Thesis.

Design for a Reinforced Concrete Arch Bridge over the Concord River at Lawrence Street, Lowell, Mass.

George W. Bowers.

Two drawings. May 1910.

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The bridge is designed to span the Concord River at Lawrence Street, Lowell, Massachusetts.

It is to be of reinforced concrete, using gravel filling to transmit the loads to the arch ring. The walls are to be of the cantilever type and are to be reinforced both for stresses due to the lateral thrust of the filling and for temperature stresses.

There are to be two equal spans of seventy feet each. The roadway is to be fifty feet wide including two eight foot side-walks.

Skew of arches to be thirty degrees.

The concrete is to be one part cement, two parts sand, and four parts stone.
The cement is to be Portland Cement and must conform to the specifications of the American Society of Civil Engineers.
This mixture allows six hundred and fifty pounds compression on the remote fibre. Concrete is assumed to carry no stress in tension.

Steel is to have an ultimate strength of sixty thousand pounds per square inch and its elastic limit is to be not less than one half its ultimate strength.
This allows a working strength of eighteen thousand pounds per square inch.
The ratio of the modulus of elasticity of concrete to that of steel $= \frac{E_c}{E_s} = \frac{1}{15}$.

Stresses are to be figured for five cases and section designed for loading giving the largest stress at the point in question. The five cases are:-

1. Dead load only.
2. Live load over entire span.
3. Live load over left half, roller at crown.
4. Live loads over middle third of span.
5. Live load over left third.

A rise and fall of thirty five degrees is to be allowed for temperature changes, and the corresponding stresses calculated. The coefficient of expansion of steel to be taken as .000006

All stresses to be figured by the Elastic Theory as described by Turneaure and Maurer.

Loadings.

Live load has been assumed as one hundred pounds per sq. ft. and a fifteen ton roller. Dead loads are due to weight of concrete; one-hundred forty pounds per cubic ft. and the weight of the fill - one hundred pounds per cubic foot.

Pt.	Dead	Live	Totals
1	1020	210	1230
2	1480	320	1800
3	1780	330	2110
4	2250	380	2630
5	2800	425	3225
6	3470	450	3920
7	4840	500	5340
8	6040	492	6532
9	8110	490	8600
10	9270	375	9645

The arch Ring has been figured by the Elastic Theory as shown in the analytical treatment of the arch in the "Principles of Reinforced Concrete Construction" by Turneaure and Maurer.

A concrete arch without hinges is staticaly indeterminate as there are six unknown quantities and only three equations of statics, namely-

$\Sigma H = 0$, $\Sigma V = 0$, and $\Sigma M = 0$.

The unknown quantities are the moments the vertical and the horizontal components of the reactions.

In order to calculate the stresses in the arch three more equations or conditions must be obtained from some means other than statics. These three equations are furnished by the Elastic Theory and are as follows:-

1) Length of span is a constant.

2) Total central angle is a constant.

3) Difference of elevations of abutments is a constant.

$$\Sigma \frac{Mx\,ds}{EI} = 0 \qquad \Sigma \frac{M}{EI} ds = 0 \qquad \Sigma \frac{M}{EI} y\,ds = 0$$

Division of Arch Ring into Constant ds/I

Each half of the arch ring has been divided into ten parts or divisions such that $\frac{ds}{I}$ is a constant for each division. The arch was assumed as twenty four inches thick at the crown and three feet six inches thick at the springing line. No account was taken of the steel reinforcing rods. The effect of these rods is greatest at springing and least at crown.

The arch as computed requires twenty three inches at the crown, that is, twenty three inches from extrados to centre line of steel rods, and three feet eight inches at springing. To make a better curve for the extrados the thickness of the arch ring has been increased to four feet at the springing where the radius of curvature of the intrados is small. This not only makes a better looking arch ring but it also makes it possible to use less steel reinforcing bars at springing.

The assumed values are therefore as accurate as required and the values for x and Y resulting from the assumed arch ring have used throughout the design. They are as follows:-

Pt.	x	Y
1	1.08 ft.	.02 ft.
2	3.67 "	.208 "
3	6.92 "	.50 "
4	10.42 "	1.08 "
5	14.33 "	1.79 "
6	18.67 "	2.88 "
7	23.17 "	4.42 "
8	27.75 "	6.85 "
9	32.42 "	10.00 "
10	35.50	14.88

Notation.

H_o = Thrust at crown.

V_o = Shear at crown.

M_o = Moment at crown.

M = Moment at any other section.

n = Number of divisions in one half of arch ring.

x, y = co-ordinates of any point on the arch axis referred to the crown as the origin, and all to be considered as positive in sign.

m = Bending moment at any point in the cantilever due to external loads.

Thrust, Shear, and Moment at the Crown.

$$H_o = \frac{n \Sigma my - \Sigma m \Sigma y}{2[(\Sigma y)^2 - n \Sigma y^2]}$$

$$V_o = \frac{\Sigma(m_R - m_L)x}{\Sigma x^2 2}$$

$$M_o = -\frac{\Sigma m + 2H_o \Sigma y}{2n}$$

Moment at any Section.

$$M = m + M_o + H_o y \pm V_o x$$

In this equation $V_o x$ has the plus (+) sign for the left half of the arch, and negative (−) sign for the right half.

These equations hold only for symmetrical arches.

Case #1.

Pt.	m_L	m_R	$m_L + m_R$	$(m_L+m_R)y$	$(M_R - m_L)$	$(m_R - m_L)x$
1	0	0	0	0	0	0
2	-2,634	-2,634	-5,268	-1,096	0	0
3	-10,756	-10,756	-21,512	-10,756	0	0
4	-25,743	-25,743	-51,486	-55,605	0	0
5	-51,279	-51,279	-102,558	-183,579	0	0
6	-91,784	-91,784	-183,568	-528,676	0	0
7	-149,389	-149,389	-298,778	-1,320,599	0	0
8	-230,197	-230,197	-460,394	-3,029,393	0	0
9	-340,810	-340,810	-681,620	-6,816,200	0	0
10	-438,751	-438,751	-877,502	-13,057,230	0	0

$m_R + m_L = 2,682,700$ $\qquad\qquad -25,003,100$

$$H_o = \frac{-10 \times 25,003,000 + 2,683,000 \times 42.34}{-4370} = 31,200$$

$$M_o = \frac{-2,682,700 + 2 \times 31,200 \times 42.34}{20} = 2,050$$

$V_o = 0$

Case #2

Pt.	M_L	M_R	$M_L + M_R$	$(M_L + M_R)y$	$M_R - M_L$	$(M_R - M_L)x$
1	0	0	0	0	0	0
2	-3,193	-3,193	-6,386	-1,328	0	0
3	-13,073	-13,073	-26,146	-13,073	0	0
4	-31,119	-31,119	-62,238	-67.220	0	0
5	-61,539	-61,539	-123,078	-220370	0	0
6	-109,309	-109,309	-218,618	-629,620	0	0
7	-176,472	-176,472	-352,944	-1,560,000	0	0
8	269,297	-269,297	-538,594	-3,543,900	0	0
9	-394,453	-394,453	-788,906	-7,869,100	0	0
10	-503,500	-503,500	1,007,100	-14,985,700	0	0

$M_L + M_R$: $-3,104,000$ $\qquad\qquad -28,890,300$

$$H_0 = \frac{-10 \times 28,890,000 + 3,104,000 \times 42.34}{-4370} = 35,100$$

$$M_0 = -\frac{-3,104,000 + 2 \times 35,100 \times 42.34}{20} = 6,440$$

$$V_0 = 0$$

Case # 3

Pt.	M_L	M_R	M_L+M_R	$(M_L+M_R)y$	(M_R-M_L)	$(M_R-M_L)x$
1	-4370	0	-4370	-100	4370	4720
2	-18,440	-2630	-21,070	-4,430	15,810	58,022
3	-41,980	-10,760	-52,740	-26,370	31,220	216,040
4	-74,900	-25,740	-100,640	-108,690	49,160	513,250
5	-111,760	-51,280	-163,040	-291,840	60,480	866,670
6	-187,560	-91,780	-279,340	-804,500	95,780	1,788,210
7	-273,620	-149,390	-423,010	-1,869,700	124,230	2,878,200
8	-385,680	-230,200	-615,880	-4,052,490	155,480	4,314,570
9	-503,450	-340,810	-844,260	-8,442,600	162,640	5,273,690
10	-652,430	-438,750	-1,081,180	-16,087,960	213,680	7,585,640

T = 2,255,190 + 1,341,340   -31,688,680   23,509,000

= - 3,596,500

$$H_o = \frac{10 \times 31,689,000 + 3,597,000 \times 42.34}{-4370} = 37,600$$

$$M_o = \frac{-3,597,000 + 2 \times 37,600 \times 42.34}{20} = 20,650$$

$$V_o = \frac{23,509,000}{2 \times 4338} = 3,420$$

Case # 4

Pt.	m_L	m_R	m_L+m_R	$(m_L+m_R)y$	m_R-m_L	$(m_R-m_L)x$
1	0	0	0	0	0	0
2	-3,193	-3,193	-6386	-1,341	0	0
3	-13,073	-13,073	-26,146	-13,073	0	0
4	-31,119	-31,119	-62,238	-67,217	0	0
5	-61,539	-61,539	-123,078	-220,210	0	0
6	-107,465	-107,465	-214,930	-618,998	0	0
7	-170,690	-170,690	-341,380	-1,508,900	0	0
8	-257,220	-257,220	-514,440	-3,385,015	0	0
9	-373,666	-373,666	-747,332	-7,473,320	0	0
10	-475,454	-475,454	-950,958	-14,149,511	0	0

$m_L+m_R = -2,986,838$ 27,437,585

$$H_0 = \frac{-10 \times 27,438 + 2,986,800 \times 42.43}{-4370} = 33,840$$

$$M_0 = -\frac{-2,986,800 + 2 \times 42.43 \times 33,840}{20} = 6053$$

$V_0 = 0$

Case # 5

Pt.	m_L	m_R	$m_L + m_R$	$(m_L+m_R)y$	$m_R - m_L$	$(m_R - m_L)x$
1	0	0	0	0	0	0
2	-2,634	-2,634	-5,268	-1,096	0	0
3	-10,756	-10,756	-21,512	-10,756	0	0
4	-25,743	-25,743	-51,486	-55,650	0	0
5	-51,279	-51,279	-102,558	-183,579	0	0
6	-93,629	-91,784	-185,413	534,041	1,745	32,579
7	-155,171	-144,389	-299,560	-1,323,130	10,782	249,818
8	-242,278	-230,197	-472,475	-3,236,450	12,081	335,247
9	361,601	-340,810	-702,411	7,024,110	20.791	674,044
10	-466,801	-438,751	-905,552	-13,474,610	28,150	999,325

$T = 1,409,840 + 1,341,350$ $\quad -25,843,400 \quad$ $2,291,013$

$= 2,751,190$

$$H_0 = \frac{-10 \times 25,840,000 + 2,751,000 \times 42.43}{4370} = 32,690$$

$$M_0 = -\frac{-2,751,190 + 2 \times 42.43 \times 32,690}{20} = 644$$

$$V_0 = \frac{2,291,000}{2 \times 4338} = 257$$

Case #2

Pt.	Hoy	Vox	M_L	M_R	Thrusts.	Ecc. Dist.
1	700	0	+7140	+7,140	35,110	+.23
2	7,300	0	+10,550	+10,550	35,140	+.30
3	17,600	0	+10,900	+10,900	35,420	+.31
4	37,900	0	+13,240	+13,240	35,920	+.37
5	62,830	0	+7,730	+7,730	36,790	+.21
6	101,000	0	-1,900	-1,900	38,190	-.05
7	155,000	0	-15,100	-15,100	40,610	-.37
8	231,000	0	-30,900	-30,900	44,300	-.70
9	351,000	0	-37,100	-37,100	50,400	-.74
10	522,300	0	+25,200	+25,200	57,400	+.44

.02 X 35,100 + 6440 = 7,140

.208 X 35,100 + 6440 − 3,190 = 10,550

.5 X 35,100 + 6440 − 13,070 = 10,900

1.08 X 35,100 + 6640 − 31,100 = 13,240

1.79 X 35,100 + 6440 − 61,540 = 7,730

2.88 X 35,100 + 6440 − 109,300 = −1,900

4.42 X 35,100 + 6440 − 176,500 = −15,100

6.58 X 35,100 + 6440 − 269,300 = −30,900

10.0 X 35,100 + 6440 − 394,500 = −37,100

14.88 X 35,100 + 6440 − 503,500 = 25,200

37,600 X.02 = 752

37,600 X.208 = 7820

37,600 X0.5 = 18,800

37,600 X1.08 = 40,610

37,600 X1.79 = 67,300

37,600 X2.88 = 108,290

37,600 X6.58 = 247,400

37,600 X10 = 376,000

37,600 X14.88 = 569490

37,600 X 4.42 = 166,190

4320 X 1.08 = 4665

4320 X3.67 = 15,850

4320 X6.92 = 29,890

4320 X10.42 = 45,010

4320 X14.33 = 61,905

4320 X18.67 = 80,654

4320 X23.17 = 100,090

4320 X27.75 = 119,880

4320 X32.42 = 140,050

4320 X35.5 = 153,360

-4370 + 752 + 4665 + 20,650 = 23,500

-18,440 + 7820 + 15,850 + 20,650 = 25,880

-41,980 + 18800 + 29,890 + 20,650 = 27,360

-74,900 + 40,610 + 45,010 + 20,650 = 31,370

-111,760 + 67,300 + 61,905 + 20,650 = 38,100

-187,560 + 166,190 + 80,654 + 20,650 = 22,040

-273,620 + 166,190 + 100,090 + 20,650 = 13,310

-385,680 + 247,400 + 119,880 + 20,650 = -18,750

-503,450 + 376,000 + 140,050 + 20,650 = 33,250

-652,430 + 569,490 + 153,360 + 20,650 = 75,300

Case #3

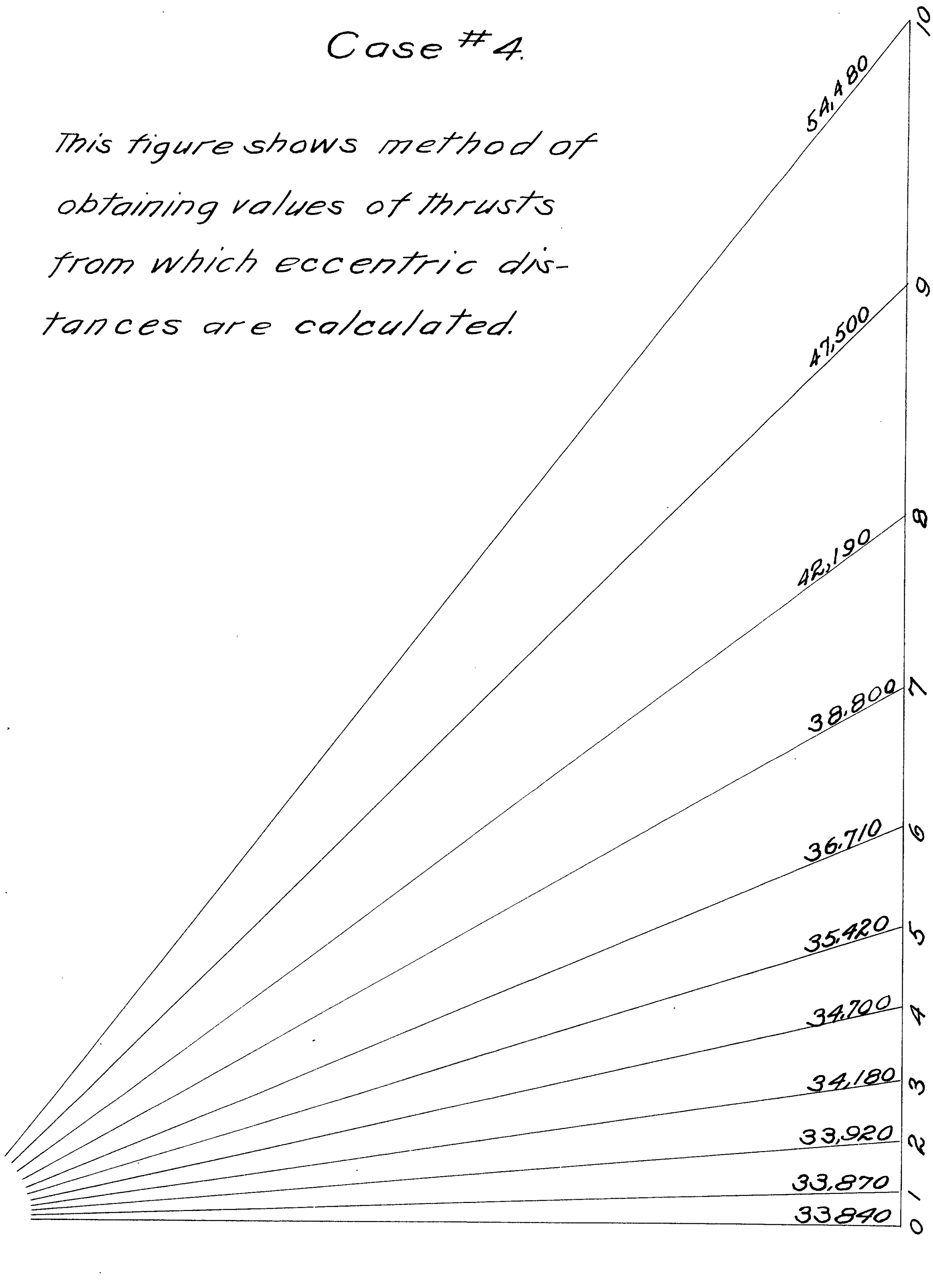
Pt.	ML.	TL.	E.D.	MR	TR	E.D
1	23,500	37,900	+.62	16,730	37,600	+.44
2	25,880	38,200	+.67	10,000	37,700	+.27
3	27,360	38,700	+.70	-1,200	38,100	-.031
4	31,370	39,200	+.80	-9,600	38,500	-.25
5	38,100	40,500	+.94	-14,240	39,200	-.36
6	22,040	42,000	+.52	-43,310	40,400	-1.07
7	13,310	44,600	+.30	-62,640	42,500	-1.47
8	-18,750	49,100	-.38	-82,030	45,500	-1.80
9	33,250	55,000	+.60	-84,210	50,400	-1.67
10	75,300	62,400	+1.20	-1,270	56,900	-.022

Case #4.

1	6,712	33,870	.20	6,712	33,870	.20
2	9,880	33,920	.30	9,880	33,920	.30
3	9,882	34,180	.31	9,882	34,180	.31
4	11,460	34,700	.37	11,460	34,700	.37
5	50,70	35,420	.21	5,070	35,420	.21
6	-3,971	36,710	-.05	-3,971	36,710	-.05
7	-15,080	38,810	-.37	-15,080	38,810	-.37
8	-28,520	42,190	-.70	-28,520	42,190	-.70
9	-29,230	47,500	-.74	-29,230	47,500	-.74
10	34,120	54,480	.44	34,120	54,480	.44

Case #4.

This figure shows method of obtaining values of thrusts from which eccentric distances are calculated.



Case #5

Pt.	M_L	T_L	E.D.	M_R	T_R	E.D.
1	1,950	32,700	+.06	1,020	32,700	+.06
2	5,750	32,800	+.18	3,870	32,800	+.12
3	7,010	33,000	+.21	4,460	33,000	+.14
4	2,880	33,500	+.08	7,530	33,300	+.23
5	11,560	34,000	+.34	4,200	33,900	+.12
6	5,960	35,100	+.17	-1,790	35,100	-.05
7	-4,090	37,550	-.11	-5,210	38,100	-.14
8	-19,400	41,000	-.47	-21,590	40,300	-.63
9	-25,940	46,650	-.56	-21,800	45,500	-.53
10	29,390	53,800	+.55	-39,200	52,500	-.75

Springing Line.

Case	M_L	T_L	E.D.	M_R	T_R	E.D.
2	+47,720	57,400	+.82	+47,720	57,400	.82
3	+29,640	62,400	+.42	+86,400	50,900	1.5
1	+4,400	50,100	+.08	+4,400	50,100	+.08

Temperature Stress.

$$H_0 \quad \frac{EI}{\Delta s} \quad \frac{ctln}{2[n\Sigma y^2-(\Sigma y)^2]}$$

$$M_0 = -\frac{H_0 \Sigma y}{n}$$

$$M = H_0 y + M_0$$

Stress Due to Shortening of Arch from Thrust

$$H_0 = -\frac{I}{\Delta s} \quad \frac{f_c ln}{2[n\Sigma y^2-(\Sigma y)^2]}$$

Notation

t = Degrees rise of temperature.

c = Coefficient of expansion.

l = Span

$\frac{\Delta s}{I}$ = A constant

Moments due to Temperature Changes.

$$\frac{288{,}000{,}000}{3.69} \times \frac{.000006 \times 10 \times 72 \times 35}{2[(10 \times 3977) - (42.34)^2]} = H_o$$

$$\frac{780{,}000{,}000 \times .0151}{2[3977 - 1792]} = -2690 = H_o$$

$$M_o = \frac{-2690 \times 42.34}{10} = -11{,}400$$

H_o due to shortening of arch

$$-\frac{1}{3.69} \times \frac{200 \times 144 \times 72 \times 10 \times 35}{4370} = -1290$$

$$M_o = -\frac{-1290 \times 42.34}{10} = 5{,}450$$

The above values are for an increase of thirty five degrees. For a decrease of 35 degrees the signs are opposite. Signs for the shortening of the arch do not chang, as these are indipendent of changes of temperature although they are directly proportional to them.

Since the value of the ratio of the moment caused by changes of temperature to the moment caused by the shortening of the arch ring is numerically equal to the ratio of their corresponding thrusts, and since the polygon for temperature changes is a straight line, it follows that all the moments and thrusts due to temperature changes and to arch shortening will have the same ratio.

The simplest method of taking account of the stresses due to the shortening of the arch is to apply them as a correction to the temperature stresses. This method has been followed in this design.

The temperature stresses according to the elastic theory as figured may be as great as or even greater than those due to the actual loads. The temperature moments are as follows:-

1- −11,400	4- −8,440	7- +530
2- −11,350	5- −6,560	8- +3,750
3- −10,840	6- −3,600	9- +12,900
	10- +26,100	

Design of Arch Ring.

Crown

$H_o = +37,600^{\#}$ } due to $M + 11,000 \text{ ft}^{\#}$ } Due to $H: -1240$

$M_o = +20,650 \text{ ft}^{\#}$ } Loads $H + 2,690^{\#}$ } Temp. $M + 5280$

Total Moment = 53,880 ft# $\qquad \dfrac{53,880}{39,050} = 1.38' = \text{Ecc. Dist.}$

" Thrust = 39,050 #

$E/h = \dfrac{1.38 \times 12}{23} = .72$

$A = 23 \times 12 + 3.6 \times 15 = 330$

Let $K = \dfrac{M}{bh^2 f_c}$ From curves K for 1.1% steel & $\frac{E}{h} = .72$ is .183

$$f_c = \frac{53,880 \times 12}{12 \times 23 \times 23 \times .183} = 540^{\#}$$

$$\frac{39,000}{330} = \frac{115}{655}\,\#$$

$$\frac{1.8 \times 2.5 \times 1.5 + 10.35 \times 6 \times 3.4}{1.8 \times 15 + 10.35 \times 6} = 3.05$$

$$f_s = \frac{53,800 \times 12}{1.8 \times 19.95} = 17,900^{\#}$$

Point # 3.

$M = 42,400$ $\qquad \dfrac{42,400}{34,600} = 1.228$

$T = 34,580$

assume $d = 22''$ $\qquad \dfrac{1.228 \times 12}{22} = .66 = e/h$

area of steel $= 3.6^{\square''}$ per ft. of width.

$\dfrac{3.6}{264} = .0136$ say 1.4% of steel. $\therefore k = .208$

$$f_c = \frac{42,400 \times 12}{.208 \times 12 \times 22^2} = 422$$

$3.6 \times 15 = 54$
$\quad 264$
$A_T = 318$

$\dfrac{34,600}{318} = 112$

$£ = 534$ Total

distance of centre of compression from top of beam $=$

$$\frac{1.8 \times 2.5 \times 15 + 12.3 \times 6 \times 4.1}{1.8 \times 15 + 12.3 \times 6} = 3.7$$

$$f_s \times 15.8 \times 1.8 = 42,400 \times 12$$

$$f_s = \frac{42,400 \times 12}{1.8 \times 15.8} = 17,900 \text{ \# per sq. in.}$$

Point #5

$M = 47{,}800$ $\quad \frac{47{,}800}{36{,}400} = 1.32 \quad \frac{1.32 \times 12}{24} = .66' = e/h$

$T = 36{,}390$

assume $d = 24$ in. and $3.6\ \square''$ of steel

$\frac{3.6}{342} = 1.1\%$ of steel.

Valve of K for 1.1% and $e/h = .66$ is $.185$

$$f_c = \frac{47{,}800 \times 12}{.185 \times 12 \times 24^2} = 450$$

$$\frac{36{,}390}{342} = \underline{106}$$

$f_c = 556$ # total.

$$\frac{1.8 \times 2.5 \times 15 + 12.2 \times 6 \times 4.06}{1.8 \times 15 + 12.2 \times 6} = 3.8$$

$24 - 3.8 - 2.5 = 17.7$

$f_s \times 1.8 \times 17.7 = 47{,}800 \times 12$

$$f_s = \frac{47{,}800 \times 12}{1.8 \times 17.7} = 17{,}900 \text{ \# per sq. in.}$$

Point #10.

$M = 113{,}000$ $\qquad \dfrac{113{,}000}{63{,}300} = 1.78 = E.D$

$T = 63{,}300$ $\qquad \dfrac{1.78 \times 12}{50} = .428$

K for .6% steel and $\frac{E}{H} = .428 = .138$

$$f_c = \frac{113.000 \times 12}{.138 \times 12 \times 50^2} = 328\#$$

54+600 = 654

$$\frac{63{,}300}{654} \qquad = \frac{97}{425}\#$$

$$\frac{1.8 \times 2.5 \times 15 + 29.8 \times 9.9 \times 6}{1.8 \times 15 + 29.8 \times 6} = 8.1$$

$50 - 8.1 = 41.9$

$$f_s = \frac{113{,}000 \times 12}{1.8 \times 41.9} = 18{,}000\#$$

Springing Line.

$M = 102,800$ $\qquad$ $\dfrac{102,800}{54,900} = 1.87$

$T = 54,900$

$$\frac{1.87 \times 12}{57} = .394$$

$d = 57''$ area of steel $= 3.6$

$\dfrac{3.6}{738} = .5\%$ of steel

For $.5\%$ steel and $e/h = .394$ K is $= .129$

$$f_c = \frac{54,900 \times 12}{.129 \times 12 \times \overline{57}^2} = 130$$

$$\frac{54900}{739} = 74$$

$f_c = 200^{\#}$ Total

$$\frac{1.8 \times 2.5 \times 15 + 33 \times 6 \times 11}{1.8 \times 15 + 33 \times 6} = 10$$

$60 - 10 - 2.5 = 47.5$

$$f_s = \frac{102,800}{1.8 \times 47.5} = 14,500^{\#}$$

Note:- The arch ring is much thicker at the springing than actually required for strength in order to make a better shaped curve. This also effects the points from seven to ten.

Pier and Abutments.

Since the pier and both abutments are on bed rock, and since in all cases the spring-ing lines are practically at the river bottom, the stresses in both abutments and pier are small. In order to have a suitable base for the arch ring the pier had to be made ten feet wide, while but half this width is required to take the stresses. The same condition is true for the abutments.

Design of Walls.

$$P = \frac{100 \times \overline{17}^2}{2} \times \frac{1}{3} = 4810^{\#}$$

Moment at 16 ft. from surface of fill

$$M = \frac{4810 \times 16 \times 12}{3} = 307{,}500 \text{ ''}\#$$

Batter = 1 in 24, wall 15 ins. thick at surface and therefore 15" + 8" = 23" thick 16 ft. below surface. Use 0.5% of steel.

$j = .885 \times 20 = 17.7 \qquad k = .32$

$.32 \times 20 = 6.4$

$$\frac{f_c \times 12 \times 6.4}{2} \times 17.7 = 307{,}500$$

$$f_c = \frac{307{,}500}{6 \times 6.4 \times 17.7} = 450^{\#}$$

$$f_s = \frac{307{,}500}{1.2 \times 17.7} = 14{,}500^{\#}$$

These stresses are low but as we know very little about earth-pressure it is well to have a large factor of safety.

Moment at $10\frac{1}{2}$ ft from surface =

$$M = 307{,}500 \times \frac{8}{27} = 91{,}200$$

$t = 15 + 5 = 20''$ Effective depth = 17 ins.

Use .3% of steel.

$K = .28 \qquad .28 \times 17 = 4.75$

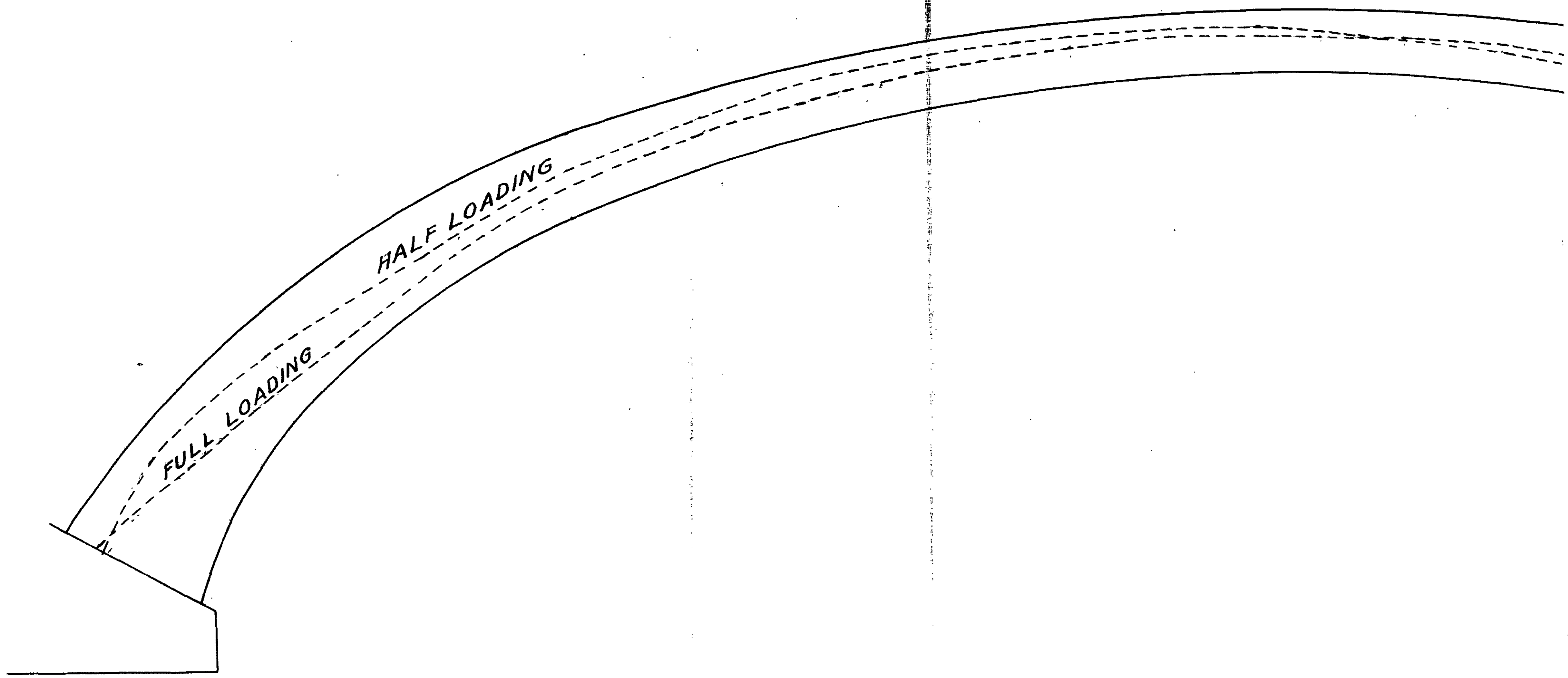
$J = .92 \qquad .92 \times 17 = 15.6$

$$\frac{fc \times 12 \times 4.75}{2} \times 15.6 = 91{,}200$$

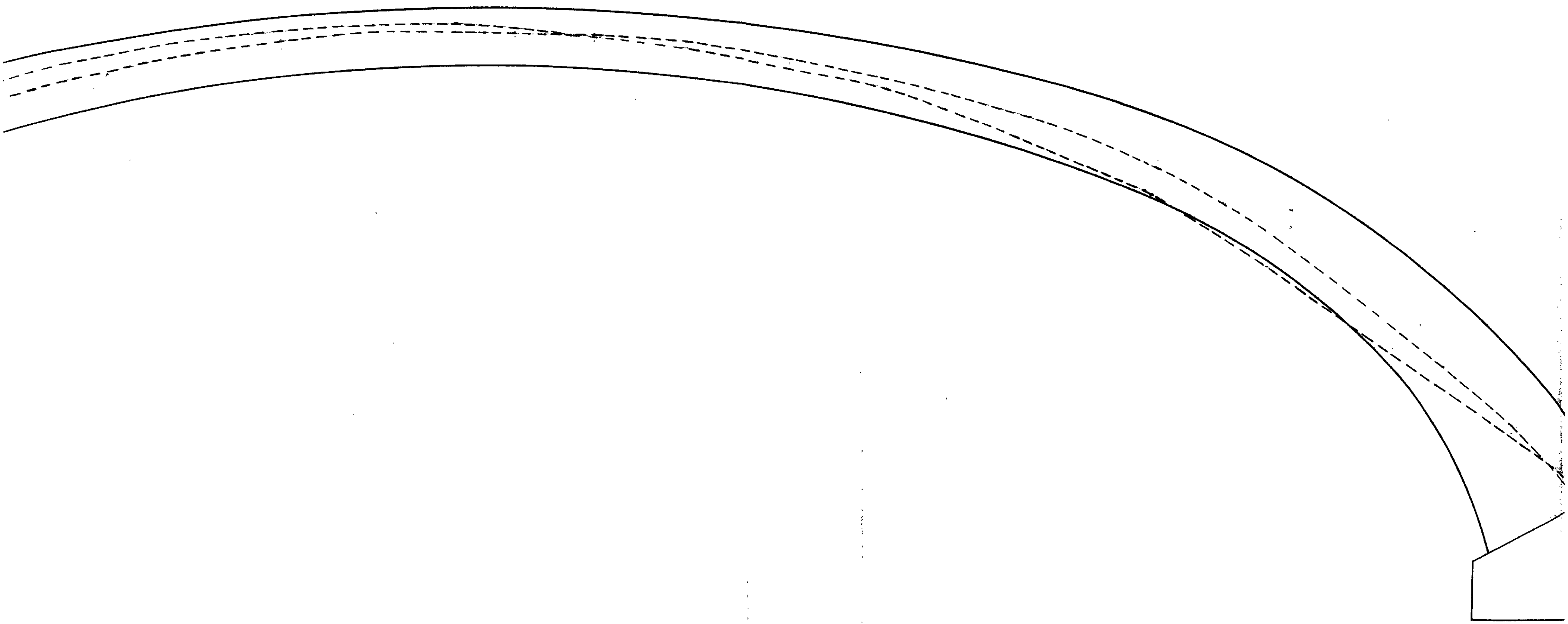
$$fc = \frac{91{,}200}{6 \times 4.75 \times 15.6} = 230^{\#}$$

$$fs = \frac{91{,}200}{.6 \times 15.6} = 9{,}730^{\#}$$

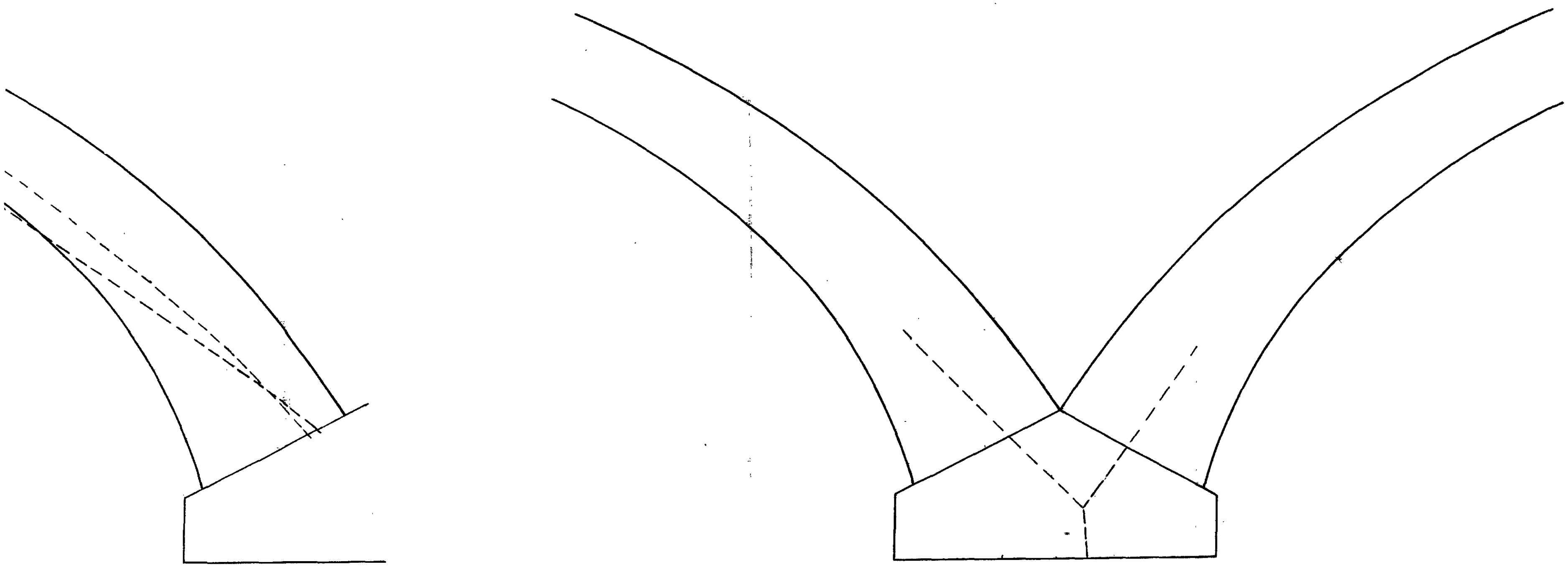
The Temperature rods to be as shown in drawings.



ARCH RING SHOWING LINES OF RES
FOR
FULL AND HALF LOADINGS.



ARCH RING SHOWING LINES OF RESISTANCE
FOR
FULL AND HALF LOADINGS.



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