ANALYSIS OF AN UNSYMMETRICAL

REINFORCED CONCRETE

ARCH

This thesis is respectfully submitted

to the Civil Engineering Department

of the

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by

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Foreword

I would like to express my appreciation to Mr. W. Bintz City Engineer for the City of Lansing for his assistance, and also Professor Vedder and Professor Allen of the Civil Engineering Department of the Michigan Agricultural College. for thier aid given to the author.

BIBLIOGRAPHY

Hool, Vol. 3. On reinforced concrete.

Holl and Johnson. Concrete Engineers' Handbook.

Malcolm. Graphic Statics.

Howe. A Treatise on Arches.

The following pages deal with the analysis of an unsymmetrical reinforced concrete arch. The arch is one of two that form the main support of Elm Street Bridge of Lansing, Michigan.

The bridge was designed by W. Bintz now City Engineer of Lansing. The bridge was built by W. Marshall and Son of Grand Rapids During the year of 1921.

The author became intrested in the bridge and wanted to analysis the arch because he worked on the bridge through out the construction as General Superentendent, and because of his intrest in reinforced concrete design, more especially of bridges.

The bridge consists in the main of two 70'-0'' arches with an elastic pier, the arches are of reinforced concrete. The concrete used was a 1; 3;4 mixture. The steel used was obtained from the Carnaige Steel Company and was therefore good steel. Most of the gravel was obtained from Battle Creek, that of the local pits being reject. The concrete was mixed on one side of the river and was transported by means of carts to where it was wanted.

A third of each arch was poured at a time, thus making of each practically three separate arches, the concrete was put in layers over the entire stretch thus preventing unequal settlement of the falsework, the concrete was well tamped around the steel in order to insure a good bond. During the process of pouring the two arches were bulkheaded off at the center of the pier so it was only necessary to work on one arch at a time.

The width of the arch is 42'-0" and beyond this is a 5'-5" of sidewalk, the total width of the sidewalk being 8'-3". There are posts inside of the spandrel wall connecting the sidewalk to the arch which takes care of the cantilever effect of the walk.

The elevation at the crown is I30.00, the elevation at the highest point of the intrados is I29.00 making a thickness of the arch ring at the crown of I.33' or I6". The thickness at the abutment springing line is 6'-4", the elevation at the abutement springing line isIII,45 making a rise of I7.55'.

The arch is a three centered curve, the radius being shown on blue print No. 2. The distance from the springing line (outside) to the crown point is 398 , should the arch have been made a symetrical arch its dimensions would be 78'-0", the arch is therefore 8'-00"

short of being a symmetrical arch.

In analysing this arch the method that the author first used is found in Hool vol. 3 of Reinforced Concrete, this method is part of the elastic theorie. Instead of taking the total load, unite loads were taken at definite points. The first thing that was done was to get the $\frac{s}{I}$ divisions, this was done by the graphical method. The unite loads were then placed at the center of gravity of these divisions and moments for a load at each section were then found about the crown section.

As the author worked these thru according to the formulas he found that the only value that came out as it should was H_c, the values of V_c were allright for half of the arch but they then became too irreguler, the values of M_c were negative for the first three divisions and they then started to increase and kept increasing over the remaining part of the arch. All of these values when plotted should show reguler curves and should decrease to zero at each springing line.

My computations were checked over about fifteen times but no mistake could be found, as the time was getting short the author then turned to the graphical solution of the arch. The method used in Hool and Johnson's Concrete Engineers Hand Book was first tried but the line of thrust fell below the arch. As there are a million Funiculars polygons to a problem there is only one that ~~fits~~ fits any case. The one that had to fit the case of the unsymmetrical arch was to pass the polygon thru three points, the two springling lines and the crown. The method used is on the following page.

at B'. Then FB' and B'A represent the reactions of the forces to the left of b, acting thru the points b and a respectfully. Point C' is common to all force polygons for the given system of forces, and point B' is common to all force polygons for the forces to the left of b. From the points C' and B', draw the lines respectively parallel to ac (the line connecting of the given points a and c) and ab, intersecting at O. Then these lines are the dividing lines corresponding to the closing strings of the required funicular polygon, and there intersection O will determine the pole forthis polgon. With this pole O , commence at a, and draw the required funicular polygon, which must pass thru the three given points a, b, c,. For, if the pole O is on the line C'O , the funicular polygon must pass thru the points a and c; and if it is on the line B'O , the funicular polygon must pass thru the points a and b.

Note :- This page should follow the next

METHOD

The problem is to draw the Funicular Polygon through three given points, the two springing lines and the crown.

The vertical load line represents in magnitude and direction a system of forces which are the weights of the different divisions of the reduced load line conture and passing thru there center of gravity,

Take any pole O', and draw the rays. Commencing at a construct the funicular polygon and close the polygon by drawing the closing ray. From the pole O' draw the dividing ray O'C' cutting the equilibrant Of the forces,at C'.Then DC'and C'A represents the
two reactio
two reactions whose line of actions are ec' and c'a, and which passthrough c and a respectfully. Now draw the line D and A which in this case is vertical, which represents the equilibrant of the forces to the left of b. Through b draw the line bb' parallel to DA , connect the points a b', and the points a and b by the lines ab' and ab, which are the closing strings of the funicular polygon for the forces to theleft of b. Through O', draw the dividing ray O' B' parallel to ab' cutting the load line

SPECIFICATIONS

Dead loads.

The dead load shall consist of the computed weight of the material used in the construction. In determining weights the following units will be assumed.

Pavements (including base)	I30 # / sq. ft.
Reinforced Concrete	I50 # / sq. ft.
Earth fill	I00 # / sq. ft.
Gravel and Broken stone	I30 # / sq. ft.

Live loads.

Whichever of the following liveloads as will give the maxium stresses.

A. Concentrated live loads.

Motor trucks of the following dimensions and weights occupying as much of the riadway as is necessary for maxium stresses.

Total weight	40,000 lbs.
Weight on rear axles	28,000 ".
Distance bet een axles	I2 ft.
Width of tread of rear wheels	24 in.
Distancebetween centers of rear wheels	6 ft.
Distance betwee	

Road space occupied, width 10 ft.

Length space " . " 30 ft.

B. Uniformly Distributed Live Load.

One hundred forty (140) pounds per square foot. The above uniform loading may be assumed to occupy all or such portions of the roadway area not occupied by the motor truck loading as in necessary maximum stresses.

Temperature.

Stresses due to an average temperature variation of 60° shall be provided for. When temperature stresses are added to dead and live loads stresses the allowable unit may be increased 25%.

Impact.

For concrete arches with spandrel filled of one foot or more no allowable impact shall be added.

On concrete slabs, girders and open spandrel arches allow 25%.

Distribution of Concentrated Loads Through Earth Filles.

Concentrated loads on earth fillings two feet or more in depth shall be assumed to be uniformly distributed over an area the side of which is equal to the widthof the concentrated load plus the depth of the filling.

UNIT STRESSES

Unite stresses shall not exeeed the values given in the following tables for the class of concrete indicated.

Class A	concrete	I:I½:3 mix
" B	"	I:2:4 "
" C	"	I;2½:5 "

	Class of Concrete		
	A	B	C
	Lbs: per sq. in.	Lbs: per Sq. in.	lbs: per sq. in.
Concrete in compression (flexural stresses)	800	650	500
Bearing on concrete (where surface to which load is applied at least two times the loaded area)	875	700	550
Axial compression on plain concrete sections of members whose length is less than six times the least diamention.	575	450	350
Shear, used as a measure of diagonal tension, on plain concrete sections.	50	40	35
Punching Shear	I50	I40	95

	Class of Concrete		
	A	B	C
	Lbs:per sq. in.	lbs:per Sq. In.	Lbs:per sq. in.
Shear, used as a measure of diagonal tension, on sections fully reinforced for diagonal tension in excess of that allowed on plain concrete.	I50	I20	95
Bond on plain bars	I00	80	65
Bond on deformed bars	I25	I00	80
Ratio of Moduli of Elasticity steel to concrete "n"	I2	I5	I5
Concrete in tension	0	0	0
Steel in tension		I6,000#/ sq. in.	

Steel in compression (where imbedded in concrete) is "n" times the stress in surrounding concrete and in no case should exceed I6,000#/ sq. in.

CONCLUSION

The author has shown by the use of the graphical theory that the arch is safe on the right side of the crown section, while on the left side the line of thrust does not pass thru the middle third and therefore it shows an unsoundness in the arch. But, this can be accounted for because this theory only applies to plain concrete arches, there fore if this arch had of been made of only concrete it would of been much thicker.

The weakness of the arch is shown in ~~compression~~ tension and this is taken care of by the use of a great deal of steel.

The author states that he found out that he did not know very much about analysis of a reinforced concrete arch and he will not be satisfied untill the arch has been analysed some other way. The amount of hours spent on this thesisprobably do not show much results but they have done the author a great deal of good.

COMPUTATIONS

Block No	I.	----- 2025 #	00	distance off center.
" "	2.	----- 2070 #	00	" " " .
" "	3.	----- 2I65 #	00	" " " .
" "	4.	----- 2I95 #	0.I	" " " .
" "	5.	----- 2420 #	0.I	" " " .
" "	6.	----- 2650 #	00	" " " .
" "	7.	------ 2790 #	0.I	" " " .
" "	8.	----- 3II5 #	00	" " " .
" "	9.	----- 3080 #	00	" " " .
" "	I0.	----- 4600 #	00	" " " .

These computations are for the right side of the crown. as shown the line of thrust follows very nearly the center of the arch showing that the arch is very safe.

Computations

Block	No I.	-------	7025 #	I.3' from middle third.
"	" 2.	-------	5430 #	I.2' " " " .
"	" 3.	-------	4020 #	I.25 " " " .
"	" 4.	-------	3960 #	I.25 " " " .
"	" 5.	-------	3550 #	I.2 " " " .
"	" 6.	-------	3000 "	I.0I " " " .
"	" 7.	-------	27I5 #	.8 " " " .
"	" 8.	-------	2475 #	.8 " " " .
"	" 9.	-------	2295 #	.5 " " " .
"	" I0.	-------	2I20 #	.4 " " " .
"	" II.	-------	2050 #	.3 " " " .
"	" I2.	-------	2050 #	.I5 " " " .
"	" I3	-------	I980 #	.00 " " " .

The computations are for the right hand side of thearch. as noted the first few blocks the line ofthrust are off considerable.

[redacted]

Pocket has: 4 Sheets