 12. Area = $4(5\frac{1}{2} \times 1\frac{1}{2}) = 33$ □ in.

Wt. = $33 \times 300'' \times \frac{5}{18} = 2750$ lbs. each.

Ties 4 & 10. Area = $4(6 \times 1\frac{7}{8}) = 45$ □ in.

Wt. = $45 \times 300 \times \frac{5}{18} = 3750$ lbs. each.

Ties 6 & 8. Area = $8(6 \times 1\frac{1}{16}) = 51$ □ in.

Wt. = $51 \times 300 \times \frac{5}{18} = 4250$ lbs. each.

Diagonal Ties. Call length = 23' = 276"

Ties 1 & 14. Area = $2(6 \times 1\frac{5}{8}) = 19.5$ □ in.

Wt. = $19.5 \times 276 \times \frac{5}{18} = 1495$ lbs. each

Ties 3 & 12 Area = $2(5 \times 1\frac{3}{8}) = 13.75$ □ in.

Wt. = $13.75 \times 276 \times \frac{5}{18} = 1054$ lbs. each.

Ties 5 & 10. Area $= 2(3\frac{5}{8} \times 1\frac{1}{4}) = 9\frac{1}{16}$ □ in.

$Wt. = \frac{145}{16} \times 276 \times \frac{5}{18} = 695$ lbs. each.

Ties 7 & 8. Area $= 2(2\frac{1}{4} \times 1) = 4\frac{1}{2}$ □ in.

$Wt. = \frac{9}{2} \times 276 \times \frac{5}{18} = 345$ lbs. each.

Ties 6 & 9 (Counter) Area $= 1\frac{1}{8} \times \frac{1}{2} = .56$ □ in, or $\frac{9}{16}$

$Wt. = .56 \times 276 \times \frac{5}{18}$

$= \frac{9}{16} \times 276 \times \frac{5}{18} = 43$ lbs. each.

Joint wt. of all the ties, Horizontal and Diagonal.

Ties	0 & 14.	1042 × 2	=	2084
	2 & 12.	2750 × 2	=	5500
	4 & 10.	3750 × 2	=	7500
	6 & 8.	4250 × 2	=	8500
(Diagonal)	1 & 14.	1495 × 2	=	2990
	3 & 12.	1054 × 2	=	2108
	5 & 10.	695 × 2	=	1390
	7 & 8.	345 × 2	=	690
	6 & 9.	43 × 2	=	86
		Total	=	30848 lbs.

The Strength of the longitudinal Timber Beams.

There are four beams, two under rail, an inch apart.
The dimensions of the cross-sections, 16" × 8".
The breaking moment M_0 is expressed as follows:—

$M_0 = mWl$, in which $m = \frac{1}{4}$, the load being at the middle of the beam.

W = the breaking load,

l = the length of the beam.

$$\therefore W = \frac{M_0}{ml} = \frac{4M_0}{l} \qquad l = 12' = 144"$$

$M_0 = \frac{fI}{y_1}$ in which f = 10000 lb. per sq. in., the modulus of rupture for the timber used, I = the moment of inertia of the cross-section, $y_1 = \frac{1}{2}$ the depth of the beam = 8"

$$= \frac{10000}{8}\,\frac{1}{12}\,bh^3$$

$$= \frac{10000}{8 \times 12} \times 8 \times 16^3$$

$$= \frac{10000 \times 16^3}{12}$$

$$= \frac{10000 \times 4096}{12}$$

$$= \frac{40960000}{12} = 3,413,333.33$$

$$\therefore W = \frac{4 \times 3,413,333.33}{144} = \frac{3,413,333.33}{36} = 94537 \text{ lbs.}$$

For 4 beams, the breaking load = 94537 × 4 = 378,148 lbs.

Supposing the total load per 12 ft. of the bridge to be concentrated at the middle of the beams, we have for that load, multiplied ~~for~~ by the factor of safety 4.8,

$$\left.\begin{matrix} 800\times 12\times 2 \\ 1200\times 12\times 2 \end{matrix}\right\}\times 4.8 = 230400 \text{ lbs.}$$

So that the beams are stronger than safety requires.

Calculation of the Dimensions of Pins.

The dimensions are calculated for wrought iron, but the pins should be made of steel.

Resistance of wrought iron to shearing = 48000 lbs. per □ in.

Factor of safety = 4.8

48000 ÷ 4.8 = 10000 lbs.

Pins in the lower chord.

Pins 0 & 16.

Pull = 120000   Sheared in two sections.

Area of the pins = $\frac{120000}{2 \times 10000}$ = 6 sq. in.

Area " used = 7.06 □ in. — the diameter = 3 in.

Pins 2 & 14.

Pull = 312000   Sheared in six sections.

Area of the pins = $\frac{312000}{6 \times 10000}$ = 5.2 □ in.

Area used = 5.94 □ in. — the diameter = $2\frac{3}{4}$"

Pins 4 & 12.

Pull = 44,000 Sheared in eight sections.

Area of the pins = $\frac{44000}{8 \times 10000}$ = 5.5 □ in.

Area used = 5.94 □ in. — the diameter = $2\frac{3}{4}''$

Pins 6 & 10.

Pull = 504000 Sheared in six sections.

Area of the pins = $\frac{504000}{6 \times 10000}$ = 8.4 □ in.

Area used = 9.62 □ in. — the diameter = $3\frac{1}{2}''$

Pin 8.

Pull = 504000 Sheared in twelve sections.

Area of the pins = $\frac{504000}{12 \times 10000}$ = 4.2 □ in.

Area used = 7.07 □ in. — the diameter = 3''

Pins in the upper chord.

Pins #15. Pull = 188600. Sheared in two sections.

Area of the pins $= \frac{188600}{2 \times 10000} = 9.43$ sq in.

Area used $= 9.62$ sq in. — the diameter $= 3\frac{1}{2}$ in.

Pin 3 & 13. Pull = 136300. Sheared in two sections.

Area of the pins $= \frac{136300}{2 \times 10000} = 6.81$ sq in.

Area used $= 7.06$ sq in. — The diameter $= 3''$.

Pins 5 & 11. Pull = 88300. Sheared in two sections.

Area $= \frac{88300}{2 \times 10000} = 4.41$ sq in.

Area used $= 4.9$ sq in. The diameter $= 2\frac{1}{2}''$

Pin 7 & 9. Pull = 44707. Sheared in two sections

Area $= \frac{44707}{2 \times 10000} = 2.23$ sq in.

Area used $= 4.9$ sq in. — The diameter $= 2\frac{1}{2}''$

Calculation of the weights of pins.

Pins in the lower chord.

Pins 0 & 16. Area = 7.06 □ in. Length = 24.5"
$Wt. = 7.06 \times 24.5 \times \frac{5}{18} = 48$ lbs. each.

Pins 2 & 14. Area = 5.94 □ in. Length = 28"
$Wt. = 5.94 \times 28 \times \frac{5}{18} = 46$ lbs. each.

Pins 4 & 12. Area = 5.940 □ in. Length = 28"
$Wt. = 5.94 \times 28 \times \frac{5}{18} = 46$ lbs. each.

Pins 6 & 10. Area = 9.62 □ in. Length = 31"
$Wt. = 9.62 \times 31 \times \frac{5}{18} = 83$ lbs. each.

Pin 8. Area = 7.07 □ in. Length = 33"
$Wt. = 7.07 \times 33 \times \frac{5}{18} = 65$ lbs.

Pins in the upper chord.

Pins 1 & 15. Area = 9.62 □ in. Length = 24"
Wt. = $9.62 \times 24 \times \frac{5}{18}$ = 64 lbs. each.

Pins 3 & 13. Area = 7.06 □ in. Length = 24"
Wt. = $7.06 \times 24 \times \frac{5}{18}$ = 47 lbs. each.

Pins 5 & 11. Area = 4.9 □ in. Length = $24\frac{1}{2}$"
Wt. = $4.9 \times 24.5 \times \frac{5}{18}$ = 33 lbs. each.

Pin 7 & 9. Area = 4.9 □ in. Length = 23"
Wt. = $4.9 \times 23 \times \frac{5}{18}$ = 31 lbs. each

Joint weight of all the pins.

Pin 0 & 16.	48 × 2 = 96		Pins 1 & 15.	64 × 2 =	128 lbs.
2 & 14.	46 × 2 = 92		3 & 13.	47 × 2 =	94 "
4 & 12.	46 × 2 = 92		5 & 11.	33 × 2 =	66 "
6 & 10.	83 × 2 = 166		7 & 9.	31 × 2 =	62 "
8.	65 = 65				350
	511				

Total wt. of pins = 511 + 350 = 861 lbs.

The transverse floor beams.

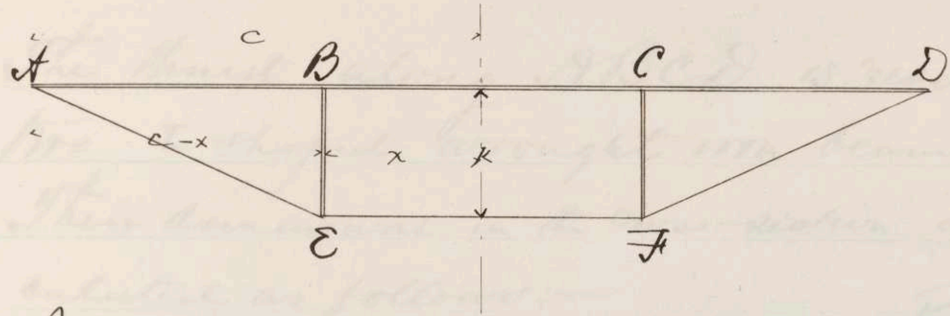
The form of beams adopted is Trapezoidal Truss. Their Construction is shown on the accompanying drawing.

Calculation of Stresses in the Struts and ties.

Travelling load per 12 ft. of the bridge $= 2400 \times 12 = 28,800$ lbs.

Fixed load consists of the following:—

Rails at 65 lbs. per yd. — 8 yds. $= 2 \times 12'$	=	520
Six wooden ties, $8'' \times 8'' \times 120''$, at .03 lb. cu. in.	=	1380
Four longitudinal wooden beams, $16'' \times 8'' \times 144''$, at .03 lb. cu. in.	=	2212
Two I beams of wrought iron, 17' long, at 60 lbs. per yd.	=	680
Four Inclined ties, $60'' \times \frac{7}{2}'' \times 1''$, at $\frac{5}{18}$ lbs. cu. in.	=	233
Two Horizontal ties, " "		117
Two Vertical Struts (wt. assumed)	=	100
Total fixed load	=	5242



In the diagram, c denotes the half-span of the truss.

x " the distance of B and C from the centre.

k " the depth of the truss.

Let W denote the greatest load on each of the points B & C, including one-quarter of the weight of the truss, so that

$$W = \tfrac{1}{4}(5242\times3)+(6\times14450)$$

$$= 90330 \text{ lbs.}$$

Let H = the total thrust along ABCD

T = " " tension on each of the inclined ties AE & DF.

Then $H = W(c-x) \div k = \frac{90330\times(7-2\frac{1}{2})}{2} = 203,243$,

$T = \sqrt{W^2+H^2} = \sqrt{90330^2+203243^2} = 222,410.$

The thrust along ABCD is resisted by two I-shaped wrought iron beams. Their dimensions in the cross-section are calculated as follows:—

Applying the formula, $S = \frac{P}{36000 \div (1 + \frac{l^2}{36000 r^2})}$ to the case of I or H shaped beams, we have $S = \frac{P(1 + \frac{l^2}{36000} \frac{b^2}{12} \frac{4}{A(B)})}{36000}$ in which S denotes the sectional area of the beam; P, the breaking or crushing load; l, the length of the beam; b, the breadth of the flanges; A the joint area of the flanges; B, the area of the web. In the present case A is assumed to be = B, $b = 3\frac{1}{2}''$, and the depth of the beams 7″.

$$S = \frac{102000}{36000}\left(1 + \frac{(14' \times 12)^2}{36000 \cdot \frac{49}{4} \cdot \frac{1}{2} \cdot \frac{1}{12}}\right)$$

$$= \frac{102000}{36000}\left(1 + \frac{28224 \times 2 \times 12 \times 4}{36000 \times 49}\right) = \frac{17}{6}(1 + 1.536)$$

$$= 7.1850 \square \text{ in.}$$

Make flanges $3\frac{1}{2} \times \frac{5}{8}''$, or for two flanges Area $= 4.375$
" Web $5\frac{3}{4}'' \times \frac{1}{2}$, area $= \underline{2.875}$
7.250 □in.

The tension along EF is resisted by two wrought iron ties.

The req. area $= \frac{203243}{60000} = 3.4$ □in. for both.

Making each tie $3'' \times \frac{5}{8}''$, area $= 1.875$ □"

joint area $= 3.750$ □in.

The tension along AE & DF is resisted by two wrought iron ties,

The req. area $= \frac{222410}{60000} = 3.7$ □in. for both.

Making each tie $3'' \times \frac{5}{8}''$, area $= 2.25$ □in,

joint area $= 4.5$ □in,

The thrust along the vertical Struts BE & CF is simply the greatest load on each of them, or 90330

The req. area $= \frac{90330}{100000} = .9$ □in.

These Struts have more area than is required for greater safety against vibrations, &c.

The different pieces of the truss are joined to one another by means of steel pins.

Pins at A & D have to resist the shearing stress of 222,410, but require for their sectional area only one half of the area $= \frac{222,410}{50000} = 4.44$ □ in being sheared in two sections.

∴ the required area = 2.22 □ in.

Making the diameter 2", the area = 3.14 □ in.

For the joints E & F, pins of the same dimensions are used.

At the joints A & D, thickening plates of cast iron are riveted on to the webs of the I beams to resist the crushing.

The floor trusses are hung by means of wrought iron suspending rods, from each side of the cast iron joints in the upper chord.

The total load which ~~each~~ pair of rods must bear is the sum of travelling load per 12', multiplied by the factor of safety, 6, and the fixed load per 12', multiplied by the factor of safety 3, as follows:—

$$\left.\begin{array}{r}14402 \times 6 \\ 5242 \times 3\end{array}\right\} = 102126 \text{ lbs. for each pair rods.}$$

51063 " for each rod.

Area req. $= \frac{51063}{60000} = .85 \square$ in.

Calling the diameter $1\frac{1}{2}''$, area $= 1.767 \square$ in.

Weights of Cast Iron joints.

In calculating these weights, the joints are considered to have twice the average area of the struts abutting into them, with a common length of 36". Joints 1 & 15 are excepted.

Joints 1 & 15. 2 Average area = 30 × 2 = 60 □ in.
Length = 15 in.
Wt. = $60 \times 15 \times \frac{5}{18}$ = 250 lbs.

Joints 3 & 13 2 average area = 83 □ in.
Length = 36"
Wt. = $36 \times 83 \times \frac{5}{18}$ = 830 "

Joints 5 & 11. 2 average area = 115 □ in.
Wt. = $115 \times 36 \times \frac{5}{18}$ = 1150 "

Joints 7 & 9. 2 Average area = 128 □ in.
Wt. = $128 \times 36 \times \frac{5}{18}$ = 1280 "

Cast Iron shoes.

In calculating the weights of these pieces, they have been considered to have a common length of 20" and an area equal to twice the area of the struts that rest on them.

Joints 2 & 14. 2 Area = 43 □ in.
$Wt. = 43 \times 20 \times \frac{5}{18} =$ 239 lbs

Joints 4 & 12. 2 area = 30 □ in.
$Wt. = 30 \times 20 \times \frac{5}{18} =$ 167 "

Joints 6 & 10 2 area = 20 □ in.
$Wt. = 20 \times 20 \times \frac{5}{18} =$ 111 "

Two counter struts at Joint 8. 2 Area = 12 □ in.
$Wt. = 12 \times 20 \times \frac{5}{18} =$ 67 "

The total weight of cast iron joints and shoes.

Joints	1 + 15.	250 lbs.
	3 + 13.	830 "
	5 + 11.	1150 "
	7 + 9.	1280 "
Shoes	2 + 14.	239 "
	4 + 12.	167 "
	6 + 10.	111 "
	8 .	67 "

4094 × 2 = 8188 lbs. on one girder.
16376 " both girders.

Horizontal Bracing.

Roof ties $29' \times 1.77$ □ in. Total number = 14.

Diameter = $1\frac{1}{2}''$

Combined Wt. $348'' \times 1.77 \times \frac{5}{18} \times 14 = 2395$ lbs.

Roof Struts. Length = $13' 6'' = 162''$

Area = 2.8 □ in. Total no. = 8.

Combined Wt. = $162 \times 2.8 \times \frac{5}{18} \times 8 = 1008$ lbs.

Floor ties. Length = $21' = 252''$

Area = 3.14 □ in. diameter = $2''$

Total number = 32.

Combined weight = $252 \times 3.14 \times 32 \times \frac{5}{18} = 7034$ lbs.

Total weight of bracing = $2395 + 1008 + 7034 = 10437$ lbs.

Suspending rods.

These rods have a common length of 20'
Their sectional area = 1.770 in.

Diameter = $1\frac{1}{2}''$.

Total number = 32 (for both girders).

Combined weight = $240'' \times 1.77 \times \frac{5}{18} \times 32 =$ 3776 lbs.

Total Weight of the bridge.

Struts, horizontal & diagonal,	72926
Ties " "	61696
Pins, in the upper & lower chords,	1722
Cast iron joints & shoes,	16376
Suspending rods,	3776
Bracing ties & struts,	10437
Flooring for 15 panels	78630
Two end half panels	4112
Grand Total =	249675

The fixed load per foot $= \frac{249600}{192} = 1300$ lbs.

The given fixed load per foot $= 800 \times 2 = 1600$ lbs.
The gain per foot $=$ 300 lbs