Thesis of S. D. Mason

1870.

DESIGN

FOR AN IRON GIRDER BRIDGE

PLATE A

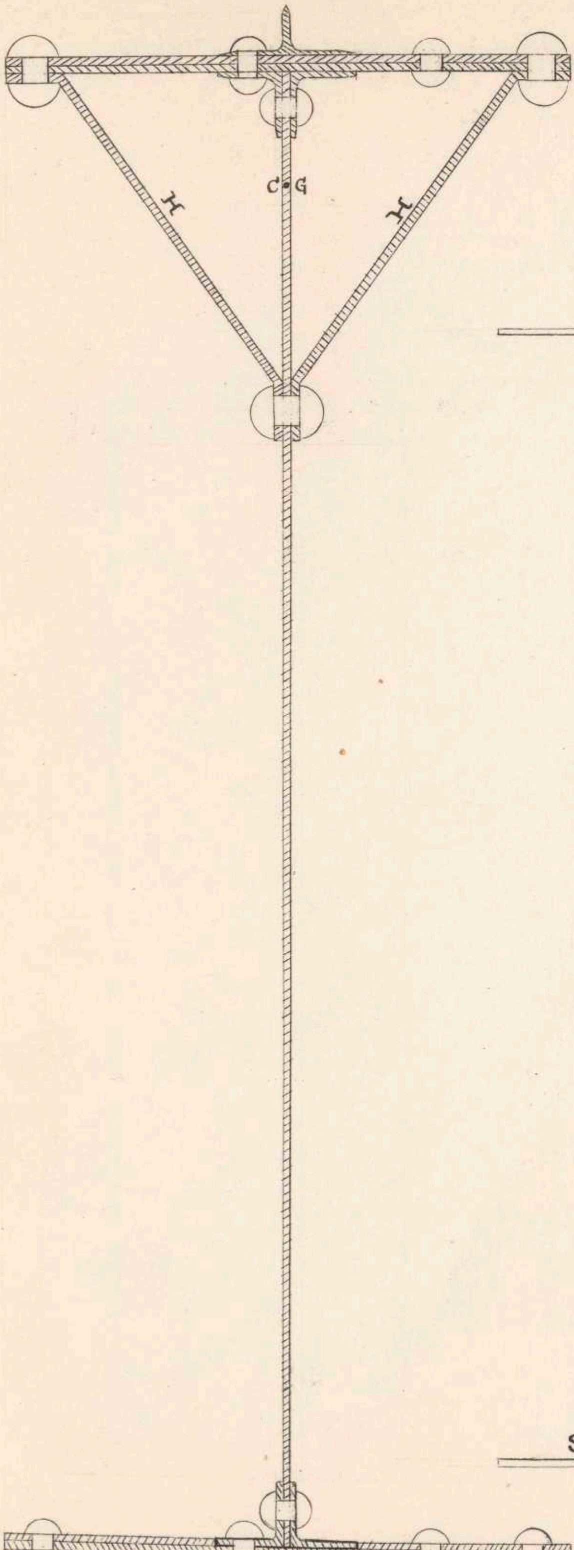


FIG. 1

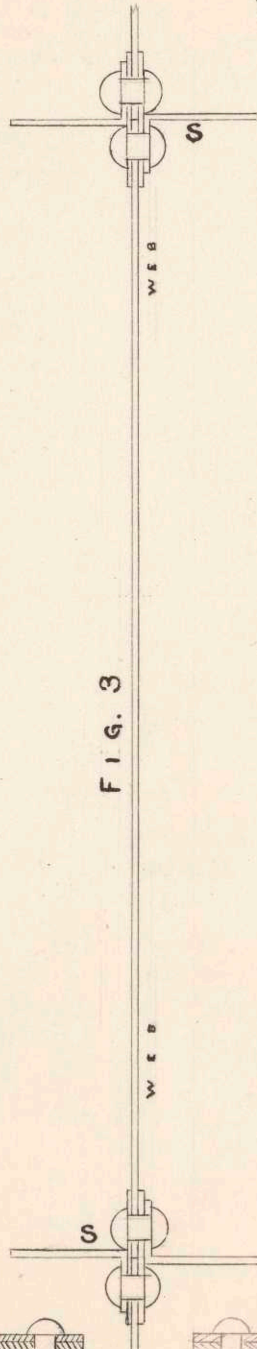


FIG. 3

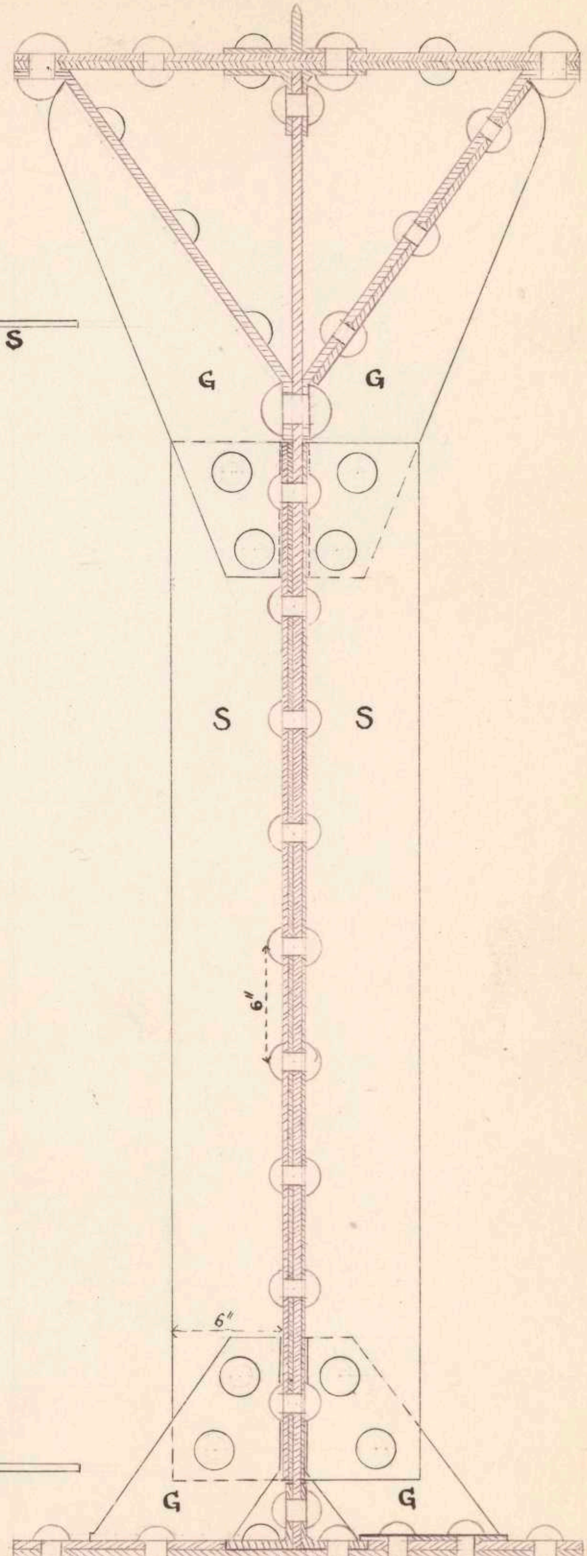


FIG 2

SCALE $\frac{1}{10}$

PLATE
B

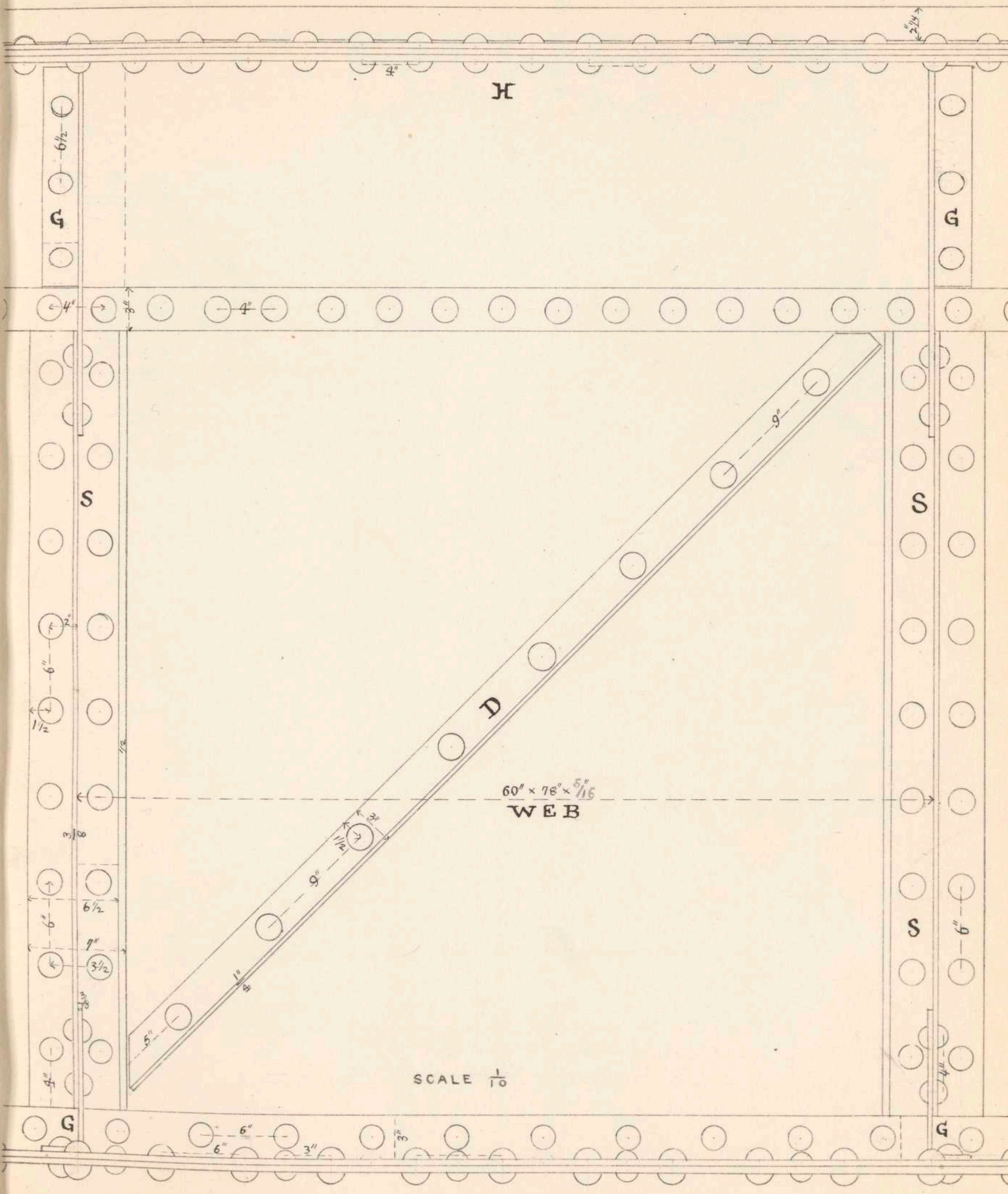
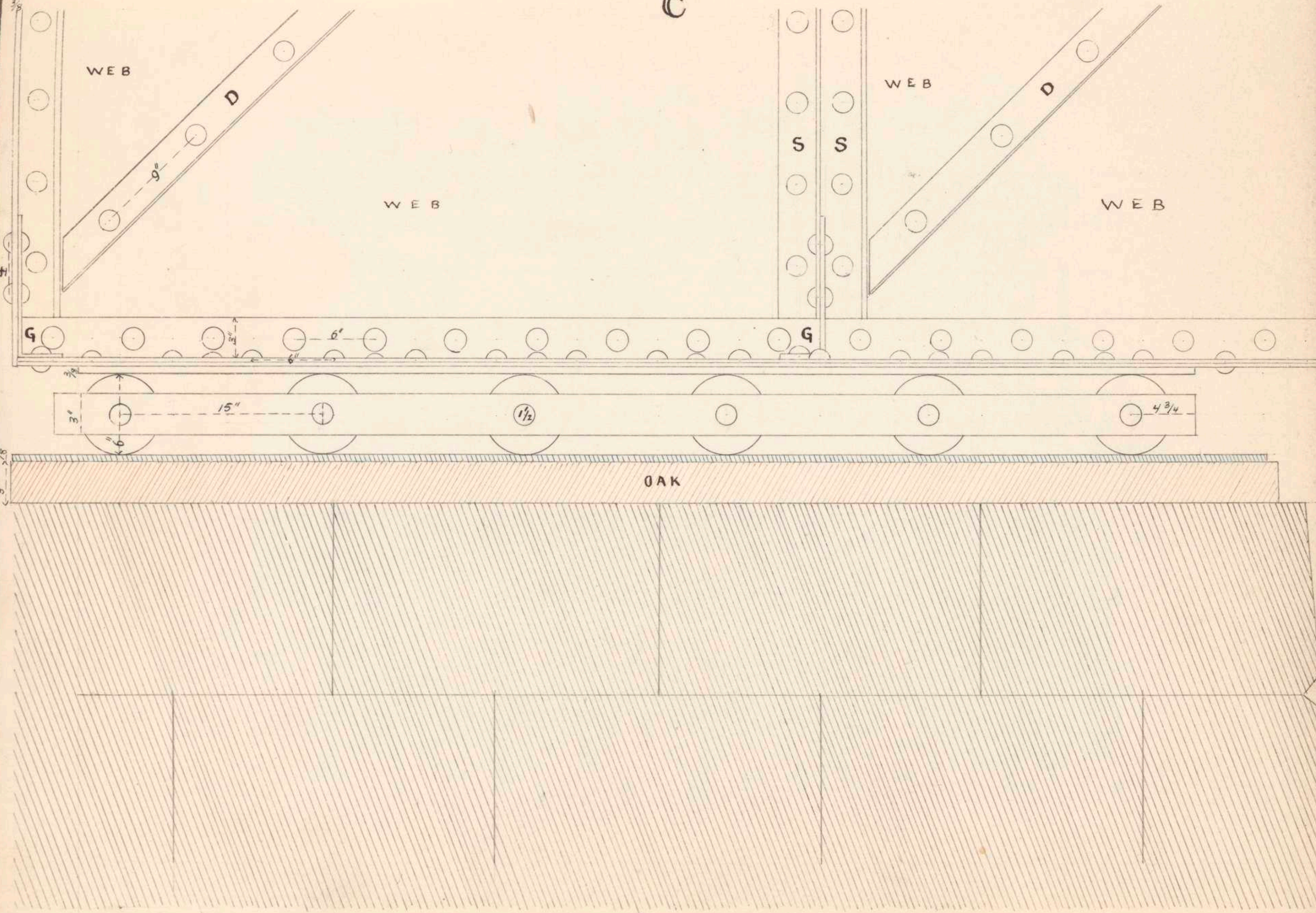
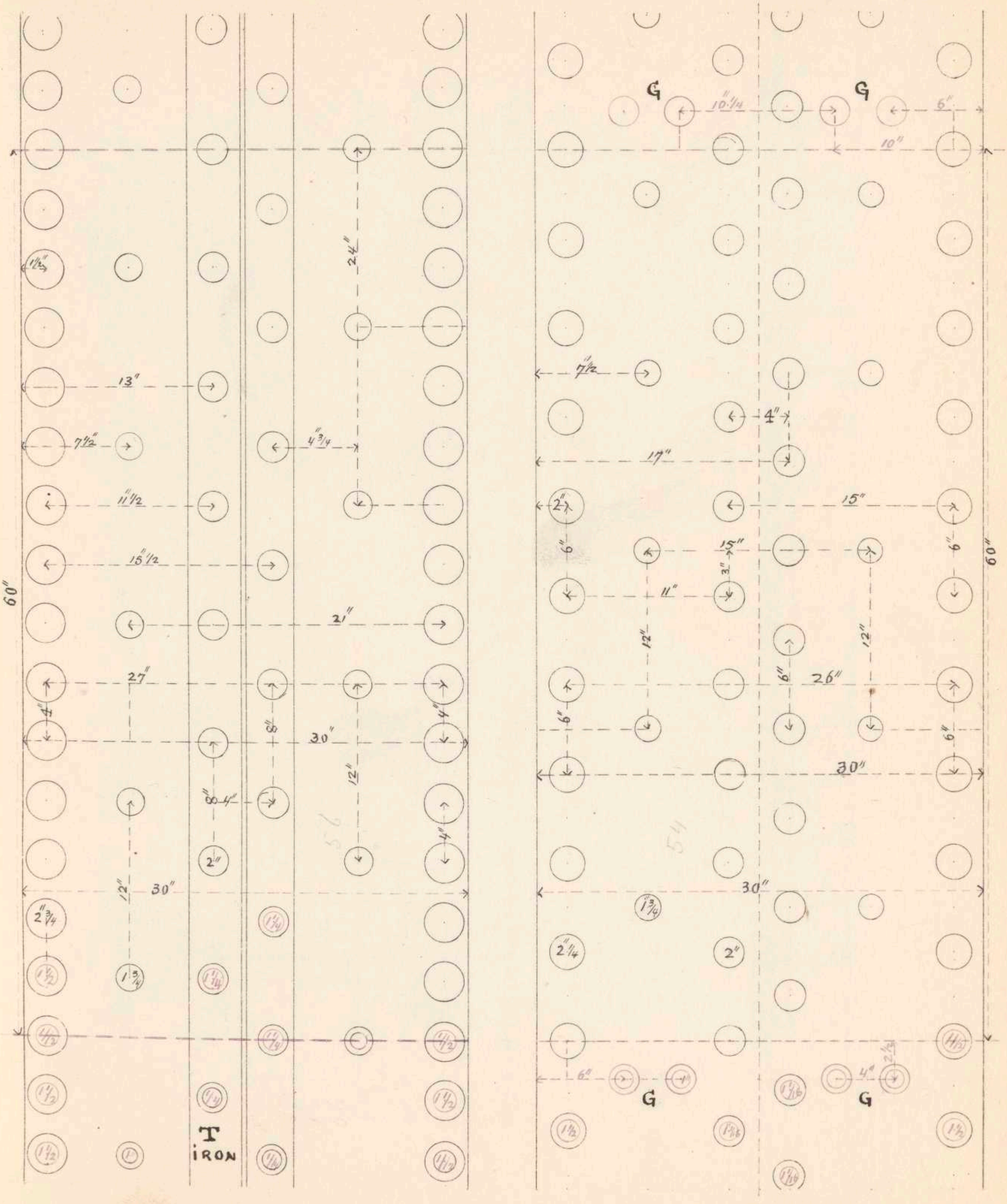


PLATE C



SCALE 1/10

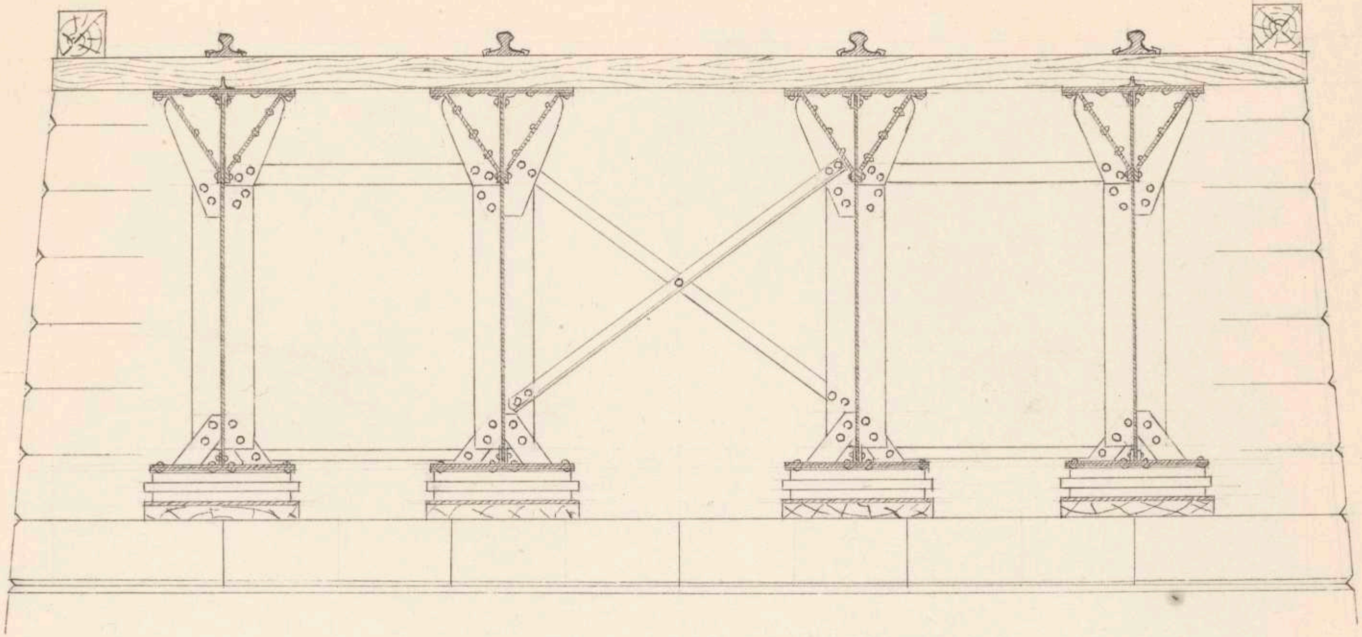
PLATE D



UPPER CELL
LOOKING DOWN
SCALE 1/10

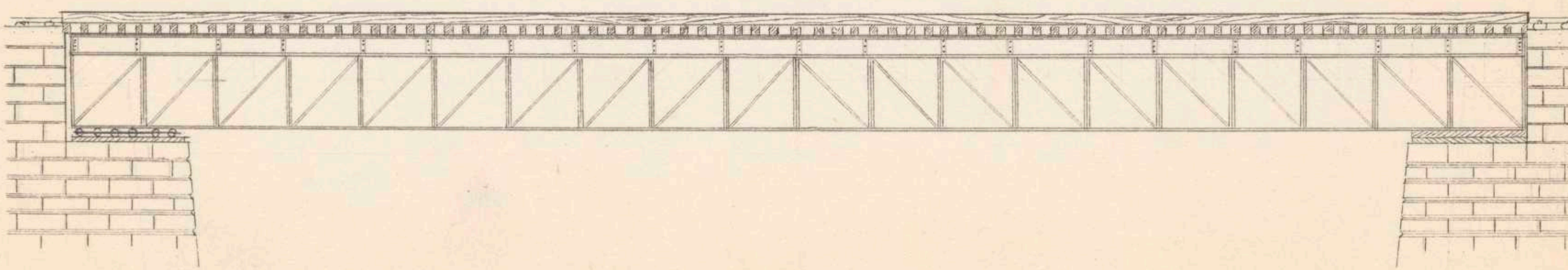
LOWER FLANGE
LOOKING UP
SCALE 1/10

PLATE
E



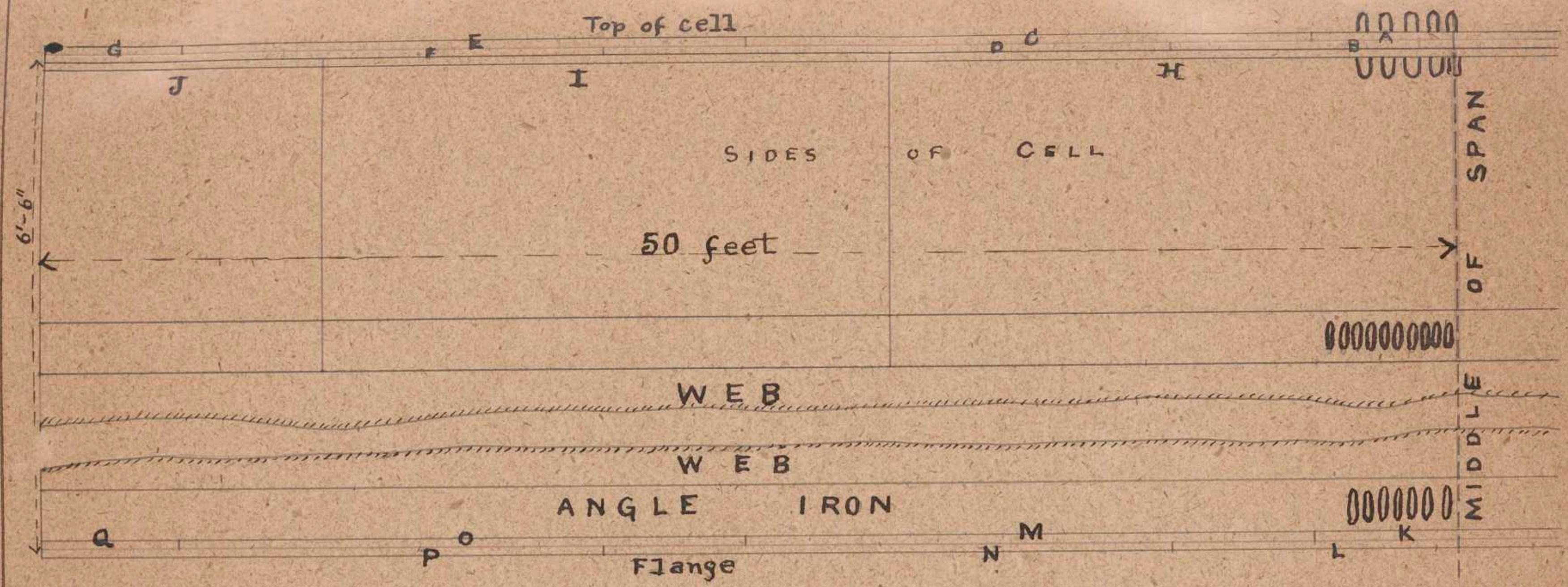
TRANSVERSE SECTION

$\frac{1}{40}$



SIDE ELEVATION

$\frac{1}{150}$



Vertical Scale $\frac{1}{10}$; horizontal Scale $\frac{1}{72}$

TOP OF CELL

		Thickness for outer Girders	Thickness for inner Girders
PLATE	A	10' × 30" × 7/16	× 6/16"
"	B	20' × 30" × 7/16	× 6/16
"	C	20' × 30" × 6/16	× 5/16
"	D	20' × 30" × 6/16	× 5/16
"	E	20' × 30" × 4/16	× 4/16
"	F	20' × 30" × 4/16	× 4/16
"	G	5' × 30" × 4/16	× 4/16

SIDES OF CELL

SAME FOR OUTER AND INNER GIRDERS

PLATE	H	20' × 24" × 8/16
"	I	20' × 24" × 5/16
"	J	10' × 24" × 4/16

FLANGE

		Thickness for outer Girders	Thickness for inner Girders
PLATE	K	10' × 11¼" × 7/16	× 6/16
"	M	20' × 11¼" × 5/16	× 5/16
"	O	20' × 11¼" × 4/16	× 4/16
"	Q	5' × 11¼ × 4/16	× 4/16
"	L	20' × 30" × 7/16	× 6/16
"	N	20' × 30" × 5/16	× 5/16
"	P	20' × 30" × 4/16	× 4/16

M

Wrought Iron Girder Bridge;

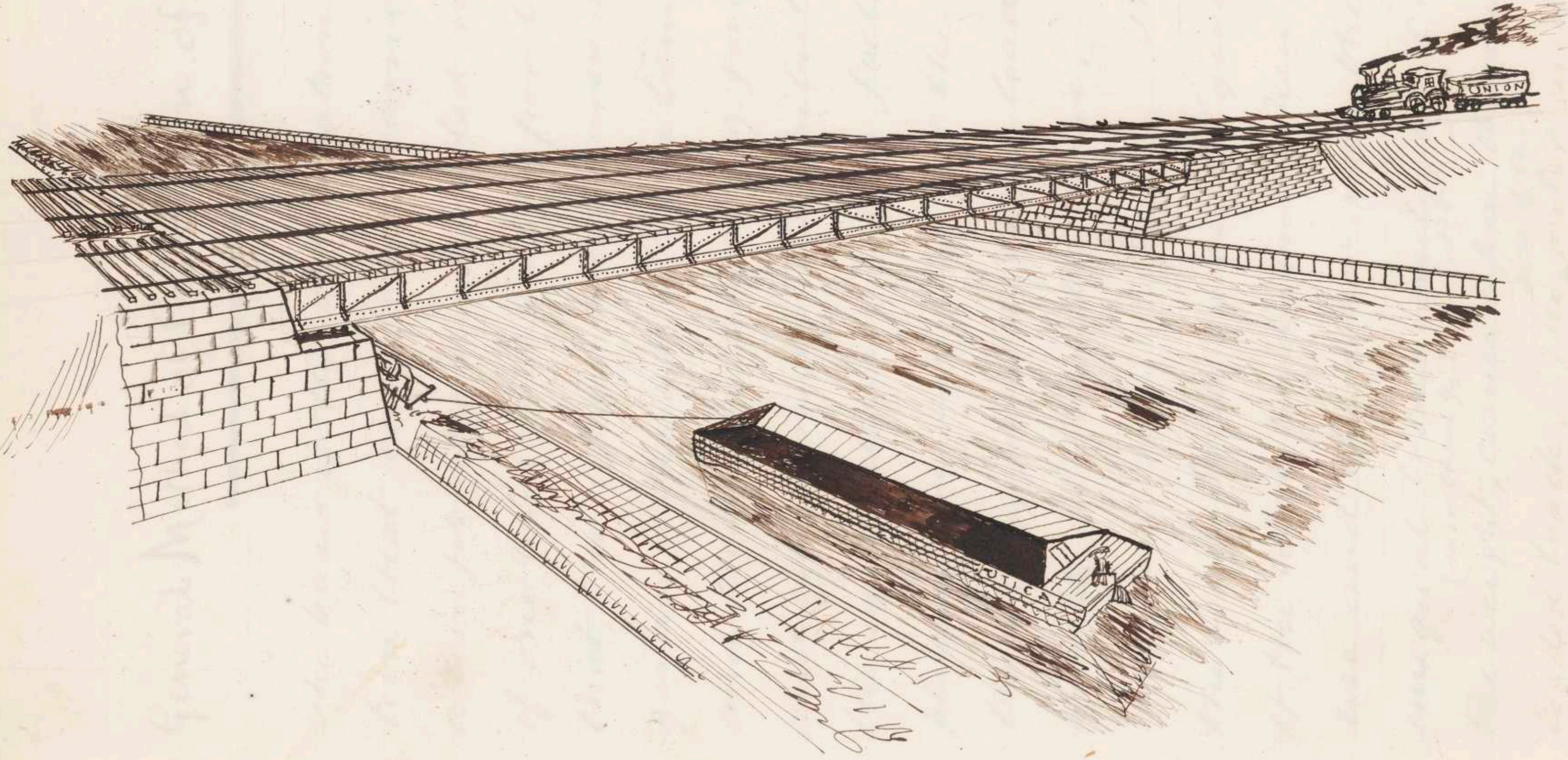
for a double track, narrow guage railway.

General Description.

The bridge consists of four parallel, similar, plate iron girders, one under each line of rail. The purpose of the bridge is to carry a railroad over a canal and tow path, necesitating a clear span at the surface of the water of eighty-two feet. Since the abutments have a batter of one in twelve - sloping away from the bank, and the head-room is to be twelve feet, the span of the girders will be eighty-four feet. The line of road crosses the canal squarely, and the girders have all the same length - one hundred feet - eight feet of each end resting on the abutments. The grade of the approaches is such, that the requisite head-room may be obtained, if the depth of the bridge be made one fifteenth of the span. The girders have a cross-section of equal strength above and below, and the longitudinal section is varied proportionally to the varying strains. The lower members are flat flanges, or tables: while the upper, are triangular cells with their apices downwards, rivetted to the upper edges of their respective webs. Upon the upper, flat surfaces of the cells, rests a platform of cross-timbers, to which the rails are spiked. A heavy longitudinal timber bolted along the ends of the cross-pieces keeps them from spreading; while motion transversely is prevented by the indentation of ⊥ irons, rivetted to the tops of the outermost girders.

Although similar in form, and in arrangment of material, the two inner girders are not exact counterparts of the outside ones, for upon them comes a smaller share of the load, and therefore a smaller ammount of iron will suffice.

To retain the girders in their proper vertical planes, they are so connected by braces as to render it next to impossible for any one of them to have an independant transverse motion. The centre ones are held in their relative positions by pairs of diagonal braces of T iron, rivetted to the gussets of either girder. There are nine pairs of these diagonals, one at every second stiffener. The two so connected, form as it were ~~one~~ a single beam, to which horizontal braces of T iron hold the two outer girders. The four form a system of considerable rigidity, not likely to be displaced. The arrangment of braces is exemplefied in the section of plate E. The abutments are of ashlar masonry, twenty-three feet six inches wide where the bridge rests, and have a batter of one in twelve. At one abutment the girders are fixed, at the other the end of each rests upon a frame of rollers, admitting of longitudinal motion produced by changes of temperature. The rollers are shown in the elevation of plate E, and on an enlarged scale in plate C. Between each girder and the stonework, is interposed a cushion, three inches thick, of white oak plank. All the rivet holes are to be drilled, not punched; and made one sixteenth of an inch larger than the diameter of the rivet, to allow for the expansion of the latter when heated. The plates are to be carefully cut into rectangular forms, and all abutting surfaces that transmit thrust, to be planed. The interior of the cell is to receive a coat of paint previous to its parts being put together. Each girder is cambered to the extent of three fourths of an inch. Throughout the design similarity of corresponding parts of different girders is aimed at to avoid complication in the manufacture of the iron —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General Method of Calculation of the Strains –

The basis of the calculations is the supposition that each track carries (at the same time) a uniformly distributed rolling load (w'), of one ton (of 2240 lbs.) per linear foot; also that the upper and lower members of each girder take up all the bending moment, and that the shearing force is entirely and uniformly distributed throughout the vertical web. The factors of safety employed are six (s_1), for the rolling load and three (s_2), for the dead load, which is the weight of the structure.

The mean share of the load borne by each girder is one quarter of the total load; but when one track is in use and the other not, the distribution is unequal transversely, and more than half the weight (more than ½ T. per foot) comes upon the outer girder of the loaded track. The size of the outer and inner girders are seperately calculated with due regard to this variation of load. In case of two trains on the bridge, the load is considered as equally distributed transversely, and the inner girders are calculated to sustain 1/2 Ton per linear foot.

The proportion of depth to span is taken as about one fifteenth or six feet. This is made the depth from the centre of gravity of the cross-section of the triangular cell, to the upper side of the flange. The centre of gravity of the cell is 6 inches below the lower side of the base. Its position is marked CG on fig. 1, plate A. From the assumed intensity and distribution of the rolling load, the bending moment in inch pounds is calculated for the centre of the span, then multiplied by the proper factor of safety, and the product divided by the depth. The result is the force P (times the factor of safety), acting at the transverse plane of the middle section, in the longitudinal plane of the bridge. To this force is opposed, in case of the cell, the resistance of the iron to <u>crushing</u>, and in the flange, the <u>tenacity</u>

of the material.

Since the tenacity is independant of the length, a proper value of its modulus (f_b), in lbs. on the □ inch, may be found in tables of the strength of materials. ~~The~~ The force P, of the bending moment, divided by the modulus of tenacity f_b, gives the provisional sectional area S_F, for the <u>flange</u> But the <u>cell</u> is in a condition analagous to that of a long, wrought iron strut; it tends to give way by bending sideways, and the modulus of resistance f_a, is not a constant quantity — (36000), but is less as the base of the cell is made narrower in comparison with the span. f_a is therefore modified in accordance with this formula, f_a (lbs per □ in.) $= 36000 \div 1 + \frac{l^2}{5000 b^2}$, in which l is the span, and b the breadth of the base of the cell. The provisional sectional area S_c, of the plates of the cell results from the formula $\frac{P}{S_c} = f_a \div 1 + \frac{l^2}{f_a r^2}$; r being the least radius of gyration of the cross-section.

If we put $f_a \div 1 + \frac{l^2}{f_a r}$ = A, then $\frac{P}{S_c}$ = A, and $S_c = \frac{P}{A}$.
The web is assumed of a thickness that will be much more than sufficient to withstand the greatest shear at any section. From the provisional areas of cell, web and flange is computed the weight of the bare girders. This is approximate since it is calculated as though the cross-section were everywhere the same as at the centre; furthermore, the weight of a girder of 84 ft. length only, is here calculated. In reality the section diminishes towards the ends, and the weight will be in excess. To the above found weight is added the weight of the superstructure, and the aggregate of covering plates, diagonals, stiffeners &c. Thus is obtained with sufficient accuracy for the next step, the intensity of the dead load, and multiplied by its factor of safety (3), is used in connection with the intensity of the rolling load, for determining the true moment of resistance that the girder must possess.

The result of taking into account the dead load, is increased sectional areas, and consequently an increase of dead load, due to increase of weight. But a recalculation of the weight is unnecessary for further designing the beam; particularly as the weight already found is known to be too large.

The greatest bending moment in foot pounds is now calculated for the centre of the span, and for cross-sections respectively 5, 10, 20 & 30 ft. from the centre, by the formula $M = \frac{ws_2 + w's_1}{2}(c^2 - x'^2)$, c being the half span $= \frac{l}{2}$, $\left(l = \frac{84}{2}\text{ ft}\right)$, and x′ the distance of the section in question from the centre. The force P, of the couple constituting the bending moment, is found by dividing M by 6 feet, which is the arm of the couple M. Longitudinal variations of section are made in accordance with various values of P.

The greatest shearing force acts immediately over the edge of an abutment, and its intensity may be as great as the greatest supporting force. Supposing it to have its greatest possible value, calculation C shows the excess of strength possessed by the web, while D shows the resistance that a stiffener, considered as a strut, can oppose to the crushing action of the greatest supporting force. The girders have a cross-section varying along the beam, making it approximately of uniform strength, and uniform depth; further the depth is about 1/15 of the span, hence the anticipated working deflection v_1 will be $= \frac{3l}{2000}$ or an inch and a half. In order that the girder may become nearly straight under its load, it is proposed to give it an upward camber, but not so great as the working deflection resulting from calculation E. Confidence is expressed that the girders will prove stiffer than the formula for v_1 would show, and the

deflection be reduced to a minimum.
The closeness of the stiffeners (5 ft apart), and the advantageous slope of the diagonals (45°); combined with the stiffness of the triangular cell, and the lateral connection of the girders with each other, tend to produce this result. A camber of 3/4" is allowed for each of the four girders.
The weakening effect of rivet holes is taken account of only in the flange, which is in a state of extension. One seventh more area is given in order to secure the proper effective section.

Throughout the calculations, formulae, and important results, are entered in red.

CALCULATIONS.

84 feet of span. 1 T per ft. of single track. 84 T on two girders

84 T (of 2240 lbs) = 188160 lbs.

on an outer girder — .551 × 188160 = 103676.16 lbs. = W.

$M_0 = Wl \div 8$ $l = 84$ ft. (= 1008 inches) $M_0 = 103676.16 \times \frac{1008}{8} = 13063196.16$

$M_0 S_1 = 13063196.16 \times 6 = 78379176.96$ inch pounds.

h = depth = 6 ft = 72 inches

$P_{S_1} = 78379176.96 \div 72 = 1088599$ say = 1088600

$f_a = 36000 \div 1 + \frac{l^2}{5000 b^2}$ $l^2 = \overline{1008}^2 = 1016064$

$b^2 = \overline{30}^2 = 900$

$5000 \times 900 = 4500000$ $1016064 \div 4500000 = .22579$

f_a (lbs per □ in. resistance to crushing) = $36000 \div 1.22579$ = say 29500

S_c = area cell $\frac{P_s}{S_c} = 29500 \div 1 + \frac{1016064}{29500\, r^2}$

$r^2 = b^2 \div 12 = \overline{30}^2 \div 12 = 900 \div 12 = 75$

$29500 \times 75 = 2212500$ $1016064 \div 2212500 = .4592$

$\frac{P_{S_1}}{S_c} = 29500 \div 1.4592 = 20216$ say = 20200

then $S_c = P_{S_1}/20200$ no allowance for weight of beam

$= 1088600 \div 20200 = 53.9$ □ inches.

Area flange = S_F. $f_b = 51000$ lbs per □ inch.

$S_F = P_{S_1} \div f_b = 1088600 \div 51000 = 21.3$ □ inches.

no allowance yet for wt. of beam.

Approximate Weight.

Weight of 84 feet only. = 1008 inches.

cell 53.9 □in × 1008" = 54331

flange 21.3 × 1008 = 21470

web 60" × 3/8" × 1008 = 22680

98481 cu in.

÷ 1728 = 57 cu.ft.

wt. diagonal. 6' long 6" wide 1/4" thick

72" × 6" × 1/4" = 108 cu. in.

Stiffener 5' long 9" wide 3/8" thick

60" × 9" × 3/8" = 202 1/2 cu. in

covering plates. 5' long 7" wide 1/4" thick

60" × 7" × 1/4" = 105 cu. in.

34 diagonals = 108 × 34 = 3672

34 stiffeners = 202 1/2 × 34 = 6885

34 plates = 105 × 34 = 3570

14127 cu. in

÷ 1728 = 8 cu.ft.

57 + 8 = 65 cu. ft. iron 1 ft weighs 480 lbs

65 × 480 = 31200 lbs } iron

Rail 20 × 84 = 1680 " }

Timber – say = 4300 "

37180 lbs dead load

Intensity of the loads. **Outer Girders.**

$37180 \div 84 = 443 = w$. per foot of span dead load

$103676 \div 84 = 1234 = w'$. " " " " live load

$w_{S_2} = 443 \times 3 = 1329$ say = 1300 lbs

$w'_{S_1} = 1234 \times 6 = 7404$ say = 7400 "

$M_{0\,S_1S_2} = \frac{(w_{S_2} + w'_{S_1})}{2} c^2$ $c = l \div 2 = 42$ ft.

$\overline{42}^2 = 1764 = c^2$ $1300 + 7400 = 8700$

$1764 \times 8700 \div 2 =$ 7673400 foot lbs.

$P_{S_1S_2} = M_{0\,S_1S_2} \div 6' = 7673400 \div 6 =$ 1278900

BENDING MOMENTS.

let $x' = 5$ ft. then $\overline{x'}^2 = 25$ $1764 - 25 = 1739$

$1739 \times 8700 \div 2 = 7564650 = M_{S_1S_2}$

$P_{S_1S_2} = 7564650 \div 6 =$ 1260775

let $x' = 10$ ft. then $\overline{x'}^2 = 100$ $1764 - 100 = 1664$

$1664 \times 8700 \div 2 = 7238400 = M_{S_1S_2}$

$P_{S_1S_2} = 7238400 \div 6 =$ 1206400

let $x' = 20$ ft. then $\overline{x'}^2 = 400$ $1764 - 400 = 1364$

$1364 \times 8700 \div 2 = 5933400 = M_{S_1S_2}$

$P_{S_1S_2} = 5933400 \div 6 =$ ~~626400~~ 988900 let $x' = 30$ ft. then $\bar{x}'^2 = \bar{30}^2 = 900$ $\quad 1764 - 900 = 864$

$864 \times 8700 \div 2 = 3758400 = M_{S_1 S_2}$

$P_{S_1 S_2} = 3758400 \div 6 = 626400$

Calculation A Outer Girders.

Various cross-sections resulting from above calculations

S_C = sectional area of the triangular cell

S_F = " " " " lower flange

f_a = ~~20200~~ 29500 $\quad f_b = 51000 \quad$ 20200 = ~~A~~ (see top page 8)

			$P_{S_1 S_2}$		~~fa~~		final sections
at centre.	S_C	=	1278900	÷	20200	=	63 □ inches
5 ft. out	"	=	1260775		———	=	62 " "
10 " "	"	=	1206400		———	=	59 " "
20 " "	"	=	988900		———	=	49 " "
30 " "	"	=	626400		———	=	31 " "

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							effective section	final sections total section $= S_F + \frac{S_F}{7}$
at centre	S_F	=	1278900	÷	51000	=	25 □ in.	29
5 ft. out	"	=	1260775		———	=	25 "	say = 28
10 " "	"	=	1206400		———	=	24 "	27
20 " "	"	=	988900		———	=	19 "	22
30 " "	"	=	626400		———	=	12 "	14

1/7 more area given to allow for rivet holes —

Inner Girders.

When both tracks are loaded each girder sustains ½ Ton per foot = 42 T. on the span = 84 ÷ 2

42 T = 94080 lbs. = W $M_0 = Wl \div 8$ 84 ft = 1008 in.

M_0 = 94080 × 1008 ÷ 8 = 11854080 ~~71124480~~ inch lbs.

$M_{0 s_1}$ = 11854080 × 6 = 71124480

$P_{s_1} = \frac{M_{0s}}{h}$ h = 72"   71124480 ÷ 72 = 987840

S_c = area cell (provisionally) = 987840 ÷ 20200 = 48.9 □ inches

S_F = " flange " = 987840 ÷ 51000 = 19.3

Approximate Weight.

Weight of 84 ft. only = 1008 inches.

cell = 48.9 × 1008 = 49291

flange = 19.3 × 1008 = 19454

web 60 × 3/8 × 1008 = 22680

91425 cu. in.

÷ 1728 = 53 cu. ft.

diag. stiff. plates &c. as before = 8 cu. ft.

61 " "

61 × 480 = 29280 lbs. } iron

Rail 20 × 84 = 1680 "

Timber say 4300 "

35260 " dead load. Inner Girder.

Intensities of the Loads. **Inner Girders.**

$35260 \div 84 = 419$ say $= 420 = w$ per ft. of span, dead

$94080 \div 84 = 1120 \quad = 1120 = w'$ " " " " live

$w_{s_2} = 420 \times 3 = 1260$

$w'_{s_1} = 1120 \times 6 = 6720$

Bending Moments.

$M_{o\,s_1 s_2} = \frac{w_{s_2} + w'_{s_1}}{2} \cdot c^2 \qquad c = \frac{84}{2} = 42\text{ft.} \quad \overline{42}^2 = 1764$

$\overset{w_{s_2}}{1260} + \overset{w'_{s_1}}{6720} = 7980$

$1764 \times 7980 \div 2 = 7038360$ ft. lbs. $= M_{o\,s_1 s_2}$

$P_{s_1 s_2} = 7038360 \div 6 = 1173060$

$M_{s_1 s_2} = \frac{w_s + w'_s}{2}(c^2 - x'^2)$

let $x' = 5$ft. then $x'^2 = 25 \quad 1764 - 25 = 1739$

$1739 \times 7980 \div 2 = 6938610 = M_{s_1 s_2}$

$P_{s_1 s_2} = 6938610 \div 6 = 1156435$

let $x' = 10$ ft. $\overline{x'}^2 = 100 \quad 1764 - 100 = 1664$

$1664 \times 7980 \div 2 = 6639360 = M_{s_1 s_2}$

$P_{s_1 s_2} = 6639360 \div 6 = 1106560$

let $x' = 20$ft. then $\overline{x'}^2 = 400 \quad 1764 - 400 = 1364$

$1364 \times 7980 \div 2 = 5442360 = M_{s_1 s_2}$

$P_{s_1 s_2} = 5442360 \div 6 = 907060$

let $x' = 30$ ft. then $\bar{x}'^2 = 900$ $1764 - 900 = 864$

$864 \times 7980 \div 2 = 3447360 = M_{s_1 s_2}$

$P_{s_1 s_2} = 3447360 \div 6 = 574560$

Calculation B. Inner Girders.

various cross-sections resulting from above calculations

$f_a = 29500$ $f_b = 51000$. The divisor 20200 results from

the formula $\frac{P}{S} = 29000 \div 1 + \frac{l^2}{29500 r^2}$ or $= 20200 = A$ (see top page 8)

	$P_{s_1 s_2}$		final sections
at centre S_c =	1173060	÷ 20200 =	58 □ inches
5 ft out " =	1156435	" =	57 "
10 " " " =	1106560	" =	54 "
20 " " " =	907060	" =	45 "
30 " " " =	574560	" =	28 "

		effective section	final sections total section
at centre S_c =	1173060 ÷ 51000 =	23 □ in.	26 □ in.
5 ft. out " =	1156435 " =	22 "	25 "
10 " " " =	1106560 " =	21 "	24 "
20 " " " =	907060 " =	18 "	21 "
30 " " " =	574560 " =	11	13 "

Total section = effective section + 1/7 effective section.

Calculation C

Shearing force F.

live load = 103676 × $\overset{S_1}{6}$ = 622056

dead load = 37180 × $\overset{S_2}{3}$ = 111540

2) 140856   2) 733596

supporting force = **70428** lbs $F_{S_1S_2}$ = 366798 lbs

resistance of iron to shearing ~~=~~ taken as 50000 lbs per □ in.–

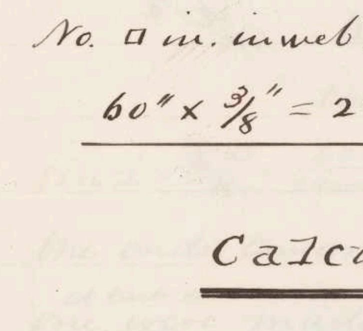
$F_{S_1S_2}$ ÷ 50000 = no □ in. required

= 366798 ÷ 50000 = 7.3

No. □ in. in web between flange and apex of cell is 60" × 3/8" = 22½ □ inches, 3 times as much area as is required to resist the greatest shear $F_{S_1S_2}$

Calculation D.

┼-section of a vertical stiffener at a web joint–



L iron = 9" × 3/8 = 3 3/8 } considered as a ~~strut~~ pillar

plate = 7 × 1/4 = 1 6/8 } five feet high

5 1/8 × 2 = 10 2/8

web 7" × 3/8" = add 2 5/8

12 7/8 □ inches

fa (mod. of crushing) = 36000 per □ inch.

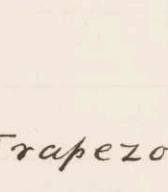
36000 × 12 = 432000 lbs. = ultimate ~~area~~ crushing load. 5 T = 11200 lbs

Calculation E.

Camber. Since the span = 15 times the depth the working deflection $V_1 = \frac{3l}{2000}$ = .126 foot or an inch and a half.

Calculation F

Trapezoidal plates to allow for a camber of $\frac{3}{4}''$ (see page 10)   Radius of curvature.



Let CA represent ½ the girder, and AD the camber. CA has a girt of 50 ft. = 600 in.
AD = .75″ Sensibly CD = CA = 600 in.

then $R = \frac{600^2}{2 \times .75} + \frac{.75}{2} = 240000.375$ inches.

$\sin i = \frac{CD}{R} = \frac{600}{240000.375}$ If the web plates were set from the ends towards the centre, and the edge of the first one at each end were made parallel to R, the centre pair would lean away from each other thus,  leaving an angle of 2i. Since the plates are each 78″ high, the space $S = 2 \times 78 \times \sin i$

$$= 2 \times 78 \times \frac{600}{240000.375}$$

$$= .390 \text{ inch}$$

So to fill this space the 7th plate from each end has the width at the top increased from 60″ to $60'' + \frac{.390}{2}$ = **60″.195**

The length of the top of the cell will be .39 inch longer than the flange.

Description of Drawings.

Plate A. Fig. 1. Transverse vertical section near centre of span, of an outer girder, between a pair of stiffeners, ~~of an outer girder~~. Scale 1/10. Diagonal D, plate B not shown. HH, continuous side plates of cell. CG, centre of gravity of triangle nearly.

Fig. 2 Section of the same at a stiffener S. Parts cut by plane of section shown in red. GGGG, gussets of 5/16" plate. Scale 1/10.

Fig. 3. Horizontal longitudinal section of one panel of the web between upper and lower members. Diagonal D, plate B not shown. Stiffeners and mode of securing adjacent plates of the web shown at SS. scale 1/10

Plate B

Side elevation of a panel near the centre. H, the sloping side plate of the triangular cell. GG, gussets, SS, stiffeners; D, the diagonal. The red lines show the position of vertical joints of the web. Scale 1/10.

Plate C. Elevation of the roller end of a girder, showing the rollers in their frame and their bearing surfaces. Scale 1/10.

Plate D. Plans showing the position of rivets in the top of cell and bottom of flange. The heavy red transverse lines mark the limits of one panel of the web. Scale 1/10.

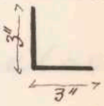
Plate E. 1. Transverse section of the bridge looking towards the roller end; showing the manner of connecting and bracing the girders. Scale 1/40.

2. Side elevation of entire bridge drawn to a scale of four 1/50 inch to a foot.

Particular Descriptions.

The vertical web.

The webs of all the girders are precisely alike. They are made of plates of iron 6'-6" by 5', placed with the largest dimension vertical. In the three panels of each end the thickness is 3/8"; in the remaining sections 5/16". Plate IB shows the elevation of a panel near the centre. The red lines show the positions of the vertical joints. The web is in no place less than 5/16" thick, because although more than sufficient to withstand the shearing force (as shown by calculation C), it is an important basis for braces and stiffeners, and a less thickness is insufficient to insure the holding force of the rivets. The sides are planed, so as to abut truly and equally; and as before mentioned the rivet holes are drilled. The vertical joints are covered with fish-plates on each side 7" wide, and 1/4" thick; reaching from the angle iron of the flange to the apex of the cell. Pieces of 3/8" plate, 5 ft. long bent to this cross-section 

, are placed over the fish plates, and the whole rivetted through from side to side with inch rivets 6" apart. The joint thus formed, becomes a pillar of the cross-section shown at S, fig. 3 plate AI, having an area of 12 □ inches. One of these pillars if brought to bear the pressure of the load on a locomotive driving wheel (say 5 tons), or of the greatest supporting force, would sustain it (Calculation D). Intermediate between the stiffeners, the web is strengthened against buckling by diagonals D, plates B & C, of 

shaped ¼" iron rivetted to each other through the web, and sloping upwards towards the centre of the span at an angle of 45°. The web is connected with the bottom flange by angle irons on each side 3" wide, secured by ⅞" rivets 6" apart. The sides H, fig. 1 plate A, of the triangular cell, are rivetted to the web, and its prolongation upwards is made fast to the base. (cross-sections, plate AI).

The Rollers &c.

The rollers are turned to cylindrical forms, with gudgeons on their ends 1½" diameter, entering holes in the frame by which they are held. This frame is a rectangular hoop of wrought iron, 3" wide and about 3/8" thick. The rivet heads are avoided, and a smooth rolling surface secured on the lower sides of the girder flanges, by drilling holes large enough and in the proper positions to receive the projections, in a plate of iron 7' long, and of sufficient thickness to prevent their protruding through. The plate so prepared is placed over the rivets. This plate should set close to the flange in order to properly distribute the supporting pressure, and not bring any of it on the rivet heads. An unequal bearing might cause the girders to rock. The lower roller-bed is a stout plate of iron covering the oaken cushion before spoken of. Plate C shows an elevation of the rollers, and their upper and lower tracks.

The flange for <u>outer</u> girders.

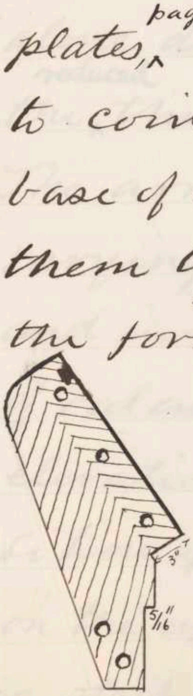
The flange is double throughout its entire length. The lower plate to which the web is immediately connected by angle irons, is 30" wide and at the centre of span 7/16" thick. The upper plate is in two strips each 11¼" wide, one each side of the web, in lengths of 20'. The upper and lower plates break joint; alternately the one serves the other as a fish-plate. At the centre, the thickness of these side strips is 7/16" but is reduced to 5/16" at a distance of 5 ft., and still further reduced in the third plate from the centre. The position and thickness of the several plates is shown in the exagerated sketch of sheet M. The flange and web are further connected, through the stiffeners, by gussets of 5/16" iron, fastened to the 6" projections of the stiffeners, then bent at right-angles and rivetted to the flange by a pair of 1"/16 rivets. This connection is shown in plate IIB, and transversely in fig. 2 plate AI.

The double flange is rivetted together along each edge by 1½" rivets 6" apart from centre to centre. Fig. 2, Plate III, shows the position of all the rivets in five feet length of flange; the rivets G, are those holding the gussets. The above results for the various thicknesses follow from calculation A.

The triangular cell for outer girders. Top.

The top of the cell is double like the flange, and the plates arranged to break joint. They are all 30" wide, and except the middle and two end ones of the upper layer are each 20' long. Position of the rivets for a single panel is shown in plate III, fig. 1. The heavy red, dotted, transverse lines, limit the length of a web plate. At the middle, the upper and lower plates are each 7/16" thick. In the next pair of 20' plates the thickness is reduced 1/16" and in the following pair a further reduction is made to 4/16" for each which thickness remains uniform for the rest of the girder.

Sides. The sloping side plates of the cell are 24" wide (when flat), in lengths of 20'. A joint comes at the centre of the span. Adjacent plates are fished on the inside, while the gusset covers the joint on the exterior. The two plates on either side the centre, are each 1/2" thick. The others have reduced thicknesses noted on sheet M, and in the summary of plates, page 30. Three inches of each edge are bent to coincidence with the planes of web, and base of cell respectively, and made fast to them by 1 1/2" rivets 4" apart. The gussets have before bent the form of the accompanying sketch. They are



further shown at G, fig. 2. plate AI & plate B. The side plates are marked H in the same.

The web bisects the cell, and is rivetted to its base through angle irons 3" wide. (Shown in the cross-sections, plate VI.)

Calculation A, gives results leading to the adoption of the ~~above~~ thicknesses of the plates.

Centre Girders.

The webs for the centre girders are precisely like those of the outer, in form, size, and arrangment of parts. The flanges and cells alone differ from the outer, and only in the reduced thicknesses of their respective plates. The arrangment is exactly the same. The varying thicknesses ~~are~~ given in sheet M, and in the summary (page 30), are results of calculation B. Sheet M ~~is~~ shows an exagerated elevation of half a girder, pointing out the position of each iron plate in cell and flange. Where joints occur on the upper sides of the cells, they are covered with a strip of ~~thin~~ sheet iron

Summary of Material.

Iron Plates.

Various thicknesses giving + sections in accordance with calculations A and B. The letters refer to sheet M.

Group	Dimensions.	cu. inches	Plates. ½ Outer Girder		Plates of ½ inner G.		For 1 outer G	For 1 inner G	2 outer G	2 inner G.	Total 4 G	Cu. in. in plates of outer girder
cells upper + lower layers - Flanges lower layers.	20′ × 30″ × 7/16″	3062.5	BL	2			2		4		4	6125.0
	20 × 30 × 6/16	2625.0	CD	2	BL	2	4	2	8	4	12	10500.0
	20 × 30 × 5/16	2167.5	N	1	CDN	3	2	6	4	12	16	4335.0
	20 × 30 × 4/16	1894.0	EFP	3	EFP	3	6	6	12	12	24	11364.0
	10 × 30 × 7/16	1531.25	A	1			1		2	2	2	1531.25
	10 × 30 × 6/16	1312.5		1	A	1		1			2	
	5 × 30 × 4/16	473.5	G	doubled *	G	1 * doubled	2	2	4	4	8	947.0
cells sides.	20 × 24 × 8/16	2880.0	H	2	H	2	4	4	8	8	16	11520.0
	20 × 24 × 5/16	1800.0	I	2	I	2	4	4	8	8	16	7200.0
	10 × 24 × 4/16	720.0	J	2	J	2	4	4	8	8	16	2880.0
Flanges upper layer	10 × 11¼ × 7/16	591.5	K	2			2		4		4	1183.0
	10 × 11¼ × 6/16	507.0			K	2		2		4	4	
	20 × 11¼ × 5/16	845.0	M	2	M	2	4	4	8	8	16	3380.0
	20 × 11¼ × 4/16	676.0	O	2	O	2	4	4	8	8	16	2704.0
	5 × 11¼ × 4/16	169.0	Q	2	Q	2	4	4	8	8	16	676.0
							43	43			172	cu. in = 64265.25

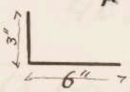
* below this sign the numbers in the 4th + 6th columns are doubled because there is a plate each side of the web.

Iron Plates.

Webs.

dimensions.	number.	solidity for one girder
78" × 60 × 5/16	56 for middle panels	25130. cu. in
78 × 60 × 3/8	24 " end "	8775. " "
	80 Total for 4 webs.	33905 " "

FISH PLATES AND L IRON &c.

	dimensions –	number	solidity for 1 girder
covering plates. (for vert. joints)	5' × 7" × 1/4"	168	4410 cu. in.
Stiffeners  shaped	5' × 9" × 3/8"	168	8505 " "
diagonals – for 20 pannels	6' × 6" × 1/4"	160	4320 " "
Gussets for cell (equivalent to)	22" × 6" × 5/16"	168	1732 " "
gussets for flange " "	15" × 6" × 5/16"	168	1181 " "
			29148 " "

ANGLE AND T iron.

T iron for 9 pairs of diagonal connectors shown in the section of plate E aggregate length of 142 ft

T iron for 9 pairs horizontal braces " " 144 ft.

T iron for tops of cells of outer girders 200 ft.

Angle iron 3" wide 1600 ft.

Rivets.

diameter	1 girder		4 girders
1½ inch	1320	× 4 =	5280
1¼ "	320	× 4 =	1280
1⅟₁₆ "	560	× 4 =	2240
1 "	1280	× 4 =	5120
⅞ "	550	× 4 =	2200
	4030		16120

Screw bolts for fishing sides of triangular cells; 30 (1 girder) × 4 = 120 (4 girders.)

Rollers.

6 × 4 = 24 6" diameter 30" long. Four wrought iron frames for them.

Timber &c.

80 cross timbers 22' × 7" × 9" spruce

longitudinal timber 10" × 10 total length of 200 ft. pine.

3 inch oak plank for cushions.

24 strips sheet iron. Paint.

Weight of an Outer Girder.

	cu. in.
Cell-and-flange;	64265.25
web;	33905.00
fish-plates, stiffeners &c.;	20148.00
angle and T iron;	11400.00
	129718.25 cu. in.

÷ 1728 = 75 cu. ft. 75 × 480 = 36000 lbs.

wt. 4000 rivet heads say = 1000 "

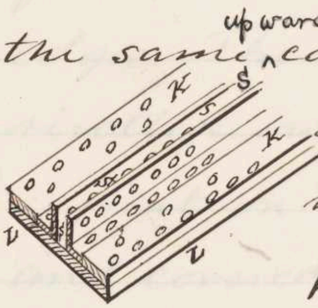
weight of an outer girder = 37000 "

$10\frac{2}{3}$ T of 2240 lbs $18\frac{1}{2}$ T of 2000 lbs.

It appears from examples of existing plate iron bridges, that the cost of the iron and labour in ~~erection~~ building and putting up, conjointly has been from 12 to 13 cents per pound of iron — At 13 cents per pound this bridge will cost $ 20000.00 exclusive of the masonry and superstructure.

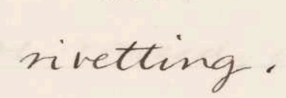
PROCESS OF PUTTING TOGETHER.

Rivet the pair of angle irons to ~~sheet M~~ plate I, (see sheet M); the angle irons being cut in such lengths that they may break joint with the plates. The bed on which the girders are built should have the same upward camber ~~as~~ that the bridge is to have. In the

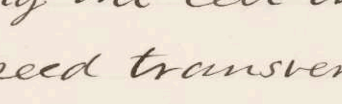


space S, left between the angle irons, set four of the web plates; they will just occupy the length of plate I. Cover the web joints, with the fish plates and stiffeners. Lay, on each side the strips K. (sheet M), completing the double thickness. Connect the stiffeners to the flange by the gussets. Proceeding thus, work out from the centre, both ways, until all the plates, stiffeners and lower gussets are in place. The seventh vertical plate from each end is cut slightly trapezoidal in form, (to an extent shown by calculation F), and placed with ~~it~~ the wider end uppermost. The object of this is to fill the space left by the plates leaning away from each other ~~owing~~ because of to the camber, causing the vertical joints to gape at the top.

When the vertical plates are all in position, the pair of angle irons that are to connect the web with the top of the cell are to be rivetted along their upper edges. The double thickness of the top is now rivetted on, begining at the centre. When a joint on the upper side occurs, it is painted and covered with a strip of sheet iron previous to rivetting. Staging will be required for fixing the cell in position, and the girder will need transverse staying. The parts to be enclosed in the cell may now be painted. The side plates will be most difficult to fix, on account of the fish plate on the interior of the triangular cell. This fish plate may be rivetted to one end of each side plate before it



is raised. Since when the next length is in position the fish plate



will be inaccessible for rivetting, the holes in the projecting part A, are cut with a thread, and screw bolts passed through the holes in the side and gusset that serves for an outer fish-plate, and the three thicknesses drawn tightly together by the screw. The inner side of the plates are to be painted before used. Green would be a good color. The upper gussets, with the exception of those covering joints, are to be rivetted in their proper positions, ~~on~~ to the side plates, before the latter are raised, and may be connected to their respective stiffeners as the work proceeds.

In the erection of the girders they are each to be moved from its bed, endwise, on rollers, over the span, on a temporary scaffolding which must be strong enough to sustain 20 tons. The centre ones may be first placed, and then on either side the outer one—.

necessitating
ammount
independant
(Rankine) 83 revetted (passim
arangment
seperately
secureing
exagerated (bis)
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