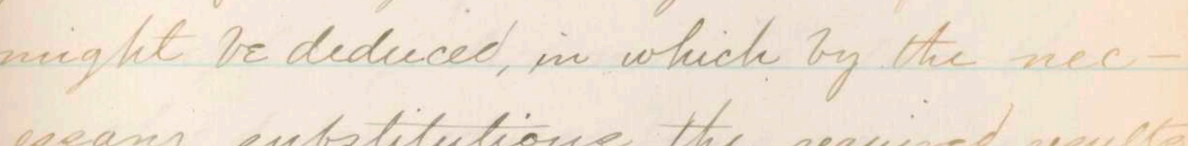
G. E. Doane 1874

The problem given is a Double Warren Girder, the span being 192 feet, and height 18 ft. It is divided into sixteen bays or panels, of twelve feet each. The wt. per. foot of the girder itself, or dead load as it is called, is 800 lbs. The weight per. foot of the passing or live load is 1200 lbs. The factors of safety are for the live load six, and for the dead load three.

This is a compound girder being composed of two Warren Girders. The problem is one to be solved by considering the load to be applied at points and not as uniformly distributed, because the transverse beams upon which the road-bed rests are not near enough together to consider the load uniform

As there are sixteen bays, there will consequently be fifteen loaded points. In order to find the stresses in various parts of the girder a general formulae might be deduced, in which by the necessary substitutions the required results would be obtained. In working out this case however, I shall use only the general principles of moments and of shearing forces.

1



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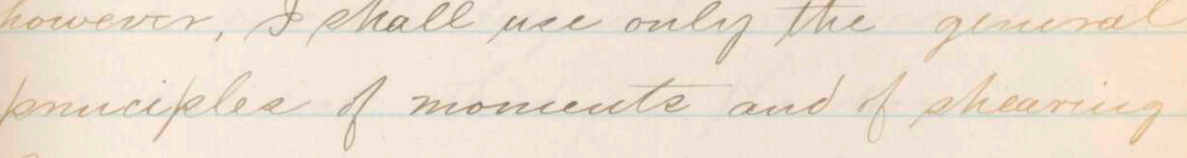

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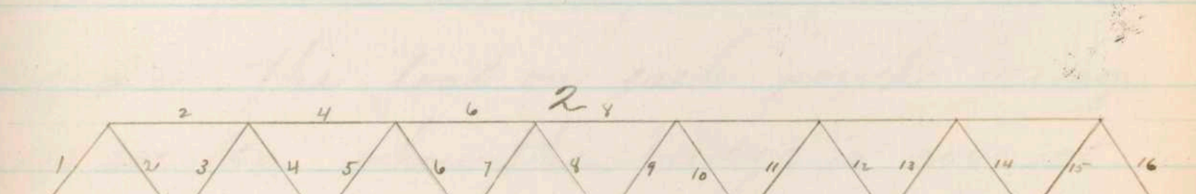

The preceding diagrams show, first the Double Girder, second and third the two simple girders of which it is composed. I first calculate the stresses in simple girder number two; the method of procedure being as follows. First, calculate the chord stresses. Second, find the diagonal stresses due to the dead load. Third, find the diagonal stresses due to the live load. Fourth, find the result stresses in diagonals.

In this girder there are seven loaded points as may seen from the diagram, the load on each point being 115200 lbs. when the bridge is covered with both the live and dead loads. The weight due to the dead load is 800 x 12' x 3 = 28800, in which 800 is the wt. per. foot, 12 the number of feet which each point has to support, and 3, a factor of safety.

The weight due to the live load = 1200 × 12 × 6 = 86400, in which 1200 is the weight per. foot, 12, the number of feet one point has to support, and 6, the factor of safety; adding the two gives as before stated 115 200 lbs. as the total load on each point.

1st. To find the chord stresses. These will be greatest when the whole bridge is covered with both the live and dead load; the method employed is, to divide the bending moment at any section by the height of the girder, which is constant.

The greatest shear acts at either of the points of support, and equals

$$\frac{115\,200 \times 7}{2} = \frac{806\,400}{2} = 403\,200 \text{ lbs} = F_0 \quad \therefore$$

$$M_1 = 403\,200 \times 12 = 4838\,400$$

$$M_2 = 403\,200 \times 24 = 9676\,800$$

$$M_3 = 403\,200 \times 36 - 12 \times 115\,200 = 13\,13\,2800$$

$M_4 = 403200 \times 48 - 24 \times 115200 = 16588800$

$M_5 = 403200 \times 60 - 12 \times 115200 - 36 \times 115200 = 18662400$

$M_6 = 403200 \times 72 - 24 \times 115200 - 48 \times 115200 = 20736000$

$M_7 = 403200 \times 84 - 12 \times 115200 - 36 \times 115200 - 60 \times 115200 = 21427200$

$M_8 = 403200 \times 96 - 24 \times 115200 - 48 \times 115200 - 72 \times 115200 = 22118400$

$H_1 = \frac{M_1}{18} = 268800, \quad H_5 = \frac{M_5}{18} = 1036800$

$H_2 = \frac{M_2}{18} = 537600, \quad H_6 = \frac{M_6}{18} = 1152000$

$H_3 = \frac{M_3}{18} = 729600, \quad H_7 = \frac{M_7}{18} = 1190400$

$H_4 = \frac{M_4}{18} = 921600, \quad H_8 = \frac{M_8}{18} = 1228800$

2nd To find the diagonal stresses due to the dead load. In order to do this I must first find the shearing forces due to the dead load, then multiply the shearing force which acts in the panel of which the diagonal in question is a member, by the sec. of the angle the diagonal makes with a verticle. In this case the sec. is 1.202, because in the right-angled triangle of which this diagonal forms the hypothenuse, the sides are respectively, twelve and eighteen feet, therefore the length of the diagonal equals $\sqrt{(12)^2+(18)^2} = 21.6333$, and consequently the $\sec.\phi = 1.202$

$F_0 = [800 \times 12 \times 3 \times 7] \div 2 = 100800$ = shear on 1 + 2

$F_1 = 100800 - 28800 = 72000$ = " " " 3 + 4

$F_2 = 72000 - 28800 = 43200$ = " " " 5 + 6

$F_3 = 43200 - 28800 = 14400$ = " " " 7 + 8

$T_0 = 100800 \times 1.202 = 121161.6$ = Stress on 1 + 2

$T_1 = 72000 \times 1.202 = 86544.0$ = " " 3 + 4

$T_2 = 43200 \times 1.202 = 51926.0$ = " " 5 + 6

$T_3 = 14400 \times 1.202 = 17308.8$ = " " 7 + 8

3rd Find the diagonal stresses due to the live load. This is done by finding the shearing forces due to the same, and multiplying by the sec ϕ. viz. 1.202.

The shearing forces are greatest, when

the longer division of the bridge is loaded with the live load; for in this case the resultant acts in the same direction as the resultant of the dead load.

When the shorter segment is loaded with the live load, the resultant shear acts directly opposite to that of the dead load. I therefore find the shearing forces due to the live load, considering one less point loaded each time

$F_0' = [14400 \times 7 \times 6] \div 2 = 302400$ = shear on 1 & 2

$F_1' = [6 \times 14400 \times 6] \times [(3 \times 24) + 12] \div 192 = 226800$ = shear on 3 & 4

$F_2' = (5 \times 86400 \times 3 \times 4) \div 192 = 162000$ = " " 5 & 6

$F_3' = (4 \times 86400 \times 60) \div 192 = 108000$ = " " 7 & 8

$F_4' = 3 \times 86400 \times 48 \div 192 = 64800$ = " " 9 & 10

$F_5' = 2 \times 86400 \times 36 \div 192 = 32400$ = " " 11 & 12

$F_6' = 1 \times 86400 \times 24 \div 192 = 10800$ = " " 13 & 14

$F_7' = 0$ = " " 15 & 16

Now multiplying each of the above by 1.202

= sec φ I obtain

T_0' = 302400 × 1.202 = 363484.8 = stress on 1+2

T_1' = 226800 × 1.202 = 272613.6 = " " 3+4

T_2' = 162000 × 1.202 = 194724.0 = " " 5+6

T_3' = 108000 × 1.202 = 129816.0 = " " 7+8

T_4' = 64800 × 1.202 = 77889.6 = " " 9+10

T_5' = 32400 × 1.202 = 38944.8 = " " 11+12

T_6' = 10800 × 1.202 = 129981.6 = " " 13+14

T_7' = 0 × 1.202 = 0 = " " 15+16

4th Find the resultant diagonal stresses. This is accomplished by combining the stresses due to the dead load, with those due to the live load. With the dead load alone the diagonals, 1, 3, 5, 7, 10, 12, 14, 16, act as struts, and 2, 4, 6, 8, 9, 11, 13, 15, act as ties, therefore.

S_0 = 121162 + 363485 = 484647 = resultant in 1+2

S_1 = 86544 + 272614 = 359158 " " " 3+4

S_2 = 51926 + 194724 = 246650 " " " 5+6

$S_3 = 17309 + 129816 = 147125$ = resultant in 7 + 8

$S_4 = 17309 - 77890 = -60581$ = " " " 9 + 10

$S_5 = 51926 - 38945 = 12981$ = " " " 11 + 12

$S_6 = 86544 - 12982 = 73562$ = " " " 13 + 14

$S_7 = 121162 - 0 = 121162$ = " " " 15 + 16

The results as far as S_4 show the greatest stress the diagonals are subject to, and act, 1 as a strut, 2 as a tie, 3 a strut, 4 a tie and so on up to diagonal number 9, when we find a minus result, which shows that diagonals 9 and 10 act alternately as a strut or or as a tie when the load is coming onto the bridge from B. If the load came from the other end, 7 and 8 would act alternately, hence, S_4 being a minus quantity, shows that the two diagonals on either side of the centre act alternately as struts and as ties. The remaining results simply show the stresses when the smaller seg-

-ment is loaded. This ends simple girder number 2. I might perhaps say a few words on the notation used. M_1 represents the moment, and H_1 the chord stress in 1 in the lower chord. M_2 and H_2 the moment, and stress, in 2 in upper boom or chord, and so on. F and T represent the shearing force, and diagonal stress due to dead load. F' and T' represent the same due to the live load. S equals resultant diagonal stress.

In finding the shearing forces due to the dead load I only go up to the centre as they are exactly the same on both sides.

Now take simple girder number three. The method of precedure is the same as for simple girder number two.

Here there are eight loaded points, and the load at each point is the same as in number 2 viz. 115 200 lbs. therefore this girder bears 8/15 of the load, while number 2 bears 7/15. In practice it is quite common to consider each simple girder as sustaining one half the load.

1st The chord stresses

$F_0 = 115200 \times 8 \div 2 = 460800$

$M_1 = 460800 \times 12 = 5529600$

$M_2 = 460800 \times 24 - 12 \times 115200 = 9676800$

$M_3 = 460800 \times 36 - 24 \times 115200 = 13824000$

$M_4 = 460800 \times 48 - 12 \times 115200 - 36 \times 115200 = 16588800$

$M_5 = 460800 \times 60 - 24 \times 115200 - 48 \times 115200 = 19353600$

$M_6 = 460800 \times 72 - 12 \times 115200 - 36 \times 115200 - 60 \times 115200 = 20736000$

$M_7 = 460800 \times 84 - 24 \times 115200 - 48 \times 115200 - 72 \times 115200 = 22118400$

$M_8 = 460800 \times 96 - 12 \times 115200 - 36 \times 115200 - 60 \times 115200 - 84 \times 115200 = 22118400$

Dividing the above by 18 we obtain the stresses,

$H_1 = \frac{M_1}{18} = 307200,$ $H_2 = \frac{M_2}{18} = 537600$

$H_3 = \frac{M_3}{18} = 768000,$ $H_4 = \frac{M_4}{18} = 921600$

$H_5 = \frac{M_5}{18} = 1075200,$ $H_6 = \frac{M_6}{18} = 1152000$

$H_7 = \frac{M_7}{18} = 1228800$ $H_8 = \frac{M_8}{18} = 1228800$

2nd Diagonal stresses due to dead load.

These are found in the same manner as in number 2.

$F_0 = (9600 \times 3 \times 8) \div 2 = 115200 =$ shear on 1

$F_1 = 115200 - 28800 = 86400 =$ " " 2 + 3

$F_2 = 86400 - 28800 = 57600 =$ " " 4 + 5

$F_3 = 57600 - 28800 = 28800 =$ " " 6 + 7

$F_4 = 28800 - 28800 = 0 =$ " " 8

Multiplying the above by sec. $\varphi = 1.202$ we obtain,

$T_0 = 115200 \times 1.202 = 138470.4 =$ stress in 1

$T_1 = 86400 \times 1.202 = 103852.8 =$ " " 2 + 3

$T_2 = 57600 \times 1.202 = 69235.2 =$ " " 4 + 5

$T_3 = 28800 \times 1.202 = 34617.6 =$ " " 6 + 7

$T_4 = 0 \times 1.202 = 0 =$ " " 8

3rd To find diagonal stresses due to the live load. Same principle as in girder No. 2

$F_0' = (14400 \times 6 \times 8) \div 2 = 345600$

$F_1' = \{7 \times 86400 \times [(3 \times 24) + 12]\} \div 192 = 264600$

$F_2' = (6 \times 86400 \times 3 \times 24) \div 192 = 194400$

$F_3' = (5 \times 86400 \times 60) \div 192 = 135000$

$F_4' = (4 \times 86400 \times 48) \div 192 = 86400$

$F_5' = (3 \times 86400 \times 36) \div 192 = 48600$

$F_6' = (2 \times 86400 \times 24) \div 192 = 21600$

$F_7' = (1 \times 86400 \times 12) \div 192 = 5400$

$F_8' = 0$

Multiplying by sec. ϕ we have,

$T_0' = 345600 \times 1.202 = 415411.2$ = stress in 1

$T_1' = 264600 \times 1.202 = 318049.2$ = " " 2 + 3

$T_2' = 194400 \times 1.202 = 233668.8$ = " " 4 + 5

$T_3' = 135000 \times 1.202 = 162270.$ = " " 6 + 7

$T_4' = 86400 \times 1.202 = 103852.8$ = " " 8 + 9

$T_5' = 48600 \times 1.202 = 58417.2$ = " " 10 + 11

$T_6' = 21600 \times 1.202 = 25963.2$ = " " 12 + 13

$T_7' = 5400 \times 1.202 = 6491.$ = " " 14 + 15

$T_8' = 0 \times 1.202 = 0 =$ stress in 16

4^{th} Find resultant diagonal stresses

$S_0 = 138470 + 415411 = 553881 =$ stress in 1

$S_1 = 103853 + 318049 = 421902 =$ " " 2 + 3

$S_2 = 69235 + 233669 = 302904 =$ " " 4 + 5

$S_3 = 34618 + 162270 = 196888 =$ " " 6 + 7

$S_4 = 0 - 103853 = -103853 =$ " " 8 + 9

$S_5 = 34618 - 58417 = -23799 =$ " " 10 + 11

$S_6 = 69235 - 25963 = 43272 =$ " " 12 + 13

$S_7 = 103853 - 6491 = 97362 =$ " " 14 + 15

$S_8 = 138470 - 0 = 138470 =$ " " 16

The above as far as S_4, shows the greatest amount of stress the diagonals are ever subject too, S_4 and S_5 being minus, show that the three diagonals on either side of the centre act alternately as struts or as ties. The remaining results, show the amount acting when the shorter segment is loaded. With the dead load alone the diagonals 8 and 9 are not needed, and although they are in the position of a struts, yet they are not called into action.

Now having calculated each of the two simple girders of which the given girder is composed, by combining them we obtain the required stresses in the given girder.

First, find the stresses in the upper chord
Second, the stresses in the lower chord
Third, stresses in diagonals acting as struts
Fourth, stresses in diagonals acting as ties
Fifth, stresses in diagonals which act alternately.

1st Upper chord stresses

$H_1 = 307\,200$

$H_2 = 307\,200 + 537\,600 = 844\,800$

$H_3 = 537\,600 + 768\,000 = 1305\,600$

$H_4 = 768000 + 921600 = 1689600$

$H_5 = 921600 + 1075200 = 1996800$

$H_6 = 1075200 + 1152000 = 2227200$

$H_7 = 1152000 + 1228800 = 2380800$

$H_8 = 1228800 + 1228800 = 2457600$

2nd Lower chord stresses.

$H_1 = 268800$

$H_2 = 268800 + 537600 = 806400$

$H_3 = 537600 + 729600 = 1267200$

$H_4 = 729600 + 921600 = 1651200$

$H_5 = 921600 + 1036800 = 1958400$

$H_6 = 1036800 + 1152000 = 2188800$

$H_7 = 1152000 + 1190400 = 2342400$

$H_8 = 1190400 + 1228800 = 2419200$

3rd Diagonals acting as struts are. (fig 1).

1, 2, 3, 4, 5. the stresses are.

1, = 48464.7 , 2, = 42190.2

3. = 35915.8 4. = 30290.4

5. = 24665.0

4th Diagonals acting as ties are, (fig 1) a, b, c, d, e, f, the stresses to which they are subject are,

a = 553881	b = 484647
c = 421902	d = 359158
e = 302904	f = 246650

5th Diagonals acting alternately as a strut or as a tie. Those which act alternately are, (fig. 1) 6, 7, 8, g, h,

6 as a tie	= 58417	as a strut = 34618
7 " " "	= 77890	" " " = 17309
8 " " "	= 103853	" " " = 0
g " " "	= 58417	" " " = 34618
h " " "	= 77890	" " " = 17309

Now having obtained the stresses which the various portions of the given girder have to bear, it becomes necessary to calculate the size of the pieces required to bear these stresses; we will begin with the lower chord.

The lower chord is under tension alone, and being made of wrought iron which has a tensile strength of 50 000 lbs per square inch, to obtain the area of cross section, divide the stress in each bay by 50000. Beginning at one end number the bays up to the centre

No 1	268800 ÷ 50 000 = 5.4 sq. in =	required	area	cr. sec.
" 2	806 400 ÷ 50000 = 16. =	"	"	" " "
" 3	1267200 ÷ 50 000 = 25.3 =	"	"	" " "
" 4	1651200 ÷ 50 000 = 33. =	"	"	" " "
" 5	1958 400 ÷ 50 000 = 39. =	"	"	" " "
" 6	2188800 ÷ 50 000 = 43.8 =	"	"	" " "
" 7	2342 400 ÷ 50 000 = 46.8 =	"	"	" " "
" 8	2419 200 ÷ 50 000 = 48.4 =	"	"	" " "

Now taking the width of the chord to be 20", by dividing the whole by 20 will give the required thickness of material in each.

No. 1 will be	.3"		No. 2 will be	.8"	
No. 3 "	"	1¼"	No. 4 "	"	1.65"
No 5 "	"	1.96"	No 6 "	"	2.2"
No 7 "	"	2.34"	No 8 "	"	2.42"

In bay No. 8 there are consequently three (3) plates, respectively ⅝", ⅝", 15/16" thick, and two angle-irons 4"×4"×½", set 1" apart to allow a piece of iron to set between them, the use of which will be mentioned farther on. The first ⅝" plate runs the entire length of the girder, and is cut thus: 18'- 24'- 24'- 24'- 6' to centre.

The second ⅝" plate begins fifteen ~~twelve~~ feet from the end and is cut thus: 18'- 24'- 24'- 18'; here, the last 18' ft. plate ends at the centre, and this is the only one cut at centre, all the others run by on each side.

this middle plate is six feet longer than it would otherwise be, if it did not project three ft on each end to cover a cut in the plate above. The third plate is $15/16''$ thick, and begins 38 feet from the end; this is also six feet longer on account of a cut in one of the $5/8''$ plates above.

Whenever one of the plates of this chord is cut, there will have to be a covering plate in order to give the chord the required strenght at this point. In riveting the cover plates, the mean thickness of a plate is $3/4''$ nearly, the thickest is $15/16''$. I therefore take as the diameter of the rivets $1\,1/8''$. Where the plates are as heavy as here used, the rivets would give way by shearing before the plates would tear; consequently, in calculating the rivets I take into account the shearing area.

The area of an 1 1/8" rivet is very near 1 inch, and as is the greatest shear per square inch a rivet will stand is 50 000 lbs., therefore one rivet will sustain a shear of 25 tons.

Calculation of Cover Plates.

Beginning at either end number towards the centre. No. 1. Here a 5/8" plate is cut, area $= 5/8 \times 20 = \frac{100}{8}$. Whole stress in the panel is 1267200 lbs. and as the area of cr. section at this point of the chord is 32.5 sq. in., the intensity of stress = 39 000 lbs. ∴ stress to be bourne by cover $= \frac{100}{8} \times 39000 = 244$ tons. As each rivet bears 25 tons $244 \div 25 = 10 =$ required number of rivets on each side of the cut. The pitch is 5" longitudinally, ∴ a covering plate 30" long is required; thickness of cover = 5/8". No. 2. Here both a 5/8" and 15/16" plate is cut; calculate each seperately then combine. Intensity $= 1958400 \div 51.25 = 38211$ lbs

$38211 \times \frac{100}{8} = 239$ tons, which divided by $25 = 10$ = required number of rivets; ∴ taking a 20" covering plate for the 5/8" plate,

In the 15/16" plate intensity also = 38211 $\left[38211 \times \frac{300}{16}\right] \div 25 = 14$ = required number of rivets; ∴ taking a covering plate of 40", combining, we have a cover 3½ feet long. No. 3. Here a 5/8" and 15/16" plate is cut and proceeding same as in previous cases we find the 5/8" plate will require 11 rivets, and a 30" cover; and the 15/16" plate 16 rivets, and a 40" cover. Combining, requires a cover 3½ ft. long. No. 4. Here a 5/8" plate is cut requiring 12 rivets, and a 30" cover.

No. 5. A 5/8" and 15/16" plate is cut, and a cover 4¾ feet long is required. No 6. This is at the centre and a 5/8" plate is cut, and a 4 ft cover required. Connected with the lower chord, but taken no account of in the calculations, is a bar 14" high and 1" thick, set on edge, between the angle-irons, for the purpose of riveting the diagonals too. In reallity this bar stiffens the chord, but this is taken no account off.

We now come to the Upper Chord. The form of cross section here chosen is a hollow square, set with its diagonals horizontal, and verticle. This is also of wrought iron. This chord is cut into lengths of which the two extreme ones are 18 feet each, the remainder 12 feet. This way of cutting is adopted on account bringing the joints in the centre of a panel, and thus not inteferring with any connections. The 18 foot pieces, being one at each end of the girder; because there the chord is smaller, and could be more easily handled than if it were larger, besides being less expensive. This chord acts only as a strut, that is it is subject to a compressive force. In calculating the required size of a strut if its lenght does not exceed ten times its diameter, it is sufficiently accurate to divide the greatest thrust it has to sustain, by the crushing strength of wrought iron. If the length exceeds ten times its diameter, then Gordon's formula must be applied. I assume 8" to be the least dimension of a side, and taking into account the projections by which the sides are riveted together, gives as the least dimension 10", and as the strut is 12 ft long. it exceeds ten times the diameter by by just 24", but, as this is the smallest part of the chord, and as it occurs at the end of the girder where it is more securely fastened than elsewhere, and as to its centre there is riveted a horizontal diagonal, it will be near enough, to simply divide the amount of stress to which it is subject, by 36000 lbs. the breaking, or crushing strength of wrought iron. This is the worst part. In the centre, by applying Gordons formula a cr. section of 68.3 inches is required, and by dividing by 36000 a cr. section of 68.5 inches is required. By trying Gordons formula in several sections I find its use unnecessary, as it gives so near the same results as dividing by 36000 gives. By taking the length of the strut as six ft. where the chord is 8" on a side, I obtain about 10 inches as required area, which is very near what dividing by 36000 gives. I therefore have for the areas of cross section in the different bays the following;

No. 1. 10 sq. in. No 2. 23.5 sq. in. No. 3. 36.3 sq. in.

No. 4. 47 sq. in No. 5. 55.5 sq. in. No. 6. 61.9 sq. in

No. 7. 66.2 sq. in No. 8. 68.3 sq. in

The following are the sizes on a side of the two adjacent pieces.

Joint No. 1 make 8" × 3/4".

" " 2 " 8" × 3/4"

" " 3 " 10" × 3/4"

" " 4 " 13" × 3/4

" " 5 " 15" × 3/4"

" " 6 " 16" × 3/4"

" " 7 " 18" × 3/4"

These joints are connected by cover plates three feet long, and one half inch thick, there of course being four covers to each joint. The projection from the lower corner is ten inches, instead of three as the rest are, in order to fasten the diagonals to this chord.

We now come to the diagonals

First calculate those running from the lower chord up, towards the centre, and which with the dead load alone act as struts. The form of cross section is a rectangle

The strut will consist of two bars, kept one inch apart by means of washers at every point, except where they are connected with the upper chord, where they will be 1½" apart, by the lower edge or tongue coming between them, and to which they are riveted. This may be seen from the drawings. The required sizes as calculated by Gordons formula are as follows.

No 1	requires	14"	make	two,	each	7"×1"
" 2	"	" 12"	"	",	"	6"×1"
" 3	"		"	",	"	6"×1"
" 4			"	",	"	6"×1"
" 5	"	" 8"	"	",	"	4"×1"
" 6	"	" 6"	"	",	"	3"×1"

also make No's. 7 and 8, 3" × 1"

Diagonals running from the lower chord away from the centre, and which act as ties with the dead load alone.

Required	area	No.	1	= 11	sq. in	make	11" × 1"
"	"	"	2	= 10	" "	"	11" × 1"
"	"	"	3	= 8	" "	"	8½" × 1"
"	"	"	4	= 7	" "	"	8½" × 1"
"	"	"	5	= 6	" "	"	8½" × 1"
"	"	"	6	= 5	" "	"	6" × 1"
"	"	"	7	= 4	" "	"	6" × 1"
"	"	"	8	= 3	" "	"	3" × 1"

Calculation of rivets in diagonals is similar to that in cover plates; by the same method used there I find one rivet will sustain 44 tons, accordingly the number of rivets in the diagonals running away from the centre is as follows.

Number of rivets required for No. 1 = 276.94 ÷ 44 = 7

" " " " " " " " 2 = 242.32 ÷ 44 = 6

" " " " " " " " 3 = 210.95 ÷ 44 = 5

" " " " " " " " 4 = 179.57 ÷ 44 = 4

" " " " " " " " 5 = 151.45 ÷ 44 = 4

" " " " " " " " 6 = 123.32 ÷ 44 = 3

" " " " " " " " 7 = 98.44 ÷ 44 = 3

" " " " " " " " 8 = 73.56 ÷ 44 = 2

Rivets in diagonals running up to the centre are:

No. 1 requires 242.3 ÷ 44 = 6 = number of rivets

" 2 " 210.95 ÷ 44 = 5 " " " "

" 3 " 179.57 ÷ 44 = 4 " " " "

" 4 " 151.45 ÷ 44 = 4 " " " "

" 5 " 123.32 ÷ 44 = 3 " " " "

" 6 " 98.44 ÷ 44 = 3 " " " "

" 7 " 73.56 ÷ 44 = 2 " " " "

" 8 " 50.77 ÷ 44 = 2 " " " "

The size of the rivets is 1 1/4" in diameter

Calculation of End Post

This is a square wrought iron column, eighteen feet high, and eleven and one half inches on a side. The manner in which it is connected with the upper and lower chords is shown by the drawings.

The stress which it has to bear is 864000 lbs. The required area of cross section as calculated by Gordons formula is 24 sq. in. I therefore make each side 11½" × ½"

Transverse I Beams

As a foundation for the roadway the two girders are connected by transverse I beams, upon which the longitudinals rest. The method of connecting these transverse beams with the girders is as follows.

The lower edge of the beam is set on the lower flange of the girder.

This gives the beam a space of nearly nine inches to rest on each girder. The beam is fastened to the girder by means of two verticle angle-irons, one on each side of the beam as can readily be seen from the drawings.

In calculating the required size of the beam its wt is taken into account. I have made use off two beams, two feet five inches apart from edge to edge, and placed fourteen + one half inches on each side of the point where the diagonals meet. This method appears to be better than suspending them as they are firmer; if this was a pin bridge suspen-sion would be better, but from all exam-ples I have met with in this class of bridges the universal method is the same as I have used.

In calculating the size I proceed just as though there was only one beam, and that was just at the point where the diagonals meet. The total wt. the beam has to bear is as follows.

4 stringers or longitudinals $8'' \times 14'' \times 12' \times 54 \times 12$
$\div 1728$ = weight = 2016

Ties " " = 2808

Rails " " = 520

Beam " " = 990

6334 = total weight of dead
3 = factor of safety

19002

1200 x 12 = 14400 = total live
6 = factor of safety

86400

$$\frac{M_o}{h} = \frac{WL}{8h} = \frac{(19002 + 86400) \times 33 \times 12}{8 \times 2 \times 15} = 188.64 \text{ tons}$$

to be borne by the flanges of the beam.
$188.64 \div 18 = 10.5$ sq. in. it will take to bear this stress. In order to sustain this stress

the dimensions of each of the two beams must be as follows. Height = 15", width of each of the flanges 6", thickness of web = 1/2", depth of Flange 3/4".

In order to give the bridge lateral stiffness I must have horizontal diagonal bracing. According to the best authorities, 25 lbs. per square foot is the correct pressure to allow for wind. Of course the lateral deflection is greatest when the bridge is covered with the live load. All the additional pressure due to the live load, must of course be resisted by the bracing of the lower chord. Taking the height of a train as 10 feet, the pressure due to the live load will be $10 \times 192 \times 25 = 48000$ lbs. The pressure that goes to the lower chord from the bridge itself is 10200 lbs.

making a total of 58200 lbs. to be resisted by the lower chord bracing.

The amount to be resisted by the upper chord = 664 × 25 = 16600 lbs.

The transverse beams are plenty strong, and the diagonals will all act as ties. To find the size of these ties proceed as follows.

$F_0 = 58200 \div 2 = 29100$, $F_1 = 29100 - 3648 = 25452$

$F_2 = 25452 - 3648 = 21804$, $F_3 = 21804 - 3648 = 18156$

$F_4 = 18156 - 3648 = 14508$ $F_5 = 14508 - 3648 = 10960$

$F_6 = 10960 - 3648 = 7312$ $F_7 = 7312 - 3648 = \cancel{4580}$ 3664

multiplying by sec ϕ. = 1.25 we have,

$T_0 = 29100 \times 1.25 = 36375$, $T_4 = 14508 \times 1.25 = 18344$

$T_1 = 25452 \times 1.25 = 38781$, $T_5 = 10960 \times 1.25 = 13700$

$T_2 = 21804 \times 1.25 = 26255$, $T_6 = 7312 \times 1.25 = 9131$

$T_3 = 18156 \times 1.25 = 22720$ $T_7 = 3664 \times 1.25 = 4580$

Now having used no factor of safety so far, I must take the tensile strength of wrought iron as 10000 lbs. per. square inch, thus giving as the required size of braces.

		cr. sec		
No. 1	requires	3.6 sq. in.	make	4" x 1"
" 2	" "	3.2 " "	"	6" x 5/8"
" 3	" "	2.7 " "	"	6" x 5/8"
" 4	" "	2.3 " "	"	6" x 1/2"
" 5	" "	1.8 " "	"	4" x 1/2"
" 6	" "	1.3 " "	"	3 1/2" x 1/2"
" 7	" "	.9 " "	"	2" x 1/2"
" 8	" "	.9 " "	"	2" x 1/2"

Make the bracing to the upper chord the same size, the reason being that there we have no transverse beams nothing but diagonal bracing, which must necessarily be stronger than if we had bars running directly ~~across~~ across.

In all the foregoing calculations I have been very liberal with the use of iron, and upon examining more closely, I find that in several places I can dispense with some material.

First in the upper chord. Here I find I can change the dimensions as given on page 26, to the following.

Joint	No 1	requires	8" x 1/2"	on a side	
"	" 2	"	8" x 1/2	"	" "
"	" 3	"	10" x 3/4"	"	" "
"	" 4	"	13" x 3/4"	"	" "
"	" 5	"	15" x 3/4"	"	" "
"	" 6	"	16" x 3/4"	"	" "
"	" 7	"	18" x 3/4"	"	" "

Also between the points of connection, the lower eye or tongue to which the diagonals are fastened, may be cut down from 10" to 5". In the lower chord, the 14" bar to which I fasten the diagonals may be cut down to the angle-irons, between the points of connection.

The ties of the roadway need not be near as large as here represented, in fact the rails might be laid directly upon the longitudinals. I therefore reduce the size from 8"x8", to 6"x2", the common size in similar cases. Plate number two shows these improvements. The weight of the bridge is computed from plate number two, and is as follows.

Weight of Road-bed = 74681 lbs.

" " Bridge = 86270 "

Total = 160951 " including the weight of End Posts. This gives 833 lbs. as the wt per. foot. Leaving out the End Posts gives 822 lbs. per. foot run. This is 22 pounds more than the limit but on using this, for 800, I find the dimensions as already calculated are not materially changed, and as before stated there is rather more material used than necessary, therefore I leave the dimensions the same as first calculated.

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