The Douro Bridge.

Theo. Parker. '81.

Thesis.

The bridge over the Douro in Portugal, given over to commerce on the fourth of Nov. 1877 which now rests upon the largest arch in the world, is also in other respects one of the most interesting constructions of the present time. In what follows will be given the discussion of the computation of the most important parts. The actual proportions are derived from a detailed account of T. Seyrig in the Mem. de la soc. des ing. civils 1878 § 741-816 only a few statements from a note in the Ann. des ponts et chaussées 1878. I § 101-107.

Abstract.

There were in all about 350 m. to be bridged over, of which the river Douro alone took up 150 m. As the track was to be about 62 m. above low water, the river was very deep and the circumstances of the ground were particularly unfavorable, so that they had to dispense with river piles. The Northern railway of Portugal opened a concourse and on the first of May 1875 one English and two French projects were offered of which the costs were as follows.

	I	II	III	IV	
Price of 1 m. of bridge	8350	4890	4270	2930	francs
" per sq. m.	169	110	85	59.2	"
Ratio of the prices	28.5	19.6	14.6	10	

On account of these remarkable differences the company feared that project No. IV of G. Eiffel + Co. of Paris might be behind the others in point of solidity and they caused a through examination and computation to be undertaken by a commission. The result was in every respect favorable and the project was accepted. 1

Details.

Clear span between points of support 352.875 m. The railroad lies between continuous girders of which in the direction of their length 3 respectively of 5, 5, 4 divisions follow each other. The five divisions of the middle continuous girder correspond with the five middle divisions of the supporting arch, they are therefore proportionately small. The distance apart of the two continuous girders that lie side by side is from axis to axis 3.1 m. The distance apart of the bounding lines at the outside is 3.5 m. The united length of the three girders that follow each other is 354.375 m., some other proportions that might perhaps be desirable to give are not clearly set forth in the publications referred to.
The computation of the continuous girders involves of course no difficulty. The traffic load of the arch is obtained from the

vertical pressure of the travelling load which rests on the continuous girders above. On account of the fixed positions of this vertical pressure we have supposed the load to be uniformly distributed and have used the corresponding approximations. The sickle formed railroad arches have a span of 160 m. and are divided by verticals into 21 divisions. The lengths of these divisions and of the verticals as well as the ordinates of the lower chord of the arch referred to an axis of abscissae through the middle points of the end hinges are shown in fig. 1. At first they attempted to use for the chords parabolas, but they found that in this way the heights of the girders near the ends would be too small for the moments to be resisted and hence they altered the form to a line of pressures drawn free hand and having regard to a pleasing appearance. The two beams in a chord of the arch are not in planes, their distance apart is 3.95 m at the hinges, so that the side pressure of the wind should be forcibly resisted and the stability of the construction preserved. It is the first time that this construction usual in hinged bridges is applied to arch girders and also the first time that sickle beams (with horizontal thrust) find use as archs.

Preliminary computation of the arch.

The most important part of the computation consists in the determination of the hor. thrust H. That the travelling load can only operates through 10 verticals, symmetrically situated with reference to the middle was suited to simplify the computation. In order to obtain the hor. thrust an undetermined load P was used at 5 points and H was calculated for all the different conditions of loading. In as much as they considered the loads concentrated in the middle lines of the supporting piles it was sufficient to take into consideration four points of loading. The axis of the arch had no definite geometrical form, the moment of inertiae θ varied in an irregular manner as even more so the value of $\theta \cos \varphi$ which is usually taken as a constant in parabolic ribs, by φ we denote the variable angle of inclination of the axis of the arch to the horizontal. Not withstanding this the hor. thrust was next determined by means of the tables of Bresse for circular arches of constant cross section. What assumption was made in regard to the load in this determination is not mentioned. After the external forces (the hor. thrust being one) were known the stresses in the bars were computed by breaking up the double system of truss work into single systems and the cross section of the members provisionally determined. It then appeared that the mean moment of inertiae in the single divisions varied from 0.246 to 4.696, and the mean values of θ cos φ from 0.170 to 4.696 while the axis of the arch lay between a parabola and a circle as the following comparison shows.

for $x =$	0.	8.4	20.4	31.0	59.2	69.6	80
Parabola $y =$	0.	8.49	18.99	26.67	39.78	41.95	42.65
Douro bridge $y =$	0.	9.00	20.42	28.30	40.35	42.25	42.65
Circle $y =$	0.	10.77	22.00	29.26	40.38	42.90	42.65.

Definite computation of the Hor. Thrust.
The definite computation was made under the direction of Dion de Mondésir. They allowed themselves to introduce for each division a constant mean value of the ordinate y, of the area of the cross-section and moment of inertia F, θ, of the bending moment M_x and of the normal and vertical forces N_x and V_x; by means of which the usual formulae for hinged

arched ribs become applicable. In the F (area) which comes in play to resist N_x the diagonals were also included. In the θ by means of which the bending M_x is resisted they hand regard to the chords alone. They drew the above mentioned constant mean values on the points of the axis of the arch which were in the middle of the single spans. The y, F and θ were taken from the first computation: their values are contained in the following table. The weight of the structure itself they appear to have taken from the first computation, but this is not explained. The travelling load was taken very high, as 4^t per metre while according to the rules of the French government 3^t would have been enough. They next computed what shortening $\Delta_{10} l$ of the bowstring would be caused by a hor. thrust of 10^t operating alone. They then determined lengthing Δl which would be caused by the load P acting

on each of the four mentioned points; and then determined the hor. thrust arising from P by means of the proportion,
$H : 10 = \Delta l : \Delta_{10} l$.
By adding the respective hor. thrusts for each P they obtained the hor. thrusts for each case of loading. The oftentimes neglected influence of the axial force is paid especial attention to.

Formulae for Hor. Thrust.

The above stated proceeding is interesting but somewhat difficult: as since we know the above stated mean values (used also in the graphical method) we can easily derive a determinate expression for the hor. thrust.
The hor. thrust of an arched rib with hinged ends is determined from the formulae (Weyrauch Theorie d. elast. Bogenträger) 1879 Eqn. 83.
$$\Delta l = -\int_0^l \Delta\varphi \, dy + \int_0^l Y \, dx.$$
But we have in general,

$\int \Delta\varphi \, dy = y\Delta\varphi - \int y \, d\varphi$, hence it follows that for symmetrical girders where for $x = 0$ and $l = 0$ we have $y = 0$, that $\Delta l = \int_0^l y \, d\varphi + \int_0^l \Upsilon \, dx$ or since (Theorie d. Bogenträger Eqn. 11, 6a and 7a).

$$d\Delta\varphi = X \, ds = \frac{M_x}{E\theta} ds \, . \; \Upsilon = \varepsilon T - \frac{N_x}{EF} \, .$$

$\Delta l = \varepsilon T l + \int_0^l \frac{yM_x}{E\theta} ds - \int_0^l \frac{N_x}{EF} dx$. where ds is the differential of the axis of the arch, T the ratio of the change temperature to the usual temperature and ε the coefficient of expansion of the material, for iron $\varepsilon = 0.000012$.

Let us give now to the mean value of y, $F\theta$, M_x, N_x in the mth division the index m and let us denote the length in the direction of the axis and the vertical projection of the axial length of this space by λ_m, δ_m, y_m. Then it follows from the last equation for n spaces

$$\Delta l = \varepsilon T l + \sum_1^N \frac{y_m \delta_m}{E\theta_m} M_m - \sum_1^N \frac{\lambda_m}{EF_m} N_m ,$$

Let farther the moment in the mth space arising from the vertical loads only be denoted by $\mathfrak{M}_m$ and the vertical shearing force in the same division by V_m, then follows by substitution from (Theorie d. Bogenträger Eqn. 88-31) $M_m = \mathfrak{M}_m - H y_m$ (1)
$N_m = V_m \frac{y_m}{\delta_m} + H \frac{\lambda_m}{\delta_m}$ (2) and if we use the following abbreviations viz.

$$A_m = \frac{\delta_m y^2_m}{\theta_m} . \qquad C_m = \frac{\delta_m y_m}{\theta_m} . \quad (3)$$

$$B_m = \frac{\lambda^2_m}{\delta_m F_m} . \qquad D_m = \frac{\lambda_m y_m}{\delta_m F_m} . \quad (4)$$

the hor. thrust

$$H = \frac{E l \varepsilon T - E \Delta l + \sum_1^N (C_m \mathfrak{M}_m - D_m V_m)}{\sum_1^N (A_m + B_m)} \quad (5)$$

a) If the very small influence of the axial force is neglected the expression becomes simplified $H = \frac{E l \varepsilon T - E \Delta l + \sum_1^N C_m \mathfrak{M}_m}{\sum_1^N A_m}$ (6)

b) If the influence of the difference of temperature and of the yielding of the supports is not to be taken into account then the terms containing E disappear. Let any loads $P_1\ P_2 \dots$ &c act the abscissae of their points of application being $a_1, a_2 \dots$ &c. Let V denote the vertical shearing force at the origin and x_m the abscissae of the middle of the mth division then we have in (5) or (6) Theorie d. Bogenträger eqns, 88, 29, 86)

$$M_m = V x_m - \sum_0^{x_m} P(x_m - a) \qquad (7)$$

$$V_m = V - \sum_0^{x_m} P \qquad (8)$$

$$V = \frac{1}{l} \sum_0^{l} P(l - a) \qquad (9)$$

The values of A_m, B_m; C_m, D_m only depend on the form and cross section and not on the loading.

Relations of the Douro bridge.

The following table contains a series of values which which with those written on the fig. describe the relations of the Douro bridge in such a way that the entire computation of the forces can be easily made from the quantities given there as is shown in some directions below. The D_m's from $m = 11$ to $m = 21$ have the same values as those m = 11 to m = 1 only with negative signs. The values in the last three columns are only for comparison.

m	X_m	y_m	λ_m	Y_m	δ_m	F_m	θ_m	A_m	B_m	C_m	D_m	$\frac{\theta_m \lambda_m^2}{\delta_m}$	$\frac{\theta_m \lambda_m}{F_m}$	$\theta_m \lambda_m$
1	2.80	3.00	5.60	6.01	8.10	0.293	0.246	296	13.21	96.77	14.18	0.95	4.70	1.38
2	8.40	9.00	5.55	5.67	8.15	0.274	0.588	1123	13.79	124.74	14.09	2.22	11.91	3.26
3	14.10	14.55	5.95	5.64	8.15	0.264	1.153	1496	16.45	102.85	15.60	5.01	25.99	6.86
4	20.40	20.42	6.65	5.70	8.80	0.253	1.848	1986	19.86	97.24	17.02	9.29	48.57	12.29
5	25.25	24.20	3.00	2.25	3.80	0.242	2.463	904	9.79	37.34	7.34	5.83	30.53	7.39
6	31.00	28.30	8.45	5.17	9.80	0.236	2.863	2741	30.87	96.87	18.89	20.86	102.51	24.19
7	39.75	32.75	9.10	4.29	10.05	0.225	3.486	3092	36.62	94.42	17.26	28.72	140.99	31.72
8	49.15	36.85	9.70	3.81	10.40	0.222	3.758	3758	40.75	101.98	16.01	34.00	164.20	36.45
9	59.20	40.35	10.40	2.76	10.75	0.223	4.220	4147	45.12	102.79	11.97	42.46	196.81	43.89
10	69.60	42.25	10.40	1.15	10.50	0.228	4.609	4066	45.18	96.24	5.00	47.48	210.23	47.93
11	80.00	42.65	5.20	0.2-02	5.25	0.228	4.696	2034	22.59	95.36	0	24.19	107.10	24.42
For half arch			80.0	42.65	93.75			25643	294			221	1044	240

The most unfavorable loading.

As a defiency in the computation of the Douro bridge we must also observe that the most unfavorable loading was not determined and this would have been so much the easier because the travelling load can act only at a few points. There were only four arrangements of the loads investigated. Dead weight only, total loading of the whole arch, loading on one side as far as the crown of the arch and loading on the middle 80m. on the upper half of the latter. In the Coblenz bridge they computed correctly in this regard (while they let the load advance by distances of $\frac{l}{20}$) the curves of the chord stresses and shearing forces for each of the so determined conditions of loadings and they took as curves of maximum stresses the bounding curves. After the finding of the line $\underline{s}$ we can however proceed more accurately. (Theorie d. Bogenträger §6, 10)

Equation of the line $\underset{\sim}{s}$.

This can be determined for any chosen form of axis and variation of cross section as follows. Let H and V be the values of the hor. thrust and the vertical reaction O, consequent upon the action of a single load P at $\underset{\sim}{a}$, the ordinate of the line $\underset{\sim}{s}$ at the point whose abscissa is $\underset{\sim}{a}$ is (Theorie d. Bogenträger Eqn. 89)

$$\underset{\sim}{b} = \frac{V}{H} a.$$

and because by (6) and (9)

$$H = \frac{\sum_1^N \frac{\delta_m y_m}{\theta_m} M_m}{\sum_1^N A_m} . \; V = \frac{l-a}{l} P.$$

$$b = \frac{a(l-a) P \sum_1^N A_m}{l \sum_1^N \frac{\delta_m y_m}{\theta_m} M_m}.$$

But now we have if x denotes the x_m which lies before $\underset{\sim}{a}$ according to (7) and (9) from $m = 1$ to $m = r$, $M_m = V_{x_m} = \frac{l-a}{l} P_{x_m}$.
from $m = r+1$ to $m = n$, $M_m = V_{x_m} - P(x_m - a)$
$= \frac{l - x_m}{l} P_a$.

By the substitution of this value in the expression for b and by the use of abbreviated expressions, $K_m = \frac{\delta_m y_m x_m}{\theta_m}$ $L_m =$

$= \frac{S_m \, y_m \, (l - x_m)}{\theta_m}$ (13), there follows the equation of the line s,

$$b = \frac{(l-a)\, a \sum_1^N A_m}{(l-a) \sum_1^N K_m + a \sum_1^N L_m} \qquad (14)$$

The line s can be thence determined as soon as the form and variation of the cross section of the arch are known.

Line of s of the Douro bridge.

Having regard to the values given in the table there follow by (13)

$K_1 = 276 = L_{21}$	$K_{12} = 8701 = L_{10}$
$K_2 = 1048 = L_{20}$	$K_{13} = 10361 = L_9$
$K_3 = 1450 = L_{19}$	$K_{14} = 11304 = L_8$
$K_4 = 1984 = L_{18}$	$K_{15} = 11354 = L_7$
$K_5 = 943 = L_{17}$	$K_{16} = 12496 = L_6$
$K_6 = 3003 = L_{16}$	$K_{17} = 5032 = L_5$
$K_7 = 3753 = L_{15}$	$K_{18} = 13575 = L_4$
$K_8 = 5012 = L_{14}$	$K_{19} = 15006 = L_3$
$K_9 = 6085 = L_{13}$	$K_{20} = 18910 = L_2$
$K_{10} = 6698 = L_{12}$	$K_{21} = 15527 = L_1$
$K_{11} = 7629 = L_{11}$	$\sum_1^N K_m = 160147 = \sum_1^N L_m$

and hence by (14) we have for $a = 0 + r = 0$

$$b = \frac{(160)(2)(25643)}{160 \times 147} = 51.24\ m.$$

for $a = 2$ and $r = 3$.

$$b = \frac{140 \times 20 \times 51286}{140 \times 2774 + 20 \times 110704} = 55.22\ m.$$

for $a = 40$ and $r = 7$.

$$b = \frac{120 \times 40 \times 51286}{120 \times 12457 + 40 \times 68247} = 58.27\ m.$$

for $a = 60$ and $r = 9$.

$$b = \frac{100 \times 60 \times 51286}{600 \times 23554 + 60 \times 46582} = 59.75\ m.$$

for $a = 80$ and $r = 11$

$$b = \frac{80 \times 80 \times 51286}{80 \times 37881 + 80 \times 30252} = 60.16\ m.$$

in the same manner the following values of b for the points of supports were calculated.

Values of z for points of Support.

A. $l-a = 134.75$; $a = 25.25$; $\Sigma A_m = 51286$; $\sum_1^{\tilde{n}} K_m = 5701$; $\sum_r^n L_m = 92097$ ∴

$$z = \frac{134.75 \times 25.25 \times 51286}{134.75 \times 5701 + 25.25 \times 92097} = 56.4 \text{ m.}$$

B. $l-a = 106$; $a = 54$; $\Sigma A_m = 51286$; $\sum_1^{\tilde{n}} K_m = 17469$. $r = 8$ $\sum_r^n L_m = 56943$ ∴

$$z = \frac{106 \times 54 \times 51286}{106 \times 17469 + 54 \times 56943} = 59.58 \text{ m.}$$

C. $l-a = 95.6$; $a = 64.4$; $r = 9$; $\Sigma A_m = 51286$; $\sum_1^{\tilde{n}} K_m = 23554$ $\sum_r^n L_m = 46582$ ∴

$$z = \frac{95.6 \times 64.4 \times 51286}{95.6 \times 23554 + 64.4 \times 46582} = 60.12 \text{ m.}$$

D. $l-a = 85.2$; $a = 74.8$; $r = 10$; $\Sigma A_m = 51286$; $\sum_1^{\tilde{n}} K_m = 30252$ $\sum_r^n L_m = 37881$ ∴

$$z = \frac{85.2 \times 74.8 \times 51286}{85.2 \times 30252 + 74.8 \times 37881} = 60.4 \text{ m.}$$

Computation of the chord stresses.

I computed the chords stresses under the rolling load only, the dead weight of the structure not being given in J. Leyrig's paper in the "Mem. de ing. civils" 1878. I first found the loads that would give the largest stresses in the chords in the following manner; take for example chord 8 fig. 1; through the middle point of the neutral axis lines were drawn to the hinges and continued until they intersected the line s (the construction of which has been explained) in the points x and y; the points a and b are on the line s vertically over the hinges; then with the rolling load from x to y there is caused compression in the upper chord and tension in the lower and with the rolling load from x to a, and y to b there is caused tension in the upper and compression in the lower (Weyrauch p.46.). In this way the loads given on page 27 were calculated.

The loads were computed as though the trusses were supported on the piers and not continuous over them for the following reasons; 1°. To have computed the supporting forces considering the trusses continuous would have been very long and laborious and too much time would have been consumed. 2°. I think sufficiently accurate results can be obtained by considering the trusses supported as my results show.

Having found the most unfavorable loading for each chord I next calculated the vertical reaction at the hinges arising from each load, by the formula $V = \frac{1}{2} P(l-a)$, these results are given on pages 28 to 34.
I next computed the horizontal thrust arising from each load. I first computed the angles made by lines drawn through the hinges and the intersection of the points of support with the line s, and the axis of the arch; one of the angles is shown in fig. 3, a o t, the tangs. of these angles are given on page 33.
H was calculated by the following formula

$H = \frac{V}{\tan\alpha}$; the results are given on pages 34 to 40.
I next calculated the bending moments due to the loads; this was done in the same manner as in a straight beam; the results are given on pages 41 to 44.
The resultant moment equals the moment due to the loads minus that due to the hor. thrust; the results of this calculation are given on pages 44 to 46.
The coefficients of work were obtained from the resultant moments by dividing them by the quantities $\frac{I}{v'}$ for coeff. in intrados and $\frac{I}{v}$ for coeff. in extrados. The quantities $\frac{I}{v'}$ and $\frac{I}{v}$ are obtained by dividing the moment of inertia of the cross-sections of the members by their distance to their respective centres of gravity from the neutral axis. The results obtained by dividing the resultant moments by these factors are given in the table on page 47.

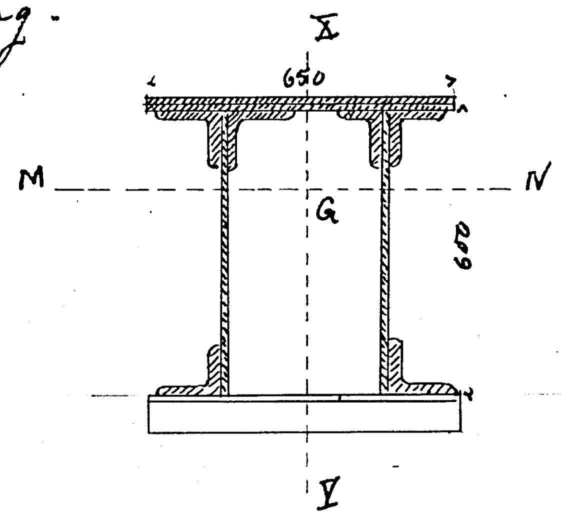
Tang. compression.

I found the tangential compression of each section graphically; fig. 2 represents the manner in which the compression was found. $ab = \Sigma H$ for any section; $bc = \Sigma V$ for the same section; from a draw a line ad parallel to the neutral axis of the section and from c draw cd perpendicular to ad; then ad equals the tang. compression at that section. By means of figs. similar to the above described the tang. compressions given in the table on page 47 were obtained.

These tang. compressions were divided by the section of the arch, and the coefficients of work due to tang. compression were thus obtained. These were then combined with those previously obtained from the resultant moments and the resultant coef. due to the rolling load were obtained. By adding to these results those due to the dead weight (obtained from page 775,

Mémoires, Société des ings. civils 1878)
the total resultant coefficients were found.
I compared these results with those given by T. Seyrig in his paper (Ings. civils, 1878) and the greatest difference is but 1.91 kil., or abt 4 lbs. a quantity that would change the cross-section but slightly.

Calculation of the greatest stress allowable on chord 8; against lateral bending.



4 angles $\frac{100 \times 100}{12}$

1 plate 650×30.

2 webs 600×12

2 angles $\frac{120 \times 90}{10}$.

The chords have the form of a square. Three of their sides are solid the fourth is lattice work of angle irons, that are not counted in the section. The weakest of these pieces, at the same time those that have the greatest length are those of chord 8, which under the effect of the wind, rolling and dead load has a coefficient of work equal to 5.58 in my case.

Calculate P by the formula $P = \frac{E I \pi^2}{l^2}$, in which, E = mod. of elasticity of the metal, I = moment of inertia of the piece, l = the length between the points of attachment.

First calculate P, taking I about XY; then I = 0.001533; E = 16 × 10⁹ and l = 10.34 m.

$$\therefore P = \frac{16 \times 10^9 \times 0.001533 \times 9.8696}{106.91} = 2264353^k.$$

with a factor of safety of six, the allowable load is $\frac{2264353}{6} = 377392^k.$

When the maximum coef. of work, 5.58 is reached the total load of the piece

will be the area multiplied by 5.58 or
$39712 \times 5.58 = 221593$ which is far from
the maximum that can be had without
bending. The stress in the piece could be
increased to $\frac{377392}{39712} = 9^k.50$ per sq. milli-
metre without danger of bending.
By I about MN a still larger stress
is admissible.
It will thus be seen that the chords
of the Douro bridge have a factor of
safety of about 12.

I did not have sufficient time to take up
the wind pressure or the deformation of the
arch, each of which would have required
a long time.
As I could not begin my calculations until
I had had the subject taken up in the
class, which could not be done until
well into the present term, my time
was quite limited. Although it was
taken up in the class, the other mem-

kers worked of course only the required time so that but a small part of my work was checked by them.

The points marked A, B, C, D, E, F, G and H in fig. 1. are the points through which the rolling load acts on the arch.

Loads for chord stresses.

		Cu Tl	Tu Cl			Cu Tl	Tu Cl
Chs. 1+2	A	115000	0	Ch. 7.	A	115000	0
	B	63408	14892		B	78300	0
	C	492	41108		C	40831	769
	D	0	41600		D	13569	28031
	E	0	41600		E	0	41600
	F	0	41600		F	0	41600
	G	0	78300		G	0	78300
	H	0	115000		H	0	115000
Ch. 3	A	115000	0	Ch. 8.	A	111830	3169
	B	71381	6923		B	78300	0
	C	3719	37877		C	41600	0
	D	0	41600		D	36400	5200
	E	0	41600		E	5200	36400
	F	0	41600		F	0	41600
	G	0	78300		G	0	78300
	H	0	115000		H	0	115000
Ch. 4	A	115000	0	Ch. 9.	A	71695	43304
	B	74577	3723		B	78300	0
	C	6923	34677		C	41600	0
	D	0	41600		D	41600	0
	E	0	41600		E	31069	10531
	F	0	41600		F	1731	39869
	G	0	78300		G	0	78300
	H	0	115000		H	0	115000
Ch. 5.	A	115000	0	Ch. 10.	A	21,062	93938
	B	77808	4920		B	69338	8962
	C	14892	26708		C	41600	0
	D	0	41600		D	41600	0
	E	0	41600		E	41600	0
	F	0	41600		F	31069	10531
	G	0	78300		G	1731	76569
	H	0	115000		H	0	115000
Ch. 6.	A	115000	0	Ch. 11.	A	1409	113591
	B	78300	0		B	37391	40909
	C	26023	15577		C	41600	0
	D	377	41223		D	41600	0
	E	0	41600		E	41600	0
	F	0	41600		F	41600	0
	G	0	78300		G	38397	39903
	H	0	115000		H	1603	113397

Chords 1 & 2. Cu. Tl.

A. $V = \frac{1}{r} \Sigma P(l - a) = \frac{1}{160} \times 115000 \times 134.75 = 96852.$

B. " = " = " $\times 63408 \times 106 = 42008.$ $\Sigma V = 139154.$

C. " = " = " $\times 492 \times 95.6 = 294.$

Chords 1 + 2. Cl. Tu.

B. $V = \frac{1}{r} \Sigma P(l - a) = \frac{1}{160} \times 14892 \times 54 = 5026.$

C. " = " = " $\times 41108 \times 64.4 = 16546.$

D. " = " = " $\times 41600 \times 74.8 = 19448.$

E. " = " = " $\times 41600 \times 85.2 = 22152.$ $\Sigma V = 236754.$

F. " = " = " $\times 41600 \times 95.6 = 24856.$

G. " = " = " $\times 41600 \times 106 = 51874.$

H " = " = " $\times 115000 \times 134.75 = 96852.$

Chord 3. Cu. Tl.

A. $V = \frac{1}{r} \Sigma P(l - a) = \frac{1}{160} \times 115000 \times 134.75 = 96852.$

B. " = " = " $\times 71381 \times 106 = 47296.$ $\Sigma V = 146370.$

C. " = " = " $\times 3719 \times 95.6 = 2222$

Chord. 3. Cl. Tu.

B. $V = \frac{1}{r} \Sigma P(l - a) = \frac{1}{160} \times 6923 \times 54 = 2336.$

C. " = " = " $\times 37877 \times 64.4 = 15245.$

D " = " = " $\times 41600 \times 74.8 = 19448.$

E. " = " = " $\times 41600 \times 85.2 = 22152.$ $\Sigma V = 232763.$

F. " = " = " $\times 41600 \times 95.6 = 24856.$

G. " = " = " $\times 78300 \times 106 = 51874.$

H. " = " = " $\times 115000 \times 134.75 = 96852.$

Ch. 4. Cu. Tl.

A. $V = 1/\tau\, \Sigma P(\tau - a) = 1/160 \times 115000 \times 134.75 = 96852.$

B. " = " = " $\times 74577 \times 106 = 49407.$ $\Sigma V = 150396$

C. " = " = " $\times 6923 \times 95.6 = 4136.5$

Ch. 4. Cτ. Tu.

B. $V = 1/\tau\, \Sigma P(\tau - a) = 1/160 \times 3723 \times 54 = 1257.$

C. " = " = " $\times 34677 \times 64.4 = 13957.$

D. " = " = " $\times 41600 \times 74.8 = 19448.$

E. " = " = " $\times 41600 \times 85.2 = 22152.$ $\Sigma V = 230396.$

F. " = " = " $\times 41600 \times 95.6 = 24856.$

G. " = " = " $\times 78300 \times 106 = 51874.$

H. " = " = " $\times 115000 \times 134.75 = 96852.$

Ch. 5. Cu. Tτ.

A. $V = 1/\tau\, \Sigma P(\tau - a) = 1/160 \times 115000 \times 134.75 = 96852.$

B. " = " = " $\times 77808 \times 106 = 51547.$ $\Sigma V = 157297.$

C. " = " = " $\times 14892 \times 95.6 = 8898.$

Ch. 5. Cτ. Tu.

B. $V = 1/\tau\, \Sigma P(\tau - a) = 1/160 \times 492 \times 54 = 166.$

C. " = " = " $\times 26708 \times 64.4 = 10750.$

D. " = " = " $\times 41600 \times 74.8 = 19448.$

E. " = " = " $\times 41600 \times 85.2 = 22152.$ $\Sigma V = 226098.$

F. " = " = " $\times 41600 \times 95.6 = 24856.$

G. " = " = " $\times 78300 \times 106 = 51874.$

H. " = " = " $\times 115000 \times 134.75 = 96852.$

Ch. 6. Cu. Tl.

A. $V = \frac{1}{r}\Sigma P(l-a) = \frac{1}{160} \times 115000 \times 134.75 = 96852.$

B. " = " = " $\times 78300 \times 106 = 51874.$

C. " = " = " $\times 26023 \times 95.6 = 15549.$ $\Sigma V = 164475.$

D. " = " = " $\times 377 \times 85.2 = 201.$

Ch. 6. Cl. Tu.

C. $V = \frac{1}{r}\Sigma P(l-a) = \frac{1}{160} \times 15577 \times 64.4 = 6270.$

D. " = " = " $\times 41223 \times 74.8 = 19272.$

E. " = " = " $\times 41600 \times 85.2 = 22152.$ $\Sigma V = 112024.$

F. " = " = " $\times 41600 \times 95.6 = 24856.$

G. " = " = " $\times 78300 \times 106 = 51874$

H. " = " = " $\times 115000 \times 134.75 = 96852.$

Ch. 7. Cu. Tl.

A. $V = \frac{1}{r}\Sigma P(l-a) = \frac{1}{160} \times 115000 \times 134.75 = 96852.$

B. " = " = " $\times 78300 \times 106 = 51874.$ $\Sigma V = 180346.$

C. " = " = " $\times 40831 \times 95.6 = 24396.$

D. " = " = " $\times 13569 \times 85.2 = 7225$

Ch. 7. Cl. Tu.

C. $V = \frac{1}{r}\Sigma P(l-a) = \frac{1}{160} \times 769 \times 64.4 = 309$

D. " = " = " $\times 28031 \times 74.8 = 13104.$ $\Sigma V = 209147.$

E to H, V as in Ch. 6.

Ch. 8. Cu. T T.

A. $V = \frac{1}{2}\Sigma P(l-a) = \frac{1}{160} \times 111830 \times 134.75 = 94181.$

B. V = 〃 = 〃 × 78300 × 106 = 51874.

C. 〃 = 〃 = 〃 × 41600 × 95.6 = 24856. $\Sigma V = 192725.$

D. 〃 = 〃 = 〃 × 36400 × 85.2 = 19383.

E. 〃 = 〃 = 〃 × 5200 × 74.8 = 2431.

Ch. 8. C T. Tu.

A. $V = \frac{1}{2}\Sigma P(l-a) = \frac{1}{160} \times 3169 \times 25.25 = 500.$

D. 〃 = 〃 = 〃 × 5200 × 74.8 = 2431. $\Sigma V = 195896.$

E 〃 = 〃 = 〃 × 36400 × 85.2 = 19383.

F to H, V as in Ch. 6.

Ch. 9. Cu. T T.

A. $V = \frac{1}{2}\Sigma P(l-a) = \frac{1}{160} \times 71695 \times 134.75 = 60381.$

B. 〃 = 〃 = 〃 × 78300 × 106 = 51874.

C. 〃 = 〃 = 〃 × 41600 × 95.6 = 24856. $\Sigma V = 174485.$

D. 〃 = 〃 = 〃 × 41600 × 85.2 = 22152.

E 〃 = 〃 = 〃 × 31069 × 74.8 = 14525.

F. 〃 = 〃 = 〃 × 1731 × 64.4 = 697.

Ch. 9. C T. Tu.

A. $V = \frac{1}{2}\Sigma P(l-a) = \frac{1}{160} \times 43304 \times 25.25 = 6834.$

E. 〃 = 〃 = 〃 × 10531 × 85.2 = 5608 $\Sigma V = 184989.$

F. 〃 = 〃 = 〃 × 39869 × 95.6 = 23822.

H 〃 = 〃 = 96852

G 〃 = 〃 = 51874

Ch. 10. Cu. TT.

A. $V = 1/t\, \Sigma P(T-a) = 1/160 \times 21062 \times 134.75 = 17738.$

B. " = " = " $\times 69338 \times 106 = 45936.$

C. " = " = $= 24856.$

D. " = " = $= 22152.$ $\Sigma V = 143219.$

E. " = " = $= 19448.$

F. " = " = " $\times 31069 \times 64.4 = 12505.$

G. " = " = " $\times 1731 \times 54 = 584.$

Ch. 10. CT. Tu.

A. $V = 1/t\, \Sigma P(T-a) = 1/160 \times 93938 \times 25.25 = 14824.$

B. " = " = " $\times 8962 \times 54 = 3025$

F. " = " = " $\times 10531 \times 95.6 = 6292.$ $\Sigma V = 171720.$

G. " = " = " $\times 76569 \times 106 = 50727.$

H " = " = " $\times 115000 \times 134.75 = 96852$

Ch. 11. Cu. TT.

V fu $= 1/t\, \Sigma P(T-a) = 1/160 \times 1409 \times 134.75 = 1187.$

B. " = " = " $\times 37391 \times 106 = 24771.$

C. " = $= 24856.$

D " = $= 22152.$ $\Sigma V = 122370.$

E " = $= 19448.$

F " = " = " $\times 41600 \times 64.4 = 16744.$

G. " = " = " $\times 38397 \times 54 = 12959.$

H " = " = " $\times 1603 \times 25.25 = 253.$

Angles used in getting the hor. thrust.

A. Tan A, left, $= \frac{56.4}{25.25} = 0.340551$ log.

" , right $= \frac{56.4}{134.75} = 9.6217877$ log.

B. Tan B, left, $= \frac{59.58}{54} = 0.0427067$ log.

" , right, $= \frac{59.58}{106} = 9.7497946$ log.

C. Tan C, left, $= \frac{60.12}{64.4} = 9.9701601$ log.

" right $= \frac{60.12}{95.6} = 9.7985881$ log.

D. Tan D, left, $= \frac{60.4}{74.8} = 9.9071353$ log.

" " , right, $= \frac{60.4}{85.2} = 9.8505973$ log.

Ch. 11. C T. Tu.

A. $V = 1/2\, \bar{x} P(l-a) = 1/160 \times 1409 \times 25.25 = 17926.$

B. " = " = " $\times 40909 \times 54 = 13807.$ $\Sigma V = 153610.$

G. " = " = " $\times 39903 \times 106 = 26375.$

H. " = " = " $\times 113397 \times 134.75 = 95502.$

Hor. Thrusts.

Chs. 1+2. Cu. T T.

A = $H = \frac{V}{\tan A}$ $\times$ log. $V = 4.9861066$
$\tan A = 0.3490551$
$4.6370515 = 43356.$

B. $H = V/\tan B.$ log $V = 4.6233300$
$\tan B = 0.0427067$
$4.5806233 = 38074.$ $\Sigma H = 81745^k$

C. $H = V/\tan C.$ log $V = 2.4683030$
$\tan C = 9.9701661$
$2.4981429 = 314.8$

Chs. 1+2. C T. Tu.

B. $H = V/\tan B.$ log $V = 3.7012268$
$\tan B = 9.7497946$
$3.9514322 = 8942.$

C. $H = V/\tan C.$ log $V = 4.2186922$
$\tan C = 9.7985881$
$4.4201041 = 26309.$

D. $H = V/\tan D.$ log $V = 4.2888749$
$\tan D = 9.8505973$
$4.4382776 = 27433.$

E. $H = V/\tan E.$ log $V = 4.3454129$
$\tan E = 9.9071353$
$4.4382776 = 27433.$

F'. $H = V/\tan F'$. $\log V = 4.3954312$
$\lg\tan F' = \underline{9.9701601}$
$4.4252711 = 27703.$

G. $H = V/\tan G$. $\log V = 4.7149477$ $\Sigma H = 208192.^{k}$
$\lg\tan G = \underline{0.0427067}$
$4.6722410 = 47016.$

H. $H = V/\tan H$. $\log V = 4.9861066$
$\lg\tan H = \underline{0.3490551}$
$4.6370515 = 43356.$

Ch. 3. Cu. TE.

A. $H = V/\tan A = 43356.$

B. " $= V/\tan B$. $\log V = 4.6747685$
$\lg\tan B = \underline{0.0427067}$
$4.6320618 = 42861.$ $\Sigma H = 88597.^{k}$

C. " $= V/\tan C$. $\log V = 3.3467641$
$\lg\tan C = \underline{9.9701601}$
$3.3766040 = 2380$

Ch. 3. CE. Tu.

B. $H = V/\tan B$. $\log V = 3.3685681$
$\lg\tan B = \underline{9.7497946}$
$3.6187735 = 4157.$

C. $H = V/\tan C$. $\log V = 4.1831415$ $\Sigma H = 201339.^{k}$
$\lg\tan C = \underline{9.7985881}$
$4.3845534 = 24241.$

From H to D, thrust same as in 1+2, CE. Tu.

Ch. 4. Cu. Tl.

A. $H = 43356.$

B. $H = V/\tan B.$

$$\begin{array}{rl} \log V = & 4.6937908 \\ \tan B = & \underline{0.0427067} \\ & 4.6510841 = 44780. \end{array}$$

C. $H = V/\tan C.$

$$\begin{array}{rl} \log V = & 3.6166322 \\ \tan C = & \underline{9.9701601} \\ & 3.6464721 = 4430.7 \end{array}$$

$\Sigma H = 92567^k$

Ch. 4. Cl. Tu.

B. $H = V/\tan B.$

$$\begin{array}{rl} \log V = & 3.0991668 \\ \tan B = & \underline{9.7497946} \\ & 3.3493722 = 2235.5 \end{array}$$

C. $H = V/\tan C.$

$$\begin{array}{rl} \log V = & 4.1448070 \\ \tan C = & \underline{9.7985881} \\ & 4.3462189 = 22193. \end{array}$$

$\Sigma H = 197370^k$

Thrust from D to H same as in 1 & 2 Cl. Tu.

Ch. 5. Cu. Tl.

A. $H = 43356.$

B. $H = V/\tan B.$

$$\begin{array}{rl} \log B = & 4.7122034 \\ \tan B = & \underline{0.0427067} \\ & 4.6694967 = 46719. \end{array}$$

C. $H = V/\tan C.$

$$\begin{array}{rl} \log V = & 3.9492909 \\ \tan C = & \underline{9.9701601} \\ & 3.9791308 = 9531 \end{array}$$

$\Sigma H = 99606^k$

Ch. 5. Ct. Tu.

B. $H = V/\tan B$.

$\log V = 2.2202389$
$\tan B = \underline{9.7497946}$
$2.4704443 = 295.$

C. $H = V/\tan C$.

$\log V = 4.0314073$
$\tan C = \underline{9.7985881}$
$4.2328192 = 17093.$

$\Sigma H = 190329^k$

Thrust from D to H same as in 1 + 2, Ct. Tu.

Ch. 6. Cu. Tt.

A. $H = 43356.$

B. $H = V/\tan B$

$\log V = 4.7149477$
$\tan B = \underline{0.0427067}$
$4.6722410 = 47016.$

C. $H = V/\tan C$.

$\log V = 4.1916953$
$\tan C = \underline{9.9701601}$
$4.2215352 = 16655.$

$\Sigma H = 107027^k$

Ch. 6. Ct. Tu.

C. $H = V/\tan C$.

$\log V = 3.7972497$
$\tan C = \underline{9.7985881}$
$3.9986616 = 9969.$

D. $H = V/\tan D$.

$\log V = 4.2849212$
$\tan D = \underline{9.8505973}$
$4.4343239 = 27185.$

$\Sigma H = 182662^k$

Thrust from E to H as in 1 + 2, Ct. Tu.

Ch. 7. Cu. Tt.

A. $H = 43356.$

B. " $= 47016.$

C. " $= V/\tan C$.

$\log V = 4.3873279$
$\tan C = \underline{9.9701601}$
$4.4171678 = 26132.$

D. " $= V/\tan D$.

$\log V = 3.8588674$
$\tan D = \underline{9.9071353}$
$3.9517321 = 8948$

$\Sigma H = 125452.^k$

Ch. 7. Cr. Tr.

C. $H = V/\tan C$. $\log V = 2.4906922$
$\tan D = \underline{9.7985981}$
$2.6921041 = 492.$

D. " $= V/\tan D$. $\log V = 4.1174200$ $\Sigma H = 164485^k$
$\tan D = \underline{9.8505973}$
$4.2668227 = 18485.$

Thrusts from E to H as in Ch. 3. Cr. Tr.

Ch. 8. Cr. Tl.

A. $H = 42161.$

B. " $= 47016.$

C. " $= 27703.$

D. " $= V/\tan D$. $\log V = 4.2874210$
$\tan D = \underline{9.9071353}$
$4.3802857 = 24004.$

E. " $= V/\tan E$. $\log V = 3.3857849$ $\Sigma H = 144313^k$
$\tan E = \underline{9.8505973}$
$3.5351876 = 3429.$

Ch. 8. Cr. Tr.

A. $H = 1194.$

D. " $= V/\tan D$. $\log V = 3.3857850$
$\tan D = \underline{9.8505973}$
$3.5351877 = 3429.$

E. " $= V/\tan E$. $\log V = 4.2874210$ $\Sigma H = 145508^k$
$\tan E = \underline{9.9071353}$
$4.3802857 = 24004$

Thrusts from F to H as in 3. Cr. Tr.

Ch. 9. Cu. TC.

A. H = 27030
B. " = 47016
C. " = 27703 $\Sigma H = 146696^{k}$
D " = 27433
E " = 16274
F " = 1239.6

Ch. 9. CC. Tu.

A. H = 16326.
E. " = 6944.7.
F. " = 25516. $\Sigma H = 139159.^{k}$
G. " = 47016.
H. " = 43356.

Ch. 10. Cu. TC.

A. H = 7941.
B. " = 41634.0
C. " = 27703.
D " = 27433. $\Sigma H = 153067.^{k}$
E " = 27433.
F " = 19884.
G. " = 1039.4

Ch. 10. CC. Tu.

A. H = 35414
B = " = 5382
F = " = 6739.8 $\Sigma H = 136868^{k}$
G. " = 45976
H. " = 43356

Ch. 11. Cu. T.T.

A. $H = 531.$

B. " = 22451.

Thrusts from C to E as in 10 Cu. T.T.

F. $H = 26624.$ $\Sigma H = 155835.^{k}$

G. " = 23056.

H. " = 604.3

Ch. 11. C.T. Tu.

A. $H = 42825.$

B. " = 24565.

G " = 23905. $\Sigma H = 134047.^{k}$

H " = 42752

Bending Moments due to loads.

Chord 1. Cu. Tr.

$X = 2.8$; $y = 3$. $\Sigma V = 139154^k$.

B.M. = $139154 \times 2.8 = 389631$.

Ch. 1. Ct. Tu.

$X = 157.2$. $\Sigma V = 236754^k$.

B.M. = $236754 \times 157.2 - 115000 \times 131.95 - 78300 \times 103.2 - 41600(92.8 + 82.4 + 72)$
$- 41108 \times 61.6 - 14892 \times 51.2 = 384676$.

Ch. 2. Cu. Tr.

$X = 8.4$; $\Sigma V = 139154^k$.

B.M. = $139154 \times 8.4 = 1168894^k$.

Ch. 2. Ct. Tu.

$X = 151.6$; $\Sigma V = 236754^k$.

B.M = $236754 \times 151.6 - 115000 \times 126.35 - 78300 \times 97.6 - 41600(87.2 + 76.8 +$
$66.4) - 41108 \times 56 - 14892 \times 45.6 = 1152813^k$.

Ch. 3. Cu. Tr.

$X = 14.1$; $\Sigma V = 146364$.

B.M. = $146364 \times 14.1 = 2063732^k$.

Ch. 3. Ct. Tu.

$X = 145.9$; $\Sigma V = 232763^k$.

B.M. = $232763 \times 145.9 - 115000 \times 120.55 - 78300 \times 91.8 - 41600(81.4 + 71 + 60.6)$
$- 37877 \times 50.2 - 6923 \times 39.8 = 1834932$.

Ch. 4. Cu. Tr.

$X = 20.4.\ \Sigma V = 150394.^k$

$B.M = 150394 \times 20.4 = 3068078^k.$

Ch. 4. Cr. Tu.

$X = 139.6;\ \Sigma V = 230396.^k$

$B.M. = 230396 \times 139.6 - 115000 \times 114.35 - 78300 \times 85.6 - 41600(75.2 + 64.8 + 54.4) - 34677 \times 44 - 3723 \times 33.6 = 2572631^k.$

Ch. 5. Cu. Tr.

$X = 25.25;\ \Sigma V = 157297.^k$

$B.M. = 157297 \times 25.25 - 57500 \times 1.5 = 3885499.$

Ch. 5. Cr. Tu.

$X = 134.75;\ \Sigma V = 226098.^k$

$B.M. = 226098 \times 134.75 - 115000 \times 109.50 - 78300 \times 80.75 - 41600(70.35 + 59.95 + 49.55) - 34677 \times 39.15 - 3723 \times 28.75 = 3121657.^k$

Ch. 6. Cu. Tr.

$X = 31;\ \Sigma V = 164475.^k$

$B.M. = 164475 \times 31 - 115000 \times 5.75 = 4437475.^k$

Ch. 6. Cr. Tu.

$X = 31;\ \Sigma V = 112024.^k$

$B.M. = 112024 \times 31 = 3472744.^k$

Ch. 7. Cu. Tr.

$X = 39.75;\ \Sigma V = 180346.^k$

$B.M. = 180346 \times 39.75 - 115000 \times 14.5 = 5501253.^k$

Ch. 7. Cr. Tu.

$X = 39.75;\ \Sigma V = 96153.^k$

$B.M. = 96153 \times 39.75 = 3822082^k.$

Ch. 8. Cu. Tr.

$X = 49.15;\ \Sigma V = 192725^k.$

$B.M. = 192725 \times 49.15 - 111830 \times 23.9 = 6799697^k.$

Ch. 8. Cr. Tu.

$X = 49.15;\ \Sigma V = 83773.^k$

$B.M. = 83773 \times 49.15 - 3169 \times 23.9 = 4041704.^k$

Ch. 9. Cu. Tr.

$X = 59.2;\ \Sigma V = 174485.^k$

$B.M. = 174485 \times 59.2 - 71695 \times 33.95 - 78300 \times 5.2 = 7488307.^k$

Ch. 9. Cr. Tu.

$X = 59.2;\ \Sigma V = 102015.^k$

$B.M. = 102015 \times 59.2 - 43304 \times 33.95 = 4569117.^k$

Ch. 10. Cu. Tr.

$X = 69.6;\ \Sigma V = 143219.^k$

$B.M. = 143219 \times 69.6 - 21062 \times 44.35 - 69338 \times 15.6 - 91600 \times 5.2 = 7735949.^k$

Ch. 10. Cr. Tu.

$X = 69.6;\ \Sigma V = 133281.^k$

$B.M. = 133281 \times 69.6 - 93938 \times 44.35 - 8962 \times 15.6 = 4970401.^k$

Ch. 11. Cu. Tl.

$X = 80;\ \Sigma V = 122370.^k$

$B.M. = 122370 \times 80 - 1409 \times 54.75 - 37391 \times 26 - 41600 \times 15.6$
$- 41600 \times 5.2 = 7875011.^k$

Ch. 11. Ct. Tu.

$X = 80;\ \Sigma V = 154190^k.$

$B.M. = 154190 \times 80 - 113591 \times 54.75 - 40909 \times 26 = 5152459.^k$

Resultant Moments.

Res. Moment = moment due to the loads minus the hor. thrust multiplied by its arm.

Ch. 1. Cu. Tl.

$M = 389631 - 81745 \times 3 = 144396^k.$

Ch. 1. Ct. Tu.

$M = 384676 - 208192 \times 3 = 239900.^k$

Ch. 2. Cu. Tl.

$M = 1168894 - 81745 \times 9 = 433189.^k$

Ch. 2. Ct. Tu.

$M = 1152813 - 208192 \times 9 = 720915.^k$

Ch. 3. Cu. Tl.

$M = 2063732 - 88597 \times 14.55 = 774666^k.$

Ch. 3. Ct. Tu.

$M = 1834932 - 201339 \times 14.55 = 1094550.^{k}$

Ch. 4. Cu. Tt.

$M = 3068078 - 92567 \times 20.42 = 1177860.^{k}$

Ch. 4. Ct. Tu.

$M = 2572631 - 197370 \times 20.42 = 1457664.^{k}$

Ch. 5. Cu. Tt.

$M = 3885499 - 99606 \times 24.2 = 1475034.^{k}$

Ch. 5. Ct. Tu.

$M = 3121657 - 190329 \times 24.2 = 1484305.^{k}$

Ch. 6. Cu. Tt.

$M = 4437475 - 107027 \times 28.3 = 1408611.^{k}$

Ch. 6. Ct. Tu.

$M = 3472744 - 182662 \times 28.3 = 1696591.^{k}$

Ch. 7. Cu. Tt.

$M = 5501253 - 125452 \times 32.75 = 1392700.^{k}$

Ch. 7. Ct. Tu.

$M = 3822082 - 164485 \times 32.75 = 1564802.^{k}$

Ch. 8. Cu. Tt.

$M = 6799697 - 144313 \times 36.85 = 1481763^{k}$

Ch. 8. Ct. Tu.

$M = 4041704 - 145508 \times 36.85 = 1364569.^{k}$

Ch. 9 Cu. Tl.

$M = 7488307 - 146696 \times 40.35 = 1569123^{k}$

Ch. 9 Cl. Tu.

$M = 4569117 - 139159 \times 40.35 = 1045949.^{k}$

Ch. 10. Cu. Tl.

$M = 7735949 - 153067 \times 42.25 = 1268868.^{k}$

Ch. 10. Cl. Tu.

$M = 4970401 - 136868 \times 42.25 = 812272.^{k}$

Ch. 11 Cu. Tl.

$M = 7875011 - 155885 \times 42.65 = 1129648^{k}$

Ch. 11. Cl. Tu.

$M = 5052459 - 134047 \times 42.65 = 664645.^{k}$

Sect.	Res. mom.	Reg. mom.	Extra. $\frac{I}{V}$	Intra. $\frac{I}{V}$	Coeffs. of work. Extrados.		Intrados.		Tang. Comp.		Sect. of arch.	Coeffs. of work.		Resultant coefs. Extra.	Intra.	Coefs. of dead load Extra.	Intra.	Total resultant Coeffs. Extra.	Intra.	French results. Extra.	Intra.	Diffs. between my results and those of the French meth. Extra.	Intra.
1	149.39	289.90	.1878	.2389	-1.28	.769	1.00	-0.609	158.0	315.0	.2933	0.539	1.07	1.308	2.07	2.33	1.37	3.64	3.44	3.65	2.98	0.01	0.46
2	433.19	720.91	.3054	.3618	-2.36	1.42	1.99	-1.19	157.0	314.0	.2739	0.577	1.15	2.57	3.14	2.50	1.26	5.07	4.40	4.35	3.23	0.72	1.17
3	774.67	1094.5	.4497	.5000	-2.46	1.74	2.19	-1.55	164.5	305.0	.2694	1.00	1.88	3.62	4.07	2.48	1.20	6.10	5.27	4.68	3.36	1.42	1.91
4	1177.9	1457.7	.5771	.6162	-2.52	2.04	2.37	-1.91	168.0	299.0	.2528	0.664	1.182	3.22	3.55	2.34	1.29	5.56	4.84	4.88	3.61	0.68	1.23
5	1475.0	1489.3	.6720	.7170	-2.21	2.19	2.07	-2.06	179.5	226.0	.2418	0.721	0.935	3.12	3.00	2.31	1.21	5.43	4.21	4.94	3.46	0.49	0.74
6	1408.6	1696.6	.7388	.7388	-1.91	2.29	2.29	-1.91	117.0	214.0	.2360	0.495	0.906	3.19	3.19	1.88	1.43	5.07	4.62	4.14	3.81	0.93	0.81
7	1392.7	1569.8	.7821	.8623	-2.00	1.78	1.81	-1.62	140.0	190.0	.2253	0.622	0.844	2.62	2.65	1.88	1.48	4.50	4.13	4.11	3.60	0.39	0.53
8	1481.8	1369.6	.7703	.8798	-1.77	1.92	1.55	-1.68	205.0	169.0	.2220	0.923	0.739	2.84	2.29	1.81	1.49	4.65	3.78	4.22	3.64	0.43	0.14
9	1569.1	1095.9	.8746	.8746	±1.19	±1.79	±1.79	±1.19	185.0	160.0	.2228	0.830	0.718	2.62	2.62	1.50	1.64	4.12	4.26	3.57	3.26	0.55	1.00
10	1268.9	812.3	.9618	.9023	-.844	1.32	0.908	-1.41	168.0	140.0	.2283	0.736	0.614	2.06	0.80	1.39	1.62	3.45	2.42	3.51	2.63	0.06	0.21
11	1129.6	664.6	.9917	.9196	-.670	1.14	0.722	-0.670	155.8	134.0	.2283	0.683	0.588	1.82	1.32	1.35	1.65	3.17	2.97	3.55	2.12	0.38	0.85

Det. of the stresses in the chords under the permanent load only. $N = 341^t.336$.

{ Coeffs. of work R_2 and R_3 due to the bending. } { Coef. of work R_1 due to comp. } { Total coef. of work. }

Nos. of Sects.	Ords. of the neutral	B.M. due to the wts.	B.M. due to the thrust	Resultant moments	$\frac{I}{V'}$ Extrados	$\frac{I}{V'}$ Intrados	Coef. of work R_2 Extrados	Coef. of work R_3 Intrados	Tang. Comp.	Sect. of the whole arch	Coef. of work R_1	Extrados $R_1 + R_2$	Intrados $R_1 + R_3$
									t		k.	k.	k.
1	3.00	1125.3	-1024.0	101.3	-0.1878	0.2389	-0.540	0.425	526.0	0.2933	-1.792	-2.332	-1.367
2	9.00	3278.0	-3072.0	206.0	-0.3054	.3618	-0.675	0.570	499.2	0.2739	-1.826	-2.501	-1.256
3	14.55	5268.9	-4966.4	302.5	-0.4447	0.5000	-0.677	0.605	477.0	0.2644	-1.805	-2.482	-1.200
4	20.42	7264.0	-6950.0	314.0	-0.5771	0.6162	-0.544	0.509	454.8	0.2528	-1.800	-2.344	-1.291
5	24.20	8642.3	-8260.3	382.0	-0.6723	0.7170	-0.568	0.532	421.0	0.2418	-1.742	-2.310	-1.210
6	28.30	9825.6	-9659.7	165.9	-0.7388	0.7388	-0.224	0.224	391.0	0.2360	-1.658	-1.882	-1.434
7	32.75	11341.7	-11178.7	163.0	-0.7821	0.8623	-0.208	0.189	376.2	0.2253	-1.674	-1.882	-1.485
8	36.85	12710.7	-12587.1	123.6	-0.7703	0.8798	-0.172	0.151	364.0	0.2220	-1.638	-1.810	-1.487
9	40.35	13709.8	-13772.9	-63.1	0.8746	-0.8746	0.072	-0.072	349.0	0.2228	-1.568	-1.496	-1.640
10	42.25	14310.7	-14421.5	-110.8	0.9618	-0.9023	0.115	-0.122	343.0	0.2283	-1.503	-1.388	-1.625
11	42.65	14412.0	-14558.	-145.7	-0.9917	0.9196	0.147	-0.158	341.3	0.2283	-1.495	-1.348	-1.653

Computation of diag. stresses.

The first thing to be done was to find the most unfavorable loading for the diags. That is the loading that would cause the greatest shear in them. This was done in the following manner, take for example sect. 7 represented in fig. 1; the most unfavorable loading for the diags. of this sect. is obtained by drawing the line <u>h n</u> normal to the neutral axis until it intersects the line s and also drawing a line through the hinge, perpendicular to <u>h n</u> until it meets the line s in the point q; then with a load from h to q there is caused compression in the upper chord and tension in the lower chord and with the load on <u>q a</u> and <u>b h</u> the opposite is obtained (Weyrauch p. 47.)
In this way the loads given on page 52. were obtained; the trusses were considered supported and not continuous for the reasons given previously.
I next calculated the vert. supporting forces

at the hinges caused by these loads, by the formula $V = \frac{1}{2}\Sigma P(l-a)$; the results are given on pages 53 to 58.
The horizontal thrusts due to each load were next obtained, these are given on page 59.

I obtained the shear in each section graphically. Fig. 2 represents the manner of proceeding; $ab = \Sigma H$ for any section $bc = \Sigma V$ for that section; ad = line drawn parallel to the neutral axis of the section and cd a line perpendicular to it; cd = shear at that section; in this way the shears given in the table on page 60 were obtained.
The total shears given in the table above referred to is the sum of the shears caused by the dead and rolling loading; dividing this total shear by the area of the diagonals projected upon a normal to the neutral axis the stress per square millimetre was obtained.
With ~~kept~~ two exceptions the stress per sq. mill. that I obtained was greater than his

this can easily be explained I think by remembering that he did not take the most unfavorable loading; but he considered the trusses continuous which I did not but as I obtain in all but two cases, where the diff. is quite small, larger results than he does I think that I can say the calculation of the continuous girder is not necessary.

The long. compressions given on page 60 were obtained graphically and in the same manner as previously explained for the chords; the coeffs. were obtained by dividing these comps. by the area of the entire cross-section.

The diagonals have to resist the compression of the arch the shearing forces and the torsion. The results of these are given in the table on page 60.

Loads for maximum Shears.

		Cu Tl	Tu Cl			Cu Tl	Tu Cl
Chs. 1 & 2.	A	115000	0	Ch. 7.	A	56648	70648
	B	63408	14892		B	65152	852
	C	492	41108		C	41600	0
	D	0	41600		D	41600	0
	E	0	41600		E	41600	0
	F	0	41600		F	41600	0
	G	0	78300		G	48139	9361
	H	0	115000		H	20461	94539
Ch. 3.	A	115000	0	Ch. 8.	A	11773	102879
	B	78300	0		B	61827	16821
	C	20800	20800		C	41600	0
	D	0	41600		D	41600	0
	E	0	41600		E	41600	0
	F	0	41600		F	41600	0
	G	0	78300		G	78300	0
	H	0	115000		H	80251	34749
Ch. 4.	A	115000	0	Ch. 9.	A	0	115000
	B	78300	0		B	78300	57500
	C	39982	1617		C	41600	0
	D	10818	30783		D	41600	0
	E	0	41600		E	41600	0
	F	0	41600		F	41600	0
	G	0	78300		G	78300	0
	H	0	115000		H	115000	0
Ch. 5.	A	110379	4620	Ch. 10.	A	0	115000
	B	78300	0		B	0	78300
	C	41600	0		C	9969	10831
	D	38208	3392		D	18831	1969
	E	7392	34208		E	41600	0
	F	0	41600		F	41600	0
	G	0	78300		G	78300	0
	H	0	115000		H	115000	0
Ch. 6	A	92586	49733	Ch. 11.	A	0	115000
	B	78300	0		B	0	78300
	C	41600	0		C	0	41600
	D	41600	0		D	5200	15600
	E	35539	192		E	15600	5200
	F	2061	3808		F	41600	0
	G	0	78300		G	78300	0
	H	0	115000		H	115000	0

Det. of the vert. supp. forces due to the loads.

Chs. 1 & 2. Cu. Tl.

A. V = 96852.

B. " = 42008 $\Sigma V = 139154^k$.

C. " = 294.

Chs. 1 & 2. Cl. Tu.

B. V = 9866.

C. " = 24562.

D. " = 22152.

E. " = 19448. $\Sigma V = 137346.^k$

F. " = 16744.

G. " = 26426.

H " = 18148

Ch. 3. Cu. Tl.

A. $V = 1/160 \times 115000 \times 134.75 = 96852.$

B. " = " $\times 78300 \times 106 = 51874.$ $\Sigma V = 161154^k$.

C. " = " $\times 20800 \times 95.6 = 12428.$

Ch. 3. Cl. Tu.

C. $V = 1/160 \times 20800 \times 95.6 = 12428.$

D. " = " $\times 41600 \times 85.2 = 22152.$

E. " = " $\times$ " $\times 74.8 = 19448.$

F. " = " $\times$ " $\times 64.4 = 16744$

$G.\ V = 1/160 \times 78300 \times 54 = 26426.$ $\quad \Sigma V = 115346^{K}.$

$H.\ " = \quad " \times 115000 \times 25.25 = 18148$

Ch. 4. Cu. Tl.

$A.\ V = 1/160 \times 115000 \times 134.75 = 96852$

$B.\ " = \quad " \times 78300 \times 106 = 51874.$ $\quad \Sigma V = 178376^{K}.$

$C.\ " = \quad " \times 39982 \times 95.6 = 23889.$

$D.\ " = \quad " \times 10818 \times 85.2 = 5761.$

Ch. 4. Cl. Tu.

$C.\ V = 1/160 \times 1617 \times 95.6 = 966$

$D.\ " = \quad " \times 30783 \times 85.2 = 16392.$

$E.\ " = \quad " \times 41600 \times 78.8 = 19448.$ $\quad \Sigma V = 98124^{K}.$

$F.\ " = \quad " \times 41600 \times 64.4 = 16744.$

$G.\ " = \quad " \times 78300 \times 54 = 26426.$

$H\ " = \quad " \times 115000 \times 25.25 = 18148$

Ch. 5. Cu. Tl

$A.\ V = 1/160 \times 110379 \times 134.75 = 92961.$

$B.\ " = \quad " \times 78300 \times 106 = 51874.$

$C.\ " = \quad " \times 41600 \times 95.6 = 24856.$ $\quad \Sigma V = 193493.$

$D.\ " = \quad " \times 38208 \times 85.2 = 20346.$

$E\ " = \quad " \times 7392 \times 74.8 = 3456$

Ch. 5. Cl. Tu.

A. V = 1/160 x 4620 x 134.75 = 3891.
D. " = " x 3392 x 85.2 = 1806
E. " = " x 34208 x 74.8 = 15992. $\Sigma V = 83007^k$
F " = " x 41600 x 64.4 = 16744.
G. " = " x 78300 x 54 = 26426.
H " = " x 115000 x 25.25 = 18148

Ch. 6. Cu. Tl.

A. V = 1/160 x 92586 x 134.75 = 77975.
B. " = " x 78300 x 106 = 51874
C. " = " x 41600 x 95.6 = 24856. $\Sigma V = 194301^k$
D. " = " x 41600 x 85.2 = 22152.
E. " = " x 35539 x 74.8 = 16614.
F " = " x 2061 x 64.4 = 830

Ch. 6. Cl. Tu.

A. V = 1/160 x 49733 x 134.75 = 52730.
E. " = " x 192 x 74.8 = 90
F. " = " x 3808 x 64.4 = 1533. $\Sigma V = 98927^k$
G. " = " x 78300 x 54 = 26426.
H " = " x 115000 x 25.25 = 18148.

Ch. 7. Cu. Tl.

A. V = 1/160 × 56648 × 134.75 = 47708.

B. „ = „ × 65152 × 106 = 43163

C. „ = „ × 41600 × 95.6 = 24856

D. „ = 22152. ΣV = 193547.^k

E. „ = 19448.

F. „ = 16744.

G. „ = „ × 48139 × 54 = 16247.

H. „ = „ × 20461 × 25.25 = 3229

Ch. 7. Cl. Tu.

A. V = 1/160 × 70648 × 134.75 = 59499

B. „ = „ × 852 × 106 = 564. ΣV = 78142.^k

G. „ = „ × 9361 × 54 = 3159.

H. „ = „ × 94539 × 25.25 = 14920.

Ch. 8. Cu. Tl.

A. V = 1/160 × 11773 × 134.75 = 9915.

B. „ = „ × 61827 × 106 = 40961.

C. „ = 24856.

D. „ = 22152. ΣV = 173167^k.

E. „ = 19448.

F. „ = 16744.

G. „ = 26426.

H. „ = „ × 80251 × 25.25 = 12665.

Ch. 8. Cl. Tm.

A. $V = 1/160 \times 102879 \times 134.75 = 86644.$

B. 〃 = 〃 $\times 16281 \times 106 = 10786.$ $\Sigma V = 102914.^{K}$

H. 〃 = 〃 $\times 34749 \times 25.25 = 5484.$

Ch. 9. Cu. Tl.

B. $V = 1/160 \times 78300 \times 106 = 51874.$

C. 〃 $= 24856$

D. 〃 $= 22152$

E. 〃 $= 19448.$ $\Sigma V = 179648.^{K}$

F. 〃 $= 16744.$

G. 〃 $= 26426$

H. 〃 $= 18148$

Ch. 9. Cl. Tm.

A. $V = 1/160 \times 115000 \times 134.75 = 96852.$ $\Sigma V = 134946.^{K}$

B. 〃 = 〃 $\times 57500 \times 106 = 38094$

Ch. 10. Cu. Tl.

C. $V = 1/160 \times 9969 \times 95.6 = 5956.$

D. 〃 = 〃 $\times 18831 \times 85.2 = 10027.$

E. 〃 = 〃 $\times 41600 \times 74.8 = 19448.$ $\Sigma V = 96749.^{K}$

F. 〃 $= 16744.$

G. 〃 $= 26426.$

H. 〃 $= 18148$

Ch. 10. Cl. Tu.

A. $V = 1/160 \times 115000 \times 134.75 = 96852.$

B. " = " $\times 78300 \times 106 = 51874.$

C. " = " $\times 40831 \times 95.6 = 6474.$ $\quad \Sigma V = 156248^{k}$

D. " = " $\times 1969 \times 85.2 = 1048.$

Ch. 11. Cn. Tl.

D. $V = 1/160 \times 5200 \times 85.2 = 2769.$

E. " = " $\times 15600 \times 74.8 = 7293.$

F. " = " $\times 41600 \times 64.4 = 16744.$ $\quad \Sigma V = 71380^{k}$

G. " = " $\times 78300 \times 54 = 26426.$

H. " = " $\times 115000 \times 25.25 = 18148.$

Ch. 11. Cl. Tu.

A. $V = 1/160 \times 115000 \times 134.75 = 96852.$

B. " = " $\times 78300 \times 106 = 51874.$

C. " = " $\times 41600 \times 95.6 = 24856.$ $\quad \Sigma V = 184320^{k}$

D. " = " $\times 15600 \times 85.2 = 837.$

E. " = " $\times 5200 \times 74.8 = 2431$

Hor. thrusts.

Chs. 1 & 2	A	43356	0	Ch. 7.	A	21357	26635
	B	38074	8942		B	39121	512
	C	315	26309		C	26624	0
	D	0	27433		D	27433	0
	E	0	27433		E	27433	0
	F	0	26624		F	26624	0
	G	0	47016		G	28905	5621
	H	0	43356		H	7714	35624
Σ	H =	81745	207113	Σ	H =	205211	68410
Ch. 3.	A	43355	0	Ch. 8.	A	4439	38787
	B	47016	0		B	37124	9776
	C	13312	13312		C	26624	0
	D	0	27433		D	27433	0
	E	0	27433		E	27433	0
	F	0	26624		F	26624	0
	G	0	47016		G	47016	0
	H	0	43356		H	30255	13101
Σ	H =	103683	185174	Σ	H =	226958	61664
Ch. 4.	A	43356	0	Ch. 9.	A	0	43356
	B	47016	0		B	47016	34256
	C	25588	1035		C	26624	0
	D	7134	20300		D	27433	0
	E	0	27433		E	27433	0
	F	0	26624		F	26624	0
	G	0	47016		G	47016	0
	H	0	43356		H	43356	0
Σ	H =	123094	165764	Σ	H =	245502	77612
Ch. 5.	A	41615	1742	Ch. 10.	A	0	43356
	B	47016	0		B	0	47016
	C	26624	0		C	6380	6932
	D	25196	2237		D	12418	1298
	E	4875	22559		E	27433	0
	F	0	26624		F	26624	0
	G	0	47016		G	47016	0
	H	0	43356		H	43356	0
Σ	H =	145326	143356	Σ	H =	163227	98602
Ch. 6.	A	34986	23604	Ch. 11.	A	0	43356
	B	47016	0		B	0	47016
	C	26624	0		C	0	26624
	D	27433	0		D	3429	10287
	E	23346	127		E	10287	3429
	F	1390	2437		F	26624	0
	G	0	47016		G	47016	0
	H	0	43356		H	43356	0
Σ	H =	160795	116540	Σ	H =	130712	130712

Sectn.	Cu / Te	Tu / Cl	Dead Load.	Sect. area.	Stress per sq. in.	Total Shear live + dead		Total Stress per sq. in.	Tang. Comp. Cu / Te	Tang. Comp. Cl / Tu	Coef. of work dead load	Coef. of work live load.	Resultant coeff.	Shearing force.	Torsion	Total
1	36000	56000	24400	.10800	0.23	.60400	80400	0.744	158000	242000	1.79	0.826	2.62	0.744	0.01	3.37
2	39000	53000	26000	.02220	1.17	65000	79000	3.55	157000	243000	1.83	0.886	2.72	3.55	0.65	6.92
3	44000	45000	9000	.02840	0.31	53000	54000	1.90	185000	213000	1.80	0.806	2.61	1.90	0.25	4.76
4	56000	32000	2000	.0300	0.07	58000	34000	1.93	208000	190000	1.80	0.822	2.62	1.93	0.76	5.31
5	23000	21000	~8800	.03760	0.23	14200	12200	0.38	199000	162000	1.74	0.822	2.56	0.38	0.23	3.17
6	0	20000	~16200	.02180	0.74	36200	0	1.66	190000	124000	1.66	0.805	2.46	1.66	0.22	4.34
7	35000	22500	1200	.02220	0.05	36200	23700	1.63	244000	65000	1.67	1.08	2.75	1.63	0.55	4.93
8	68000	0	~5000	.02220	0.22	63000	0	2.84	270000	0	1.64	1.21	2.85	2.84	0.72	6.41
9	35000	56000	~13200	.02260	0.59	48200	42800	2.13	263000	65000	1.57	1.18	2.75	2.13	0	4.88
10	65000	60000	~4400	.02300	0.19	60600	55600	2.63	172000	94000	1.50	0.754	2.25	2.63	0	4.88
11	66180	66180	0	.02600	0	66180	66180	2.54	130712	130712	1.49	0.573	2.06	2.54	0	4.60

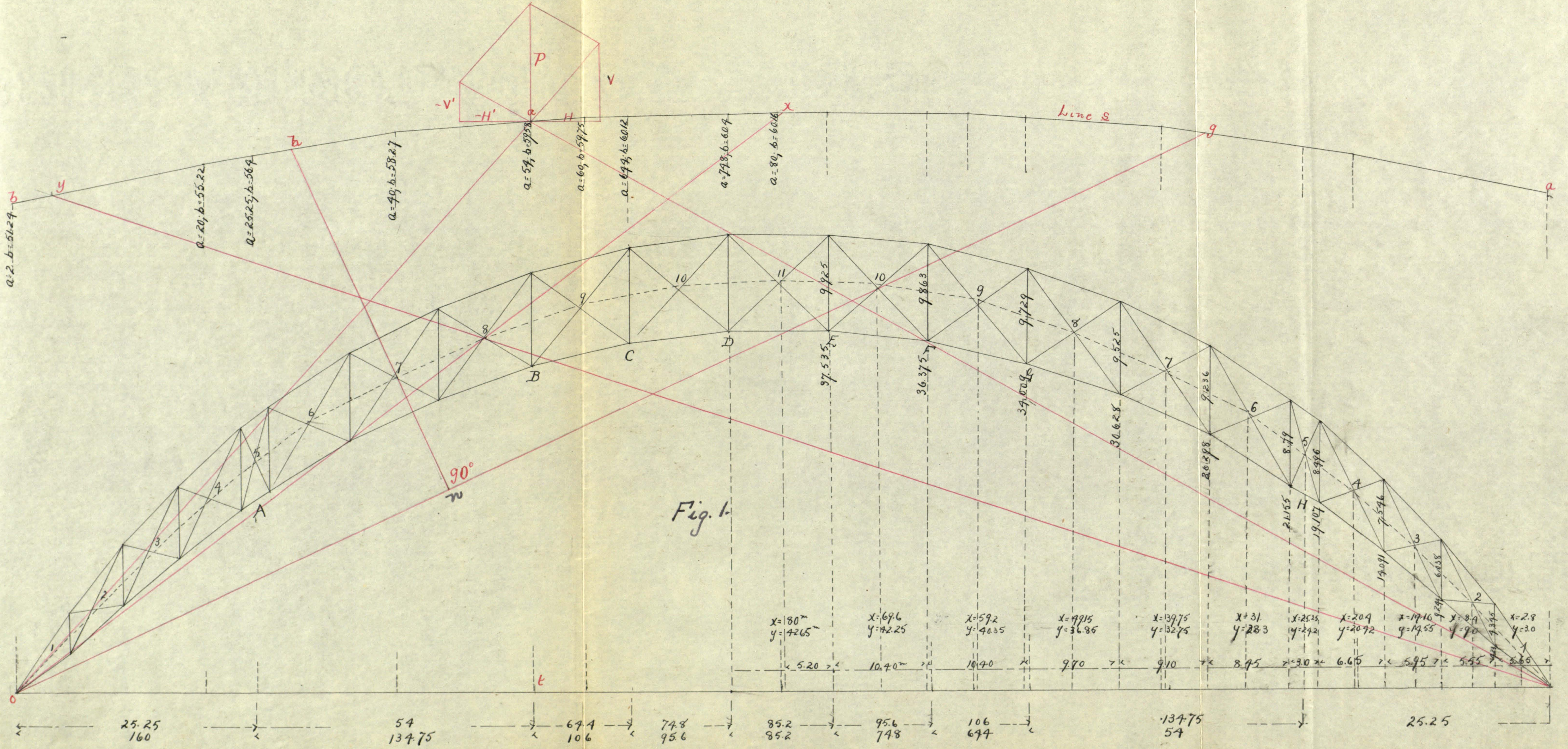


Fig. 1.

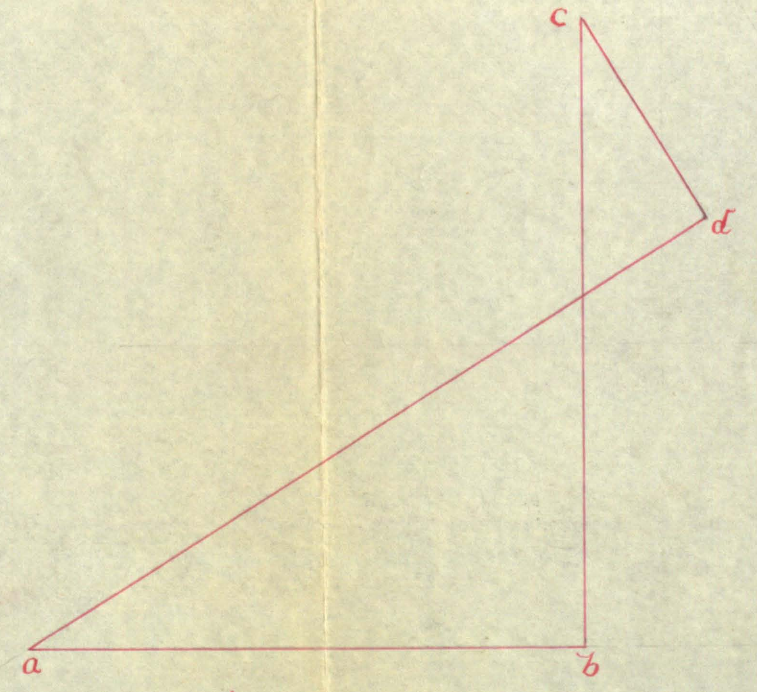


Fig. for shear and tang. comp.

Fig. 2.