Analysis of Cedar Street Reinforced Concrete Arch Bridge

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1913

This thesis was contributed by

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THESIS IN CIVIL ENGINEERING.

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ANALYSIS OF THE CEDAR STREET REINFORCED CONCRETE ARCH BRIDGE OVER CEDAR RIVER, LANSING, MICHIGAN.

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INVESTIGATED BY THE ELASTIC THEORY.

A. F. Zickgraf. E. K. Lovelace.

-1913-

THESIS

This thesis was chosen with the idea of gaining more knowledge of the theory and practice in the design of reinforced concrete arches.

This bridge was built in 1909, by the Western Bridge Co. of Chicago, Ill., following the destruction of an old wooden bridge at that place. The bridge is 30 feet wide and consists of two equal spans of 70 feet, with the springing line at the pier 2 feet higher than that of the abutments at each end. It is on a skew of 30 degrees with the river which makes the problem of design and construction mere difficult. The arch is 16 inches thick at the crown and has a rise of 10 feet. It is back-filled with earth on which rests the base of the brick pavement. The bridge seems well constructed and in good condition, no cracks of any magnitude being visible except in the railing.

The loadings and allowable stresses we used were those given in the specifications and for which the bridge was designed. A live load of 200 # per sq. ft. of roadway, 100 # per sq. ft. of walls, a concentrated moving load of a 28 ton steam roller, and a dead load of 90 # per sq. ft. for earth backfill and 150 # per sq. ft. for concrete. The stresses allowed are:

Modulus of Elas. of Concrete	1,800,000. lbs.
Modulus of Elas. of Steel	28,000,000. lbs.
Max. comp. per sq. in. on steel	10,000. lbs.
Max. comp. per sq. in. on concrete	500. lbs.

Max. shear per sq. in. on concrete (plain) 100. lbs.

Max. tension per sq. in. on concrete 50. lbs.

The theory followed in analyzing the design is on plates No. 1 and 2 and is a copy of the Elastic Theory of Arches by Prof. C. A. Melick. In our analysis most of the data for the horizontal forces, due to lateral earth pressure were calculated but owing to a lack of time only the vertical forces were considered.

The arching was divided into 20 radial parts symmetrically about the center and the loads applied at the points A, B, C, D, E, E, D, C, B, and A, the location of which being determined graphically as shown on diagram.

Tables No. 1 and 2 consist of values to be used in the further calculation and were constructed according to the properties of the arch. Plate 1 shows the general data that was computed and used in further work. The area of the arch ring where given is the equivalent area of concrete and is equal to $bh = 2pbh(n-1) = bh + A_s(n-1)$, where b and h are respectively the bredth and thickness of the ring at the section, A_s the area of the steel, p the percentage of steel in the section, and n the ratio of the Modulus of Elas. of steel to that of concrete and taken as 15. Table 3 was made of the summations of the quantities in Tables 1 and 2.

Table 4 was calculated from the formulae of the theory and from which Table 3 was made from the summations which were used to construct this table. The lead used was a 1,000 # load at on Plates 2 and 3 were plotted and besides being a comparative check on the calculations up to that point give graphical values of the moment, thrust, and shear for every point on the arch ring. These values were scaled off and make up part of Table 5. The other values shown in Table 5 were used to compute Table 6.

From Table 5 the influence lines for thrust, shear, and moment were plotted (see Plate 4).

After the thrust was calculated it's affect upon the sections of the arch was calculated but was so small it could not be noticed and was neglected. The calculations for a change in H due to this thrust depends on the following theory:

Average axial thrust $= \dfrac{\sum_o^L T}{n} = T.$

$M = Hy$ or $dx = \sum_o^L \dfrac{Hy^2 \Delta s}{E I}$.

If $H = 1{,}000$ then $a = dx = \dfrac{1{,}000}{E} \sum_o^L \dfrac{y^2 \Delta s}{I}$.

Change in dx due to axial thrust $= b = \dfrac{T \Delta x}{A E} = \dfrac{1}{E} \sum_o^L \dfrac{T \Delta x}{A}$.

H due to axial thrust $= \dfrac{b}{a} \times 1000 = Q$

or $Q = \left[\dfrac{1}{E} \sum_o^L \dfrac{T \Delta x}{A} \div \dfrac{1000}{E} \sum_o^L \dfrac{y^2 \Delta s}{I}\right]$.

$Q = \sum_o^L T \left[\sum_o^L \dfrac{\Delta x}{A} \div \sum_o^L \dfrac{y^2 \Delta s}{I}\right]$.

Actual $H = H_L - Q$.

In Table 6 from values shown in Table 5 , we have figured the stresses at the diffrent points for the top and bottom of the arch ring, for a 1,000 # load at the loaded points. The upper and lower are tabulated respectively.

The upper is $\frac{T}{A} + \frac{Mc}{I}$ and the lower $\frac{T}{A} - \frac{Mc}{I}$, where A is the transformed area of that section, c one half the thickness of the arch ring at that point, and I the moment of inertia of the transformed section. Plates 5 and 6 show respectively the influence lines for the stresses in the top and bottom fibres for a 1,000 # load, (moving). The stresses for dead and live load and for combined loads are given for top and bottom in Tables 6 and 7 respectively and give the maximum stresses in the ring and where they occur.

In testing the archfor shear the value of the shear in Table 5 were used. The shear for dead load was first computed and then the shears for live load computed so as to give the maximum positive or negative values of the same sign as the dead load shear. These values of shear are given in Table 8. This shows the max. shear to be 25 # per sq. in. The bond strength of the shear bars did not have to be tested as this strength does not have to be figured where the shear is less than 40 # per sq. in. In Table 8 the Dead and Live load loadings are also given. A slider of the axle loads of the roller was used on the shear curves of Plate 4 to get the position for max. live load shear.

On Table 9 the diagrams and Tables of the stress in the steel are given. The reinforcement was placed at a uniform distance of 3.5 inches from the outside and is shown by the dotted lines. The top and bottom lines are the stress at the top and bottom from Tables 6 and 7 and the distance apart is the ring thickness at that point.

From the specifications the pier is supported by piles, 12 inches in diameter at the large end and 8 in. in dia. at the ~~at the~~ small end and placed 3 foot c. to c. They were driven to such depth that the penetration under the last blow of a hammer weighing 2,000 # and falling 30 feet should not be greater than one inch.

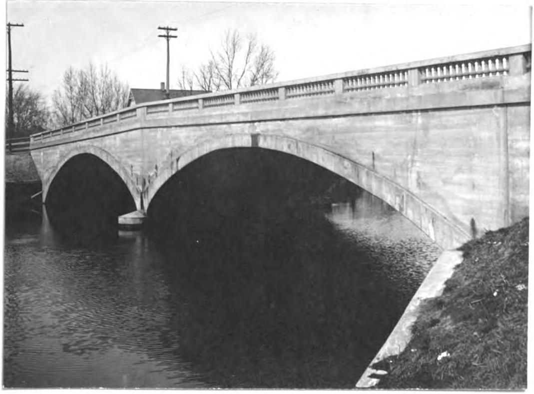
From the Engineering New's Formula, the load one pile will support or $P = \frac{2WH}{s - 1}$ where W = weight = 2,000 #, h = height of fall of hammer = 30 feet, and s = penetration = 1 inch. Then P is found equal to 60,000 #. In this pier, considering that one pile takes care of 8 sq. ft. of pier-base, which is equal to a section 1 foot wide times the width of the pier which is 8 ft., the dead load on one pile equals

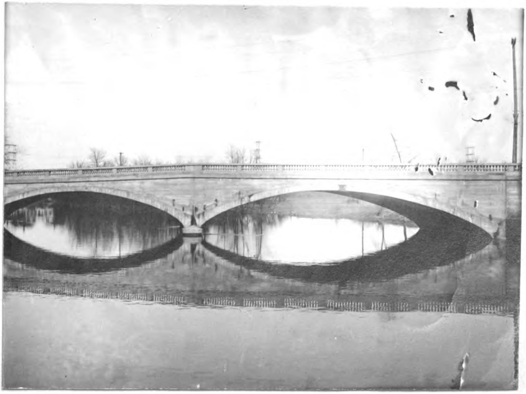
2(Dead load on all points plus Pier weight) = 2(1554 + 1946 + 2768 + 3965 + 7541 plus 150[(8' x 5.5' x 1') + (5.5 x 3 x1)] or equals 35,548 + 8,025 = 43,573 # . This shows the pier to be safe from sinking under the dead load.

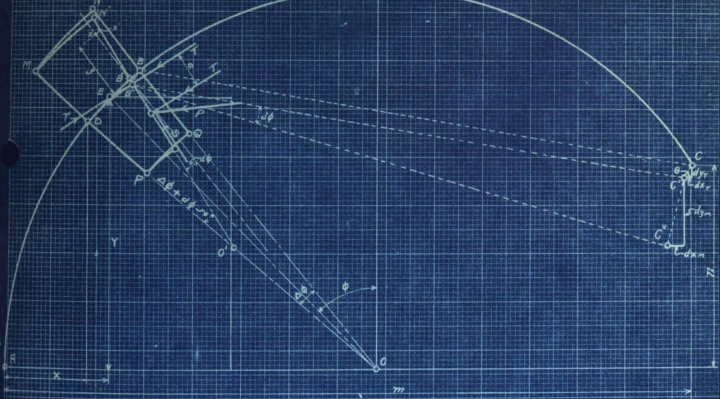
The one foot section of the arch analyzed was taken parallel to the face of the arch. For Voussoir Arches the thrust, (lines of pressure), in an oblique arch are assumed to act in planes parallel to it's faces((S. Edward Warren on Stereotomy). A monolithic arch on a skew is considered in this same way. The section 1 foot wide analyzed in this arch was taken under that

assumption and therefore the affect of skew is not considered. No other references than that of Warren's book on Stereotomy on this subject could be found as the theory of skew arches is one not taken into consideration in most of the books on arches.

The bridge was found to be safe. The stresses determined are within the allowable limits with a factor of safty of about 2 for compression and about 4 for shear. The only tension found in the arch was less than 3 pounds per sq. in. No account of forces due to the slight incline of the arch, 2 ft. in 70 ft., were considered as they were too small to affect the stresses by any amount.







Theoretical Analysis of the Elastic Arch.

Fundamental Formulae -

Let ADBC represent a portion of the linear arch, and let MNPQ be any section of the arch ring. Let E, on the linear arch, be the center of this section with Coordinates (x,y) measured from A. Let the central angle $\Delta\phi$ be subtended by the arc DB of length Δs.

This section of the Arch Ring will be acted upon by some Resultant Arch Pressure P, which may be resolved into a Radial Shear S, a Normal Axial Thrust T, and a Bending Moment $T.e = M$. Theese Shears are Small in Ordinary Arches and Arch Theories neglect them in them in the Theory of Stresses, just as done in the Common Theory of Flexure for Beams. This leaves, for consideration then, the two agents Thrust & Bending acting on the Section: theese both vary with the diffrent Sections of the Arch Ring. T shortens the section DB uniformly an amount $\frac{T\Delta s}{A E}$: A rise of Temperature lengthens the Section DB uniformly an amount $e.t.\Delta s$. The Resultant Lengthening of the Section $DB = -BB' = et\Delta s - \frac{T.\Delta s}{A.E.}$. A negative value of M will cause the Section DB to deform in the direction DB'' changing $\Delta\phi$ by an amount $d\phi$. ϕ is measured from the Vertical through the Crown - Positive to the left, Negative to the Right - hence the change $d\phi$ is a Negative one. At xx' the $\frac{S\Delta s}{E} = \frac{M z\Delta s}{E.I.}$. But $xx' = z\Delta\phi$ hence $d\phi = \frac{M\Delta s}{E.I.}$ and since when M is Negative $d\phi$ is Negative, the equation stands correct for sign. Now immagine that, for any Arch Loading, starting at A, each section is taken in order and its affect found seperately and in turn. Then MP may be regarded as firmly fixed to the last deformed section preceeding and the effect of the deformation of MNPQ on the portion of the Arch to the Right determined. Let us find the effect of this deformation on the movement of the Point C whoose co-ordinates are (m.n). The change in Δs, BB', due to Thrust & Temperature will produce an equal change CC' at C. Also the change in $\Delta\phi$ due to M will produce a change at C of C'C'' such that $C'B''C'' = d\phi$. The increase in Span - m - due to Thrust & Temperature alone on this section alone $= -dx_T = -CC'\cos\phi = -BB'\cos\phi = -BB'\frac{\Delta x}{\Delta s} = e.t.\Delta x. - \frac{T\Delta x}{A.E.}$. The increase in Rise - n - due to Thrust & Temperature on this section alone $= dy_T = -CC'\sin\phi = -BB'\frac{\Delta x}{\Delta s} = et\Delta y - \frac{T\Delta y}{AE}$. The increase in span - m - due to a Positive Bending Moment M will be dx_m. But $\frac{dx_m}{C'C''} = \frac{y-n}{B''C''} = \frac{dx_m}{B''C''d\phi}$. Hence $dx_m = (y-n)d\phi = \frac{My\Delta s}{E.I.} - \frac{n.M.\Delta s}{E.I.}$. The increase in Rise - n - due to a Positive Bending Moment M will be dy_m. But $\frac{dy_m}{C'C''} = \frac{dy_m}{B''C''d\phi} = \frac{m-x}{B''C''}$ or $dy_m = (m-x)d\phi = -\frac{M.x.\Delta s}{E.I.} + \frac{m.M.\Delta s}{E.I.}$.

The total increase in span m due to a thrust T, a Rise in Temperature of $t°F$, & a Positive Bending Moment M, acting on this section alone will be $dx = e.t.\Delta x. - \frac{T\Delta x}{A.E.} + \frac{My\Delta s}{E.I.} - \frac{n.M.\Delta s}{E.I.}$. The total increase in Rise n due to a Thrust T, a Rise in Temperature of $t°F$, & a Positive Bending Moment M acting on this section alone will be $dy = e.t\Delta y - \frac{T\Delta y}{A.E.} - \frac{M.x.\Delta s}{E.I.} + \frac{m.M.\Delta s}{E.I.}$.

In a Fixed Arch – Symetrical – the following Conditions are Assumed.

1. The Radial Lines at the Springing Remain Unchanged in Direction – Thus, suming up $d\phi$ for all Sections between Springing Points $\Sigma_0^L d\phi = \Sigma_0^L \frac{M \Delta s}{E.I.} = 0.$

2. The Supports are fixed an Immoveable Distance apart – ie. are Rigid. Thus $\Sigma_0^L dx = \Sigma_0^L e.t.\Delta x - \Sigma_0^L \frac{T \Delta x}{A.E.} + \Sigma_0^L \frac{M y \Delta s}{E.I.} = 0$ since $\Sigma_0^L \frac{n M. \Delta s}{E.I.}$ becomes $0\ \Sigma_0^L \frac{M \Delta s}{E.I.} = 0.$

3. The Supports are Relatively Immoveable in Elevation – Then $\Sigma_0^L dy = \Sigma_0^L e.t.\Delta y - \Sigma_0^L \frac{T.\Delta y}{A.E.} - \Sigma_0^L \frac{M.x.\Delta s}{E.I.} = 0$ since the term $\Sigma_0^L \frac{m M \Delta s}{E.I.}$ becomes $m \Sigma_0^L \frac{M.\Delta s}{E.I.}$ and since $\Sigma_0^L \frac{M.\Delta s}{E.I.} = 0.$

From the figure below $M = M_L + V_L x - H_L y - W_V(x-a)_{x>a} - W_H(y-b)_{y>b}.$

$T = H_L \cos\phi + V_L \sin\phi + W_H.\cos\phi_{x>a} - W_V.\sin\phi_{x>a}.$ Substituting these values in Equations 1, 2, & 3. they become

$$1.\ M_L \Sigma_0^L \frac{\Delta s}{I} + V_L \Sigma_0^L \frac{x \Delta s}{I} - H_L \Sigma_0^L \frac{y \Delta s}{I} - W_V \Sigma_a^L \frac{(x-a)\Delta s}{I} - W_H \Sigma_a^L \frac{(y-b)\Delta s}{I} = 0.$$

$$2.\ E e.t \Sigma_0^L \Delta x - H_L \Sigma_0^L \frac{\Delta x \cos\phi}{A} - V_L \Sigma_0^L \frac{\Delta x \sin\phi}{A} - W_H \Sigma_a^L \frac{\Delta x.\cos\phi}{A} + W_V \Sigma_a^L \frac{\Delta x.\sin\phi}{A} + M_L \Sigma_0^L \frac{y \Delta s}{I} + V_L \Sigma_0^L \frac{x\,y\,\Delta s}{I} - H_L \Sigma_0^L \frac{y^2 \Delta s}{I} - W_V \Sigma_a^L \frac{(x-a) y \Delta s}{I} - W_H \Sigma_a^L \frac{(y-b) y \Delta s}{I} = 0.$$

$$3.\ E e.t \Sigma_0^L \Delta y - H_L \Sigma_0^L \frac{\Delta y.\cos\phi}{A} - V_L \Sigma_0^L \frac{\Delta y \sin\phi}{A} - W_H \Sigma_a^L \frac{\Delta y.\cos\phi}{A} + W_V \Sigma_a^L \frac{\Delta y.\sin\phi}{A} - M_L \Sigma_0^L \frac{x.\Delta s}{I} - V_L \Sigma_0^L \frac{x^2 \Delta s}{I} + H_L \Sigma_0^L \frac{x.y.\Delta s}{I} + W_V \Sigma_a^L \frac{(x-a) x.\Delta s}{I} + W_H \Sigma_a^L \frac{(y-b) x \Delta s}{I} = 0.$$

Rewriting the above equations they become

1. $a_1 M_L + b_1 V_L + c_1 H_L + d_1 = 0.$ or $H_L = -\frac{a_1}{c_1} M_L - \frac{b_1}{c_1} V_L - \frac{d_1}{c_1}$
2. $a_2 M_L + b_2 V_L + c_2 H_L + d_2 = 0.$ or $H_L = -\frac{a_2}{c_2} M_L - \frac{b_2}{c_2} V_L - \frac{d_2}{c_2}.$
3. $a_3 M_L + b_3 V_L + c_3 H_L + d_3 = 0.$ or $H_L = -\frac{a_3}{c_3} M_L - \frac{b_3}{c_3} V_L - \frac{d_3}{c_3}.$

Substituting 3 in 1 & 2

$M_L\left(\frac{a_1}{c_1} - \frac{a_3}{c_3}\right) = -V_L\left(\frac{b_1}{c_1} - \frac{b_3}{c_3}\right) - \left(\frac{d_1}{c_1} - \frac{d_3}{c_3}\right)$ or $A_1 M_L = B_1 V_L + C_1$ or $M_L = \frac{B_1}{A_1} V_L + \frac{C_1}{A_1}.$

$M_L\left(\frac{a_2}{c_2} - \frac{a_3}{c_3}\right) = -V_L\left(\frac{b_2}{c_2} - \frac{b_3}{c_3}\right) - \left(\frac{d_2}{c_2} - \frac{d_3}{c_3}\right)$ or $A_2 M_L = B_2 V_L + C_2$ or $M_L = \frac{B_2}{A_2} V_L + \frac{C_2}{A}.$

Solving the last two equations gives

$\left(\frac{B_1}{A_1} - \frac{B_2}{A_2}\right) V_L = -\left(\frac{C_1}{A_1} - \frac{C_2}{A_2}\right)$ or $D_1 V_L = E_1$ or $V_L = \frac{E_1}{D_1}.$

But for Symetrical Arches $A = 0.$ hence $V_L = -\frac{C_1}{B_1}.$

The following terms are constants for any given arch and are independant of the loading.

$a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3, A_2, B_1, B_2.$ Their values are – from above –

$a_1 = \Sigma_0^L \frac{\Delta s}{I}.$ $\quad b_1 = \Sigma_0^L \frac{x \Delta s}{I}$ $\quad c_1 = -\Sigma_0^L \frac{y \Delta s}{I}$ $\quad A_1 = 0.$ $\quad B_1 = \frac{b_3}{c_3} - \frac{b_1}{c_1}.$

$a_2 = \Sigma_0^L \frac{y \Delta s}{I}.$ $\quad b_2 = \Sigma_0^L \frac{x y \Delta s}{I} - \Sigma_0^L \frac{\Delta x \sin\phi}{A}.$ $\quad c_2 = -\Sigma_0^L \frac{y^2 \Delta s}{I} - \Sigma_0^L \frac{\Delta x \cos\phi}{A}.$ $\quad A_2 = \frac{a_2}{c_2} - \frac{a_3}{c_3}.$ $\quad B_2 = \frac{b_3}{c_3} - \frac{b_2}{c_2}.$

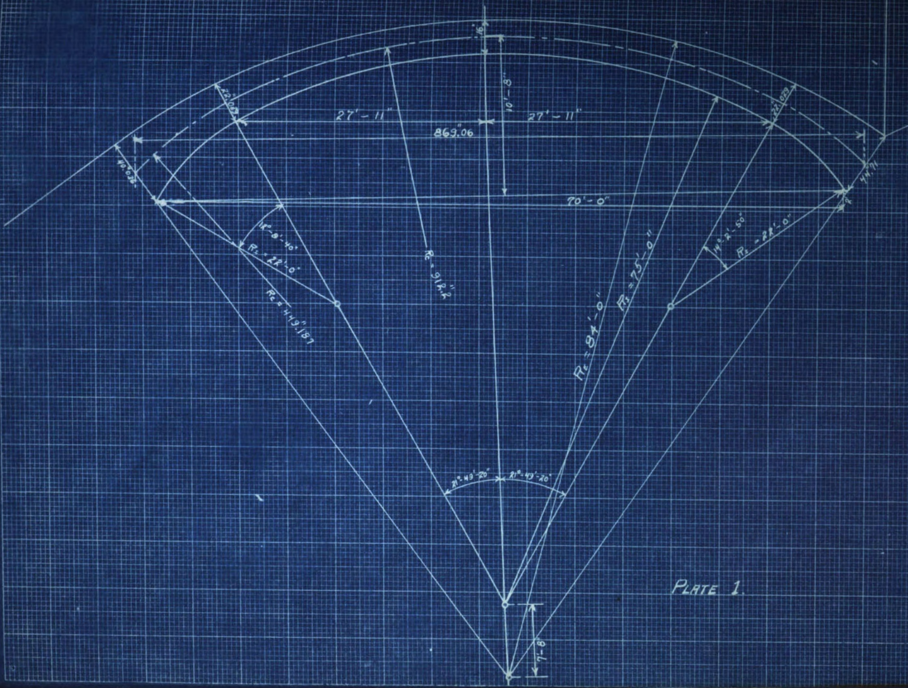
$a_3 = -\Sigma_0^L \frac{x \Delta s}{I}.$ $\quad b_3 = -\Sigma_0^L \frac{x^2 \Delta s}{I} - \Sigma_0^L \frac{\Delta y.\sin\phi}{A}.$ $\quad c_3 = \Sigma_0^L \frac{x.y.\Delta s}{I} - \Sigma_0^L \frac{\Delta y.\cos\phi}{A}.$

The following terms are dependant on the loading – d_1, d_2, d_3, C_1 & C_2 Their values are – from above –

$d_1 = -W_V \Sigma_a^L \frac{(x-a)\Delta s}{I} - W_H \Sigma_a^L \frac{(y-b).\Delta s}{I}$

$d_2 = E e t \Sigma_0^L \Delta x. - W_V\left[\Sigma_a^L \frac{(x-a) y \Delta s}{I} - \Sigma_a^L \frac{\Delta x.\sin\phi}{A}\right] - W_H\left[\Sigma_a^L \frac{(y-b) y \Delta s}{I} + \Sigma_a^L \frac{\Delta x.\cos\phi}{A}\right].$ $\quad C_1 = \frac{d_3}{c_3} - \frac{d_1}{c_1}.$

$d_3 = E e t \Sigma_0^L \Delta y + W_V\left[\Sigma_a^L \frac{(x-a) x.\Delta s.}{I} + \Sigma_a^L \frac{\Delta y.\sin\phi}{A}\right] - W_H\left[\Sigma_a^L \frac{(y-b) x.\Delta s.}{I} + \Sigma_a^L \frac{\Delta y.\cos\phi}{A}\right].$ $\quad C_2 = \frac{d_3}{c_3} - \frac{d_2}{c_2}.$

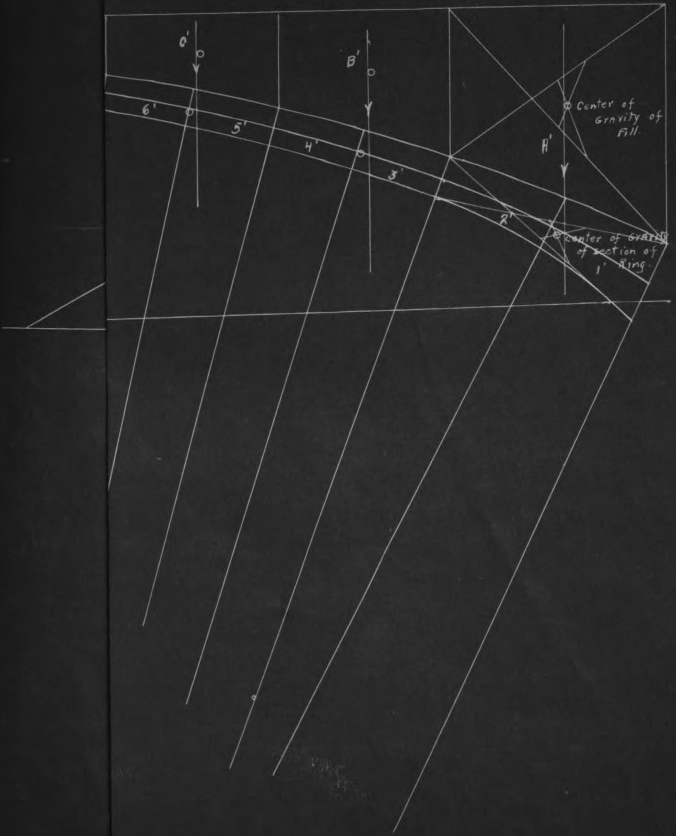


27' - 11"
27' - 11"
869.06"
10' - 8"
70' - 0"
R_c = 912.2"
R_1 = 22' - 0"
R_c = 449.187"
R_2 = 22' - 0"
R_c = 84' - 0"
R_3 = 75' - 0"
21° - 49' - 20"
21° - 49' - 20"
7' - 8"

PLATE 1.

TABLE 1.

Point	X	k	y	ΔS	φ	sin φ	cos φ	ΔX	Δy	h	A	I	$\frac{\Delta S}{I}$	$\frac{X\Delta S}{I}$	$\frac{y\Delta S}{I}$	$\frac{X^2\Delta S}{I}$	$\frac{X.y\Delta S}{I}$	$\frac{y^2\Delta S}{I}$
					MINUTES													
1	+21.464″	.024698	+13.647″	50.8785″	1855.83	.51400	.85785	43.6461	26.1515	35.533	442.146	49,835.5	.0010209	.0219126	.013932	.470332	.299041	.19013
2	+66.412″	.076418	+37.441″	"	1491.50	.46420	.90728	46.1585	23.6178	26.531	334.122	21,446.5	.0023723	.157550	.088821	10.4632	5.8988	3.32554
3	+110.067″	.126650	+55.273″	43.8290″	1227.50	.34948	.93684	41.0608	15.3130	21.652	275.574	11,996.8	.0036534	.402120	.201934	44.2601	22.2263	11.1614
4	+151.061″	.173820	+69.476″	"	1063.83	.30454	.95241	41.7432	13.3476	20.898	266.526	10,844.3	.0040416	.610530	.280794	92.2273	42.4172	19.5084
5	+192.721″	.221757	+81.809″	"	900.16	.25887	.96593	42.3357	11.3460	20.1448	257.490	9,773.08	.0044846	.864270	.366880	166.563	70.7051	30.0141
6	+234.919″	.270313	+92.035″	"	736.50	.21261	.97914	42.9147	9.31848	19.3912	248.444	8,903.61	.0049226	1.15641	.453050	271.662	106.4302	41.6964
7	+277.456″	.319374	+97.336″	"	572.33	.16587	.98615	43.2219	7.26992	18.637	239.394	7,840.82	.0055898	1.55092	.544080	430.312	150.9603	52.9585
8	+320.458″	.368890	+103.541″	"	409.16	.11874	.99293	43.5191	5.20425	17.884	230.358	6,979.33	.0062798	2.01297	.650217	645.253	208.4249	67.3241
9	+363.747″	.418680	+107.644″	"	245.50	.07136	.99745	43.7172	3.12763	17.1304	221.320	6,172.38	.0071008	2.58303	.764358	939.962	278.047	82.2785
10	+407.667″	.466341	+109.714″	"	81.830	.02381	.99972	43.8167	1.04357	16.3768	212.274	5,448.28	.0080445	3.27947	.882594	1336.93	359.803	96.8329
10′	+450.065″	.499220	+109.714″	"	81.830	.02381	.99972	43.8167	1.04357	16.3768	212.274	5,448.28	.0080445	3.62055	.882594	1629.48	397.225	96.8329
9′	+493.915″	.56833	+107.644″	"	245.50	.07136	.99745	43.7172	3.12763	17.1304	221.320	6,172.38	.0071008	3.50719	.764358	1733.15	377.528	82.2785
8′	+537.184″	.61812	+103.541″	"	409.16	.11874	.99293	43.5191	5.20425	17.884	230.358	6,979.33	.0062798	3.37341	.650217	1812.14	349.286	67.3241
7′	+580.176″	.66759	+97.336″	"	572.33	.16587	.98615	43.2219	7.26992	18.637	239.394	7,840.82	.0055898	3.243067	.544080	1881.55	315.667	52.9585
6′	+622.813″	.716651	+92.035″	"	736.50	.21261	.97914	42.9147	9.31848	19.3912	248.444	8,903.61	.0049226	3.06586	.453050	1909.45	282.166	41.6964
5′	+665.011″	.765207	+81.809″	"	900.16	.25887	.96593	42.3357	11.3460	20.1448	257.490	9,773.08	.0044846	2.982308	.366880	1983.27	243.980	30.0141
4′	+706.671″	.813144	+69.476″	"	1063.83	.30454	.95241	41.7432	13.3476	20.898	266.526	10,844.3	.0040416	2.85608	.280794	2018.31	198.429	19.5084
3′	+747.665″	.860314	+55.273″	"	1227.50	.34948	.93684	41.0608	15.3130	21.652	275.574	11,996.8	.0036534	2.73152	.201934	2042.26	150.979	11.1614
2′	+794.459″	.914159	+36.056″	57.8330″	1520.0	.42788	.90383	52.2712	24.7456	27.700	348.150	24,275.13	.0023824	1.90172	.085899	1510.84	68.5684	3.09717
1′	+845.097″	.972426	+8.168″	"	1941.5	.53521	.84472	48.8527	30.9528	39.040	484.230	65,502.9	.0008829	.746230	.0072116	630.637	6.09521	.058904
Sum													.0948929	40.66714	8.483677	21089.2	3635.135	810.2203



C'
B'
A'
6'
5'
4'
3'
2'
1'
Center of Gravity of Fill.
Center of Gravity of section of Ring.

Table 2.

Point	Load at E'						Load at D'						Load at C'					
	$\frac{(x-a)\Delta s}{I}$	$\frac{(x-a)x\Delta s}{I}$	$\frac{(x-a)y\Delta s}{I}$	$\frac{(y-b)\Delta s}{I}$	$\frac{(y-b)x\Delta s}{I}$	$\frac{(y-b)y\Delta s}{I}$	$\frac{(x-a)\Delta s}{I}$	$\frac{(x-a)x\Delta s}{I}$	$\frac{(x-a)y\Delta s}{I}$	$\frac{(y-b)\Delta s}{I}$	$\frac{(y-b)x\Delta s}{I}$	$\frac{(y-b)y\Delta s}{I}$	$\frac{(x-a)\Delta s}{I}$	$\frac{(x-a)x\Delta s}{I}$	$\frac{(x-a)y\Delta s}{I}$	$\frac{(y-b)\Delta s}{I}$	$\frac{(y-b)x\Delta s}{I}$	$\frac{(y-b)y\Delta s}{I}$
10																		
10'																		
9'	+.141412	+69.8457	+15.2222	-.0067884	-3.35287	-.730726												
8'	+.396783	+213.146	+41.0833	-.031769	-17.0661	-3.28945												
7'	+.593503	+344.336	+57.7682	-.062963	-36.5299	-6.12852	+.109873	+63.7458	+10.6944	-.0294248	-17.0715	-2.86404						
6'	+.732547	+456.240	+67.4197	-.081543	-50.7860	-7.50477	+.306644	+190.982	+28.2218	-.0520073	-32.3908	-4.78647						
5'	+.815429	+569.654	+70.0781	-.120147	-79.8991	-9.82908	+.468600	+311.624	+38.3357	-.0932393	-62.0052	-7.62780	+.082745	+55.0266	+6.71395	-.017898	-11.9024	-1.45225
4'	+.940363	+664.527	+65.3326	-.158124	-111.741	-10.9858	+.590684	+417.419	+41.0383	-.133874	-94.6048	-9.30102	+.242945	+171.682	+16.8788	-.065975	-46.6226	-4.58368
3'	+.999808	+747.521	+55.2623	-.194825	-145.664	-10.7685	+.683715	+511.190	+37.7909	-.172904	-129.275	-9.55693	+.369377	+276.170	+20.4165	-.111527	-83.3851	-6.16444
2'	+.763462	+609.423	+27.5271	-.172829	-137.958	-6.23146	+.557336	+444.886	+20.0951	-.158534	-126.548	-5.71606	+.352355	+281.262	+12.7044	-.118510	-94.5992	-4.27296
1'	+.327645	+276.924	+2.67620	-.088672	-74.9454	-.724275	+.219471	+185.496	+1.79264	-.083375	-70.4680	-.681006	+.175290	+148.154	+1.43177	-.068542	-57.9313	-.559851
Sum	+5.71095	+3,953.62	+402.3697	-.917661	-657.942	-56.1926	+2.93632	+2,125.34	+177.9688	-.723358	-532.363	-40.5333	+1.22271	+932.295	+58.1454	-.382452	-294.4406	-17.0332

Point	Load at B'						Load at A'					
	$\frac{(x-a)\Delta s}{I}$	$\frac{(x-a)x\Delta s}{I}$	$\frac{(x-a)y\Delta s}{I}$	$\frac{(y-b)\Delta s}{I}$	$\frac{(y-b)x\Delta s}{I}$	$\frac{(y-b)y\Delta s}{I}$	$\frac{(x-a)\Delta s}{I}$	$\frac{(x-a)x\Delta s}{I}$	$\frac{(x-a)y\Delta s}{I}$	$\frac{(y-b)\Delta s}{I}$	$\frac{(y-b)x\Delta s}{I}$	$\frac{(y-b)y\Delta s}{I}$
6'												
5'												
4'												
3'	+.059423	+44.4282	+3.28446	-.026038	-19.4675	-1.43918						
2'	+.150232	+119.921	+5.41671	-.0627619	-50.0989	-2.26292						
1'	+.100384	+84.8441	+.819937	-.047882	-40.4695	-3.91099	+.0147773	+12.4897	+.120701	-.0107998	-9.12789	-.088213
Sum	+.310039	+249.1933	+9.52111	-.136682	-110.0359	-4.093199	+.0147773	+12.4897	+.120701	-.0107998	-9.12789	-.088213

TABLE 1 Cont'd.

Point	$\frac{\Delta x \cos\phi}{A}$	$\frac{\Delta y \cos\phi}{A}$	$\frac{\Delta x \sin\phi}{A}$	$\frac{\Delta y \sin\phi}{A}$	$\frac{\Delta x}{A}$
1	.084681	.050739	.050739	.0304014	.0987142
2	.125332	.0641285	.0641285	.0328124	.138148
3	.139587	.0520579	.0520579	.0194197	.149000
4	.149166	.0476966	.0476966	.0152512	.156619
5	.158815	.0425626	.0425626	.0114068	.164417
6	.169130	.0367249	.0367249	.0079744	.172734
7	.178046	.0299483	.0299483	.0050371	.180547
8	.187583	.0224322	.0224322	.0026826	.188919
9	.197025	.0140957	.0140957	.00100844	.197528
10	.206358	.0049147	.0049147	.00011705	.206415
10'	.206358	.0049147	.0049147	.00011705	.206415
9'	.197025	.0140957	.0140957	.0010084	.197528
8'	.187583	.0224322	.0224322	.0026826	.188919
7'	.178046	.0299483	.0299483	.0050371	.180547
6'	.169130	.0367249	.0367249	.0079744	.172734
5'	.158815	.0425626	.0425626	.0114068	.164417
4'	.149166	.0476966	.0476966	.0152512	.156619
3'	.139587	.0520579	.0520579	.0194197	.149000
2'	.135701	.0642418	.0642418	.0304126	.150139
1'	.0852216	.0539959	.0539959	.0342115	.100887
Sum	3.202356	.733969	.733969	.2536326	3.320246

TABLE 3.

a_1	$\sum_0^L \frac{\Delta s}{I}$	+.0948929
a_2	$\sum_0^L \frac{y \Delta s}{I}$	+8.483677
a_3	$-\sum_0^L \frac{x \Delta s}{I}$	-40.66714
b_1	$\sum_0^L \frac{x \Delta s}{I}$	+40.66714
b_2	$\sum_0^L \frac{x y \Delta s}{I}$	+3635.135
b_3	$-\sum_0^L \frac{x^2 \Delta s}{I}$	-20 89.2
c_1	$-\sum_0^L \frac{y \Delta s}{I}$	-8.483677
c_2	$-\sum_0^L \frac{y^2 \Delta s}{I}$	-810.2203
c_3	$\sum_0^L \frac{x y \Delta s}{I}$	+3635.135
	$\frac{a_2}{c_2}$	-.0104708
	$-\frac{a_3}{c_3}$	+.01118724
A_2	Sum	+.00071684
	$\frac{b_3}{c_3}$	-5.80149
	$-\frac{b_1}{c_1}$	+4.79357
B_1	Sum	-1.00792
	$\frac{b_3}{c_3}$	-5.80149
	$-\frac{b_2}{c_2}$	+4.48660
B_2	Sum	-1.31489
	$\frac{a_1}{c_1}$	-.01118535
	$-\frac{a_3}{c_3}$	+.01118734
A_1	Sum	+.00000189

$$d_1 = -1000 \sum_0^L \frac{\Delta s}{I}(x-a).$$

$$d_2 = -1000 \sum_0^L \frac{(x-a)\,y\,\Delta s}{I}.$$

$$d_3 = +1000 \sum_0^L \frac{(x-a)\,x\,\Delta s}{I}.$$

$$C_1 = \frac{d_3}{c_3} - \frac{d_1}{c_1}.$$

$$C_2 = \frac{d_3}{c_3} - \frac{d_2}{c_2}.$$

$$V_L = -\frac{C_1}{B_1}.$$

$$M_L = \frac{B_2}{A_2} V_L + \frac{C_2}{A}.$$

$$H_L = -\frac{a_1}{c_1} M_L - \frac{b_1}{c_1} V_L - \frac{d_1}{c_1}.$$

$$M_R = M_L + Y_L L - 1000(L-a).$$

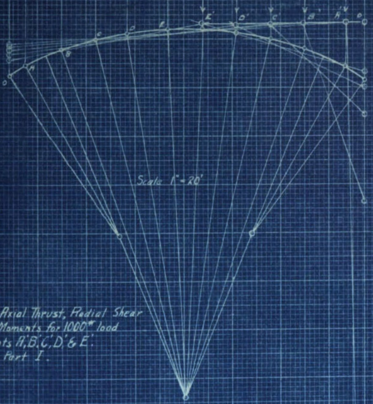
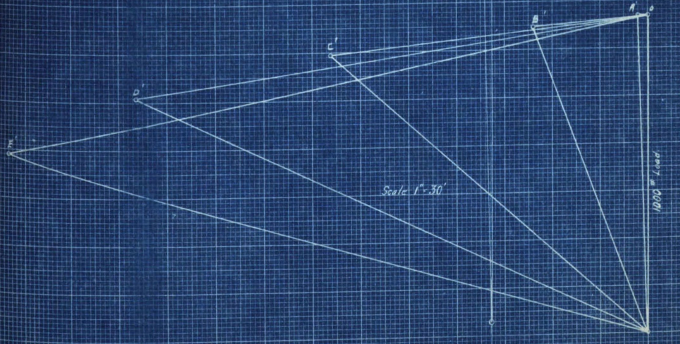


Diagram of Axial Thrust, Radial Shear
& Bending Moments for 1000# load
at Points A', B', C', D' & E'.
Part I.

PLATE 2.



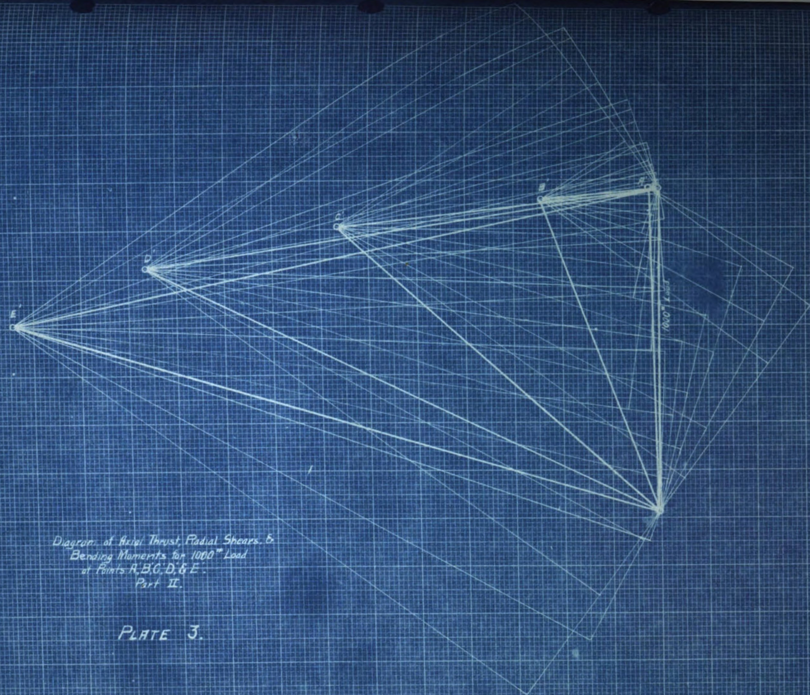


Diagram of Axial Thrust, Radial Shears & Bending Moments for 1000# Load at Points A, B, C, D, & E.
Part II.

PLATE 3.

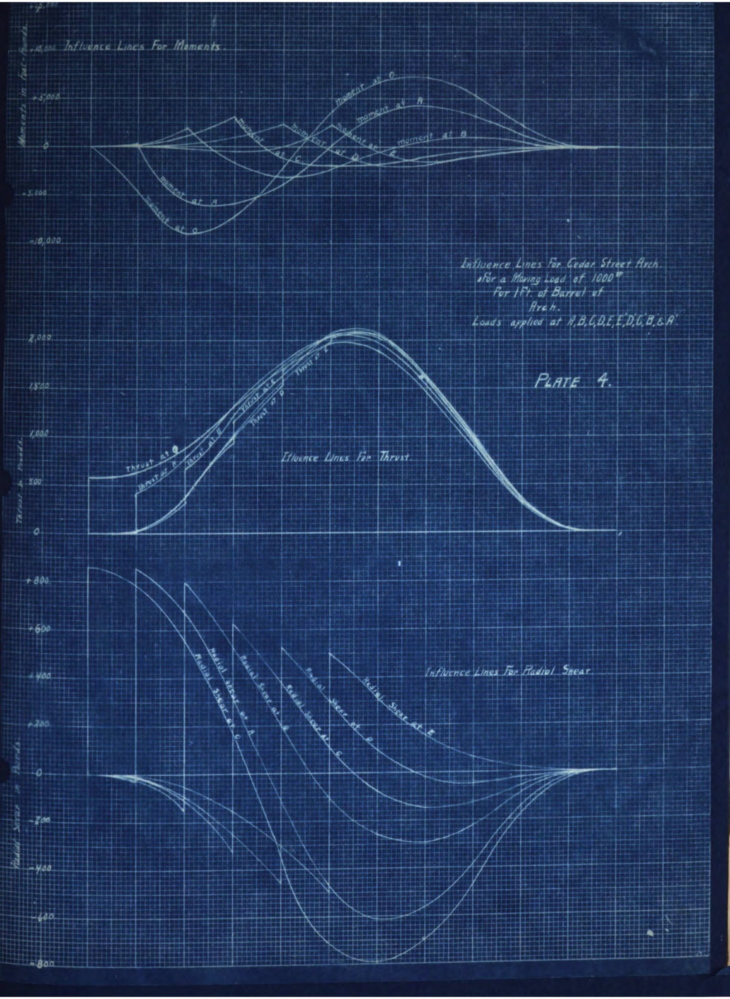

Influence Lines For Moments.
Moments in Foot-Pounds.
+10,000
+5,000
0
-5,000
-10,000
moment at O
moment at A
moment at B
moment at C
moment at D
moment at E
moment at A
moment at O
Influence Lines For Cedar Street Arch
for a Moving Load of 1000#
For 1 Ft. of Barrel of
Arch.
Loads applied at A,B,C,D,E,E',D',C',B',& A'.
PLATE 4.
Thrust in Pounds.
2,000
1,500
1,000
500
0
Thrust at O
Thrust at A
Thrust at B
Thrust at C
Thrust at D
Thrust at E
Itluence Lines For Thrust.
Radial Shear in Pounds.
+800
+600
+400
+200
0
-200
-400
-600
-800
Influence Lines For Radial Shear
Radial Shear at O
Radial Shear at A
Radial Shear at B
Radial Shear at C
Radial Shear at D
Radial Shear at E

TABLE 4.

Load at	d_1	d_2	d_3	d_3/c_3	$-d_1/c_1$	C_1	d_3/c_3	$-d_2/c_2$	C_2
E'	+5,710.95	+ 402,369.	+ 3,953,620.	+ 1,087.61	- 673.17	414.44	1087.61	496.62	590.99
D'	+2,936.2	+ 177,968.	+2,125,340.	+ 584.666	- 346.11	238.556	584.666	219.65	365.01
C'	+1,222.71	+ 58,145.	+ 932,295.	+ 256.467	- 144.125	112.342	256.467	71.764	148.703
B'	+ 310.04	+ 9,521.	+ 249,193.	+ 68.551	- 36.55	32.001	68.551	11.75	56.801
A'	+ 14.779	+ 120.	+ 12,489.	+ 34.356	- 1.74	1.695	3.4356	.148	3.2876

Load at	V_L	$\frac{B_2}{A_2} V_L$	C_2/A_2	M_L	$\frac{a_1}{c_1} M_L$	$-\frac{b_1}{c_1} V_L$	$-d_1/c_1$	H_L	M_R
E'	411.183	- 755,120.	+ 824,437.	+ 69,317.	+ 775.335	+ 1,971.03	- 673.17	+ 2,073.195	+ 31,600.
D'	236.671	- 434,120.	+ 509,193.	+ 75,073.	+ 839.718	+ 1,134.50	- 346.11	+ 1,628.108	- 27,786.
C'	111.459	- 204,447.	+ 257,662.	+ 53,215.	+ 595.226	+ 534.287	- 144.125	+ 985.388	- 72,425.
B'	31.749	- 58,240.	+ 79,238.	+ 20,998.	+ 234.870	+ 152.190	- 36.550	+ 350.510	- 89,070.
A'	1.646	- 3,019.	+ 4,586.	+ 1,567.	+ 17.527	+ 7.890	- 1.740	+ 23.677	- 37,703.

Table 5.

Load At E'

Stress At	T	S	M	T/A_T	Mc/I_T	$\frac{T}{A_T}+\frac{Mc}{I_T}$	$\frac{T}{A_T}-\frac{Mc}{I_T}$
O	1894	-792	+3.3 +6659.6	3.840	1.858	5.698	1.982
A	1965	-610	+1.7 +3420.4	5.230	1.679	6.901	3.550
B	2040	-260	-.1 -201.2	7.500	-.1861	7.314	7.686
C	2052	-76	-.9 -1810.8	8.645	-2.182	6.463	10.827
D	2053	+98	-.9 -1810.8	9.150	-2.436	6.710	11.588
E	2031	+318	-.1 -201.2	9.300	-.2889	9.011	9.589
E'	1989 2029	+504 -498	+1.2 +2414.2	9.150 9.335	3.465	12.615 12.800	5.685 5.870
D'	2040	-303	-.1 -201.2	9.088	-.2707	8.817	9.359
C'	2092	-103	-1. -2012.	8.815	-2.428	6.387	11.243
B'	2092	+98	-1.1 -2213.2	7.730	-2.048	5.682	9.778
A'	2044	+465	+.1 +201.2	5.273	.0930	5.360	5.180
O'	1966	+717	+1.75 +3521.0	3.560	.810	4.370	2.750

Load At D'

Stress At	T	S	M	T/A_T	Mc/I_T	$\frac{T}{A_T}+\frac{Mc}{I_T}$	$\frac{T}{A_T}-\frac{Mc}{I_T}$
O	1450	-607	+4.4 +7031.2	2.924	1.967	4.891	.957
A	1512	-561	+2.6 +4154.8	4.052	2.040	6.092	2.012
B	1587	-295	+.4 +639.2	5.835	.5912	6.426	5.244
C	1607	-148	-.6 -958.8	6.765	-1.155	5.610	7.920
D	1612	-15	-1.1 -1757.8	7.180	-2.363	4.817	9.543
E	1604	+160	-1. -1598.0	7.380	-2.292	5.088	9.672
E'	1580	+308	0 0	7.270	0	7.270	7.270
D'	1542 1680	+460 -533	+1.5 +2397.0	6.870 7.485	3.225	10.095 10.710	3.645 4.260
C'	1626	-397	-.7 -1118.6	6.850	-1.348	2.806	5.502
B'	1750	-204	-2. -3196.0	6.435	-2.955	3.48	9.390
A'	1762	+105	-2.5 -3995.0	4.544	-1.845	2.699	6.389
O'	1686	+327	-1.5 -2397.0	3.053	-.551	2.502	3.604

Load At C'

Stress At	T	S	M	T/A_T	Mc/I_T	$\frac{T}{A_T}+\frac{Mc}{I_T}$	$\frac{T}{A_T}-\frac{Mc}{I_T}$
O	884	-470	+5.3 +5273.5	1.781	1.475	3.256	.306
A	928	-383	+3.3 +3283.5	2.468	1.611	4.079	.857
B	982	-220	+.9 +895.5	3.610	.8285	4.438	2.782
C	995	-125	-.6 -597.0	4.195	-.720	3.470	4.920
D	1004	-48	-1. -995.0	4.475	-1.340	3.135	5.815
E	998	+66	-1. -995.0	4.595	-1.428	3.167	6.023
E'	987	+152	-.3 -298.5	4.539	-.4284	4.111	4.967
D'	970	+252	+1.1 +1094.5	4.320	1.473	5.793	2.847
C'	944 1173	+348 -626	+3. +2985.0	3.973 4.940	3.600	7.573 8.540	.373 1.34
B'	1229	-522	-1.8 -1791.0	4.520	-1.658	2.862	6.178
A'	1302	-297	-6. -5970.0	3.358	-2.760	.598	6.118
O'	1330	-128	-7.1 -7064.5	2.407	-1.624	.783	4.031

Load At B'

Stress At	T	S	M	T/A_T	Mc/I_T	$\frac{T}{A_T}+\frac{Mc}{I_T}$	$\frac{T}{A_T}-\frac{Mc}{I_T}$
O	317	-178	+6. +2172.	.639	.608	1.247	.031
A	335	-150	+4. +1448.	.892	.711	1.603	.181
B	353	-90	+1.6 +5792.	1.297	.536	1.833	.761
C	360	-55	0 0	1.516	0	1.516	1.516
D	365	-24	-.7 -253.4	1.626	-.241	1.385	1.867
E	361	+20	-1.0 -362.	1.660	-.521	1.139	2.181
E'	358	+53	-.5 -181.	1.647	-.260	1.387	1.907
D'	352	+87	+1.0 +362.	1.567	.487	2.054	1.080
C'	345	+112	+2.8 +1013.6	1.452	1.221	2.673	.231
B'	328 654	+149 -800	+5.2 +1882.4	1.210 2.404	1.742	2.95 4.146	-.53 +.662
A'	787	-672	-16. -5792.	2.030	-2.675	-.645	4.705
O'	867	-569	-25.2 -9122.4	1.568	-2.097	-.529	3.665

Load At A'

Stress At	T	S	M	T/A_T	Mc/I_T	$\frac{T}{A_T}+\frac{Mc}{I_T}$	$\frac{T}{A_T}-\frac{Mc}{I_T}$
O	22	-23.	+6.6 +19.8	.0443	.005545	.0498	.0388
A	26	-19.	+4.6 +13.8	.0692	.00678	.0760	.0624
B	28	-10.	+1.9 +5.7	.1029	.00528	.1082	.0976
C	29	-9.	+.2 +.6	.1221	.000724	.1228	.1214
D	30	-5.	-.6 -1.8	.1339	-.00242	.1315	.1363
E	30	0	-1.0 -3.0	.1380	-.004305	.1337	.1423
E'	31	+3.	-.6 -1.8	.1426	-.00258	.1400	.1452
D'	30	+7.	+.7 +2.1	.1336	.002825	.1364	.1307
C'	27	+9.	+2.4 +7.2	.1137	.00868	.1224	.1050
B'	25	+11.	+4.7 +14.1	.0920	.01305	.1051	.0789
A'	23 413	+13. -860.	+9. +27.	.0593 1.0650	.01248	.0718 1.0777	.0468 1.053
O'	620	-790.	-159. -4770.	1.1210	-1.0970	.024	2.218

Stress At	A_T	I_T	C	C/I_T
O	496.23	71,500.00	20.00	.000280
A	375.80	30,555.00	15.00	.000491
B	272.07	11,541.97	10.68	.000926
C	237.51	7,655.80	9.24	.001206
D	224.55	6,460.13	8.70	.001346
E	217.35	5,852.95	8.40	.001435
E'	217.35	5,852.95	8.40	.001435
D'	224.55	6,460.13	8.70	.001346
C'	237.51	7,655.80	9.24	.001206
B'	272.07	11,541.97	10.68	.000926
A'	387.80	33,556.00	15.50	.000462
O'	552.32	97,250.00	22.35	.000230

Table 6. Top Stresses.

Load at	Stress at O' 1000#	Dead	Live	Stress at A' 1000#	Dead	Live	Stress At B' 1000#	Dead	Live	Stress at C' 1000#	Dead	Live	Stress at D' 1000#	Dead	Live	Stress at E' 1000#	Dead	Live
A'	.024	.1888	.0345	.0718 1.0797	.541 8.12	1.444	.1051	.792	.151	.1224	.923	.176	.1364	1.028	.194	.1400	1.055	.202
B'	-.529	-2.095	-.762	-.645	-2.555	-.865	2.95 4.146	11.69 16.45	.597	2.673	10.60	3.850	2.054	8.15	2.975	1.387	5.50	1.998
C'	.783	2.130	1.049	.598	1.655	.801	2.862	7.92	4.138	7.573 8.540	20.95 23.62	12.30	5.793	16.03	13.510	4.111	5.92	5.913
D'	2.502	4.867	3.605	2.699	5.255	3.635	3.48	6.775	5.014	2.806	5.455	4.04	10.095 10.710	19.65 20.83	67.650	7.27	14.14	16.95
E'	4.37	6.795	10.200	5.366	8.345	12.53	5.682	8.84	13.25	6.387	9.935	14.91	8.817	13.69	20.60	12.615 12.800	19.62 19.90	79.65
E	5.698	8.865	35.480	6.901	10.730	42.93	7.314	11.36	45.50	6.463	10.10	40.41	6.71	10.43	15.65	9.011	14.00	21.01
D	4.891	9.805	11.410	6.092	12.21	14.11	6.426	12.88	14.99	5.610	11.24	13.09	4.817	9.66	6.84	5.088	10.20	11.86
C	3.256	9.335	7.590	4.079	11.70	9.52	4.438	12.73	10.35	3.470	9.95	8.10	3.135	8.99	4.453	3.167	9.08	4.56
B	1.247	4.870	1.797	1.603	6.26	2.149	1.833	7.16	10.30	1.516	5.92	2.182	1.385	5.41	1.967	1.139	4.445	1.641
A	.0498	.349	.072	.076	.533	.109	.1082	.759	1.093	.1228	.86	.177	.1315	.923	.187	.1337	.938	.193
Sum		45.101	70.475		61.253	86.363		85.646	110.756		88.603	99.235		95.141	134.096		85.138	143.977
Total			115.576			147.616			196.402			187.838			229.237			229.115

Table 7. Bottom Stresses.

Load at	Stress at O' 1000#	Dead	Live	Stress at A' 1000#	Dead	Live	Stress at B' 1000#	Dead	Live	Stress at C' 1000#	Dead	Live	Stress at D' 1000#	Dead	Live	Stress at E' 1000#	Dead	Live
A'	2.218	16.7	3.193	.0468 1.0530	.355 7.940	1.517	.0789	.595	.114	.105	.792	.151	.1307	.986	.188	.1458	1.094	.209
B'	3.665	14.53	5.278	4.705	18.65	6.775	-.53 +.662	-2.101 2.65	.954	.231	.916	.332	1.08	4.282	1.555	1.907	7.56	2.747
C'	4.031	11.15	5.805	6.118	16.97	8.813	6.187	17.1	8.90	.373 1.340	3.715	1.931	2.847	7.880	4.100	4.967	13.74	7.152
D'	3.604	7.015	5.188	6.389	12.43	9.207	9.390	18.26	13.52	5.502	10.70	12.83	3.645 4.260	7.095 8.295	9.94	7.27	14.14	16.95
E'	2.750	4.275	6.420	5.180	8.055	12.08	9.778	15.20	22.80	11.243	17.47	70.00	9.359	14.55	58.20	5.688 5.870	8.545 9.130	36.50
E	1.982	3.082	12.33	3.55	5.521	22.20	7.686	11.95	47.80	10.827	16.84	25.30	11.588	18.02	27.03	9.589	14.91	22.37
D	.957	1.918	2.232	2.012	4.065	4.695	5.244	10.51	12.22	7.92	15.87	18.46	9.543	19.12	22.27	9.672	19.39	22.53
C	.306	.878	.707	.857	2.457	1.998	2.782	7.98	6.492	4.92	14.10	7.085	5.815	16.67	8.38	6.023	17.27	8.675
B	.031	.051	.045	.181	.707	.261	.761	2.97	1.096	1.516	5.92	2.183	1.867	7.292	2.68	2.181	8.52	3.143
A	.0388	.272	.056	.0624	.437	.089	.0976	.685	.140	.1214	.852	.175	.1363	.956	.196	.1483	.98	.205
Sum		59.871	41.254		77.241	67.635		87.90	114.04		87.175	138.448		100.051	134.459		106.734	120.481
Total			101.125			144.87			201.94			225.563			234.51			227.215

Stress at	O'	A'	B'	C'	D'	E'
	Top	Top	Bottom	Bottom	Bottom	Top
	115.576 #□"	147.616 #□"	201.94 #□"	225.563 #□"	234.51 #□"	229.115 #□"

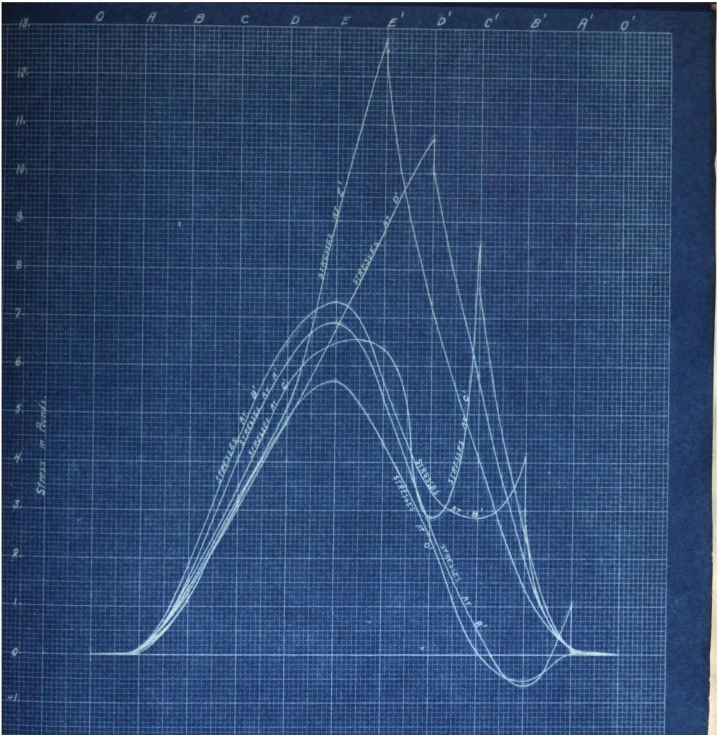


Plate
Curves of Stresses in Top of
Arch Ring for
1000# Load.

PLATE 5.

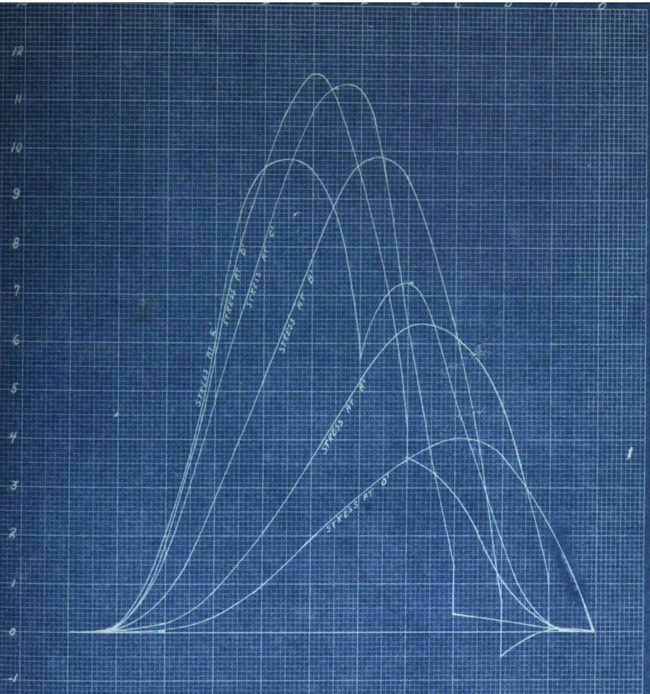


Plate
Curves for Stresses in Bottom of Arch Ring for a 1000# Load

PLATE 6.

TABLE 8.

Load	Shear at O'			Shear at A'			Shear at B'			Shear at C'			Shear at D'			Shear at E'		
At	1000#	Dead	Live	1000#	Dead	Live	1000#	Dead	Live	1000#	Dead	Live	1000#	Dead	Live	1000#	Dead	Live
A'	-23	-174.5	-37.7	-19.	-144.1	-31.2	-10.	-75.4	-13.7	-9.	-68.2	-12.6	-5.	-37.9	-7.0	0	0	0
B'	-178	-703.	-292.	-150.	-594.	-246.	-90.	-365.	-123.3	-55.	-218.	-77.	-24.	-95.1	-33.6	+20.	+79.3	+28.4
C'	-470	-1300.	-771.	-383.	-1060.	-628.	-220.	-608.	-301.5	-125.	-346.	-175.	-48.	-132.7	-67.2	+66.	+182.4	+93.8
D'	-607	-1180.	-990.	-561.	-1083.	-921.	-295.	-574.	-404.	-148.	-287.	-207.	-15.	-29.4	-21.	+160.	+313.	+227.
E'	-792	-1230.	-1300.	-610.	-948.	-1000.	-260.	-404.	-356.	-76.	-118.	-106.4	+98.	+152.	+137.	+318.	+494.	+452.
E	-717	-1114.	-1177.	-465.	-723.	-763.	-98.	-152.	-134.3	+103.	+162.	+240.	+303.	+468	+484.	-504. +498.	-790. +776.	-1173. +1160.
D	-327	-656.	-536.	-105.	-211.	-172.2	+204.	+410.	+476.	+379.	+762.	+908.	-460. +533.	-925. +1072.	-1048. +1242.	-308.	-619.	-1915.
C	+128	+367.	+298.	+297.	+862.	+692.	+522.	+1502.	+1215.	-348. +626.	-998. +1795.	-2160. +3890.	-252.	-723.	-1566.	-152.	-436.	-358.
B	+569	+2250.	+1325.	+672.	+2650.	+1565.	-149. +800.	-582. +3120.	-927. +4980.	-112.	-437.	-261.	-87.	-340.	-203.	-53.	-207.	-123.
A	+790	+5530.	+4910.	-13. +860.	-91. +6602.	-80.8 +5350.	-11.	-77.	-25.6	-9.	-63.	-12.6	-7.	-49.	-16.3	-3.	-21.	-4.3
Sum		+1763.5	+1429.3		+5260.	+3764.6		+2194.6	+4385.6		+183.8	+2026.4		-640.1	-1159.1		-228.3	-767.9
Total			+3192.8			+9024.6			+6580.2			+2210.2			-1799.2			-996.2

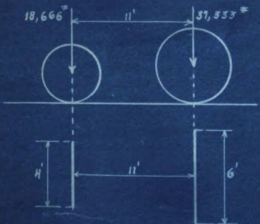
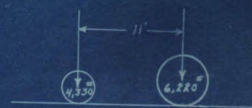


Diagram of Roller and loads.

Shear at	Dead + Live	Area	Unit Shear
O'	+3192.8	443.40 □"	+ 7.20
A'	+9024.6	378.88 □"	+23.81
B'	+6580.2	263.15 □"	+25.00
C'	+2210.2	228.59 □"	+9.668
D'	-1799.2	215.63 □"	-8.343
E'	-996.2	208.43 □"	-4.779



Load on Roller Wheels for a section 1 Foot wide.

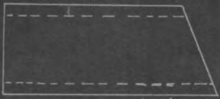
LOADINGS.

Point	A	B	C	D	E	E'	D'	C'	B'	A'
Dead Load	7008#	3905#	2868#	2010#	1554#	1554#	1946#	2768#	3965#	7541#
Live Load - 200#□'	1640#	1370#	1400#	1420#	1440#	1440#	1420#	1400#	1370#	1800#

Stress at O'


Stress at A'


Stress at B'


Stress at C'


Stress at D'


Stress at E'

Stress at	Max. Steel Stress	
	Top	Bottom
O'	64.7#□"	57.1#□"
A'	83.#□"	81.5#□"
B'	110.9#□"	113.7#□"
C'	108.#□"	122.6#□"
D'	129.9#□"	133.3#□"
E'	128.5#□"	127.7#□"

Plate 9.

Maximum Stresses in Steel Reinforcement of Arch Ring.

Scales: 1" = 20", 1" = 100#.