SURVEY AND DESIGN FOR UNDERPASS

FARM LANE AT GRAND TRUNK RAILROAD

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

W. Winston Pressley

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Survey and Design for

Underpass

Farm Lane at

Grand Trunk Railroad

A Thesis Submitted to

The Faculty of

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of

AGRICULTURE AND APPLIED SCIENCE

by

W. Winston Pressley

Candidate for the Degree of

Bachelor of Science

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THESIS

This Thesis is Dedicated to

My Father

PREFACE

This thesis has been written primarily for the author's benefit. In it, through contact with design factors with which he was previously unacquainted, he has widened his scope regarding the basic design features of the reinforced concrete rigid frame bridge.

In addition, the choice of an actual location makes it possible that at some time certain of the data compiled herein may be of use in construction at that point.

Grateful acknowledgment is made to Cornell D. Beukema who cooperated in the survey work and to Prof. Chester L. Allen and Instr. Kenneth W. Cosens for their assistence with various design problems.

W. WINSTON PRESSLEY

June 1943

INTRODUCTION

Although present conditions do not necessarily call for a complete grade separation at the Grand Trunk Railroad and Farm Lane crossing, the future plans for widening and paving of the highway point toward a structure built to improve speed and safety at this point.

A preliminary examination of the land surrounding the crossing indicates that, due to the lowness of the grade to the north of the bridge, the logical method of grade separation is to pass the highway beneath the existing railroad.

The choice of the rigid frame concrete bridge type for this job was made without too much hesitation. Many factors pointed directly to the rigid frame as the likely answer to the designer's question "What type should I use?"

Since the first appearance in construction circles in 1922 this bridge has demonstrated its excellent qualities under various conditions. During this period more than three hundred of them have been constructed and have given full service.

One of the prime factors in its favor is that it is generally simpler and more economical to build a concrete bridge continuous than otherwise.

Another benefit is derived from its continuity or rigidity. Due to the small moments in the sections near the center of the deck, the frame sections can be reduced and the bridge floor made exceptionally shallow at the center of the span. This was a large factor in this case because of the flat topography at the location, the limited headroom caused thereby, and the short distances allowable for approaches.

Also, the ultimate cost being low in the rigid frame bridge, this was applicable to the present case where an inexpensive bridge was desired.

These factors, together with the simple and pleasing external aspects of the rigid frame bridge make it <u>the</u> bridge for this location.

SURVEY

SURVEY

The surveying done on this job consisted of a preliminary survey or inspection in which it was decided that the highway should pass under the railroad, and a final profile and topo survey.

This part of the work was done in coordination with C. D. Beukema and is shown on DP 1 in the back of the thesis.

Photographs were also taken and these are shown on the following page.

Looking north along Farm Lane from crossing.

Looking southeast toward intersection.

DESIGN

DESIGN

The method of design used in this instance follows closely that outlined by A. G. Hayden in his book "The Rigid Frame Bridge" Second edition. Mr. Hayden's design method is used by many designers due to its use of simple formulas and equations to solve for the stresses, etc.

This bridge has free hinges at the top of the abutment footings. This simplifies the design work and insures a more uniform pressure on the footings than if the no-hinged method had been used.

A fifty foot clear span was decided upon so as to allow for widening and improving of Farm Lane. Fourteen feet was used as the minimum clearance as specified by the state highway department, while slopes and grades also follow the same specifications.

The railroad tracks are bedded on a one-foot gravel base over the concrete of the bridge to cushion the load.

Cooper's E-72 loading was used as the live load with allowance made for two tracks. Sixty percent of load was added for impact, but any effect due to side-sway or to wind was neglected as being of too little value to affect results.

Reinforcing steel with an f_s of 18,000 #/in.^{2} was used. In the superstructure a 3000 lb. concrete whose f_c was 1200 #/in.^{2} was used, while in the footings a 2000 lb. concrete was sufficient.

Although the railroad and highway do not meet at a right angle, the angle of skew is small enough to be neglected in the design according to Hayden.

The preliminary trial design data is shown in detail with the results of the final design following.

DESIGN OF SYMMETRICAL RIGID FRAME BRIDGE - HINGED ENDS

-*-

Clear Span - 50'

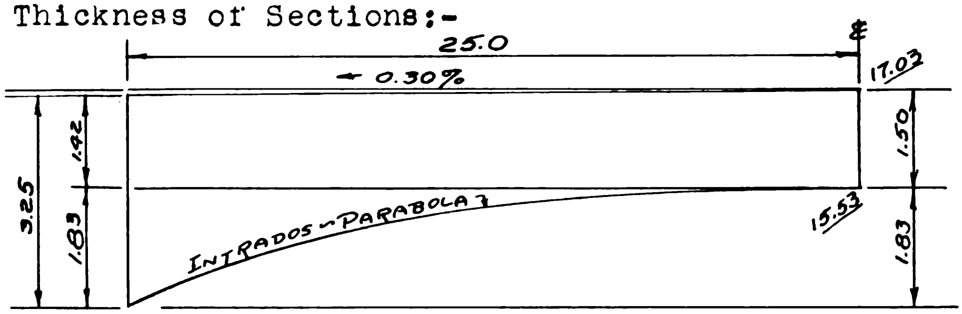
Angle of Crossing - 84° 30'

Knee Thickness - 3'-3" min. ; Ratio to span = 1/15.4

Crown Thickness - 1'-6" ; Ratio to span = 1/33.3

Curve of Intrados - Parabola

Thickness of Sections:-



Point #4 - Thickness at 45° 3.25' min.

Point #5 - 23.15 from L

Extrados $17.03 - (23.15 \times .003) = 16.96'$

Intrados $15.53 - \left(\frac{23.15}{25}\right)^2 \times 1.83 =$

13.97
2.99'

Point #6 - 20.0 from L

Extrados 16.97
Intrados 14.36
2.61'

Point #7 - 16.0 from L

Extrados	16.98
Intrados	14.78
	2.20'

Point #8 - 12.0 from L

Extrados	16.99
Intrados	15.11
	1.88'

Point #9 - 8.0 from L

Extrados	17.01
Intrados	15.34
	1.67'

Point #10 - 4.0 from L

Extrados	17.02
Intrados	15.48
	1.54'

Point #11 - at L

Thickness	1.50'

--*--

Point #1 -

$$\frac{2.25 \times 1.75}{13.45} \qquad \begin{array}{r} 1.50 \\ 0.29 \\ \hline 1.79' \end{array}$$

Point #2 -

$$\frac{6.75 \times 1.75}{13.45} \qquad \begin{array}{r} 1.50 \\ 0.88 \\ \hline 2.38' \end{array}$$

Point #3 -

$$\frac{10.75 \times 1.75}{13.45} \qquad \begin{array}{r} 1.50 \\ 1.40 \\ \hline 2.90' \end{array}$$

DEAD LOADS

Weights of substances:-

Concrete	150 Lb/Cu. Ft.
Gravel	110 Lb/Cu. Ft.

-*-

Point #1 - 1.79 x 5.0 x 150 = 1.3 Kip.

Point #2 - 2.38 x 4.0 x 150 = 1.4 Kip.

Point #3 - 2.90 x 4.0 x 150 = 1.7 Kip.

Point #4 - Areas
15.2 sq. ft x
150 +
1.55 sq. ft. x
100 = 2.6 Kip.

Point #5 - (2.99)(150) = 450 + 110 = (560)(2.3) = 1.3 Kip.

Point #6 - (2.61)(150) = 390 + 110 = (500)(4) = 2.0 Kip.

Point #7 - (2.20)(150) = 330 + 110 = (440)(4) = 1.8Kip.

Point #8 - (1.88)(150) = 280 + 110 = (390)(4) = 1.6 Kip.

Point #9 - (1.67)(150) = 250 + 110 = (360)(4) = 1.4 Kip.

Point #10- (1.54)(150) = 230 + 110 = (340)(4) = 1.4 Kip.

Point #11- (1.50)(150) = 225 + 110 = (335)(4) = 1.3 Kip.

DETERMINATION OF MOMENTS OF INERTIA (Units = Feet)

Pt.	t	I_c	x_e	A_{es}	I_{es}	x_i	A_{is}	I_{is}	I
1	1.79	.48	.68	.0165	.11	.68	.0030	.02	.61
2	2.38	1.12	.98	.0165	.24	.98	.0030	.04	1.40
3	2.90	2.03	1.24	.0165	.38	1.24	.0030	.07	2.48
4	3.25	2.86	1.42	.0165	.50	--	--	-	3.36
5	2.99	2.22	1.29	.0165	.41	1.29	.0030	.07	2.70
6	2.61	1.42	1.10	.0165	.30	1.10	.0030	.05	1.83
7	2.20	.89	.89	.0083	.10	.89	.0030	.04	1.03
8	1.88	.55	.73	.0083	.07	..73	.0083	.07	.69
9	1.67	.39	.63	.0083	.05	.63	.0083	.05	.49
10	1.54	.30	.56	.0083	.04	.56	.0165	.08	.42
11	1.50	.28	.54	.0083	.04	.54	.0165	.07	..39

$I_c = 1/12\ t^3$

$I_{es} = 15 \times A_{es} \times x^2_{es}$

Total $I = I_c + I_{es} + I_{is}$

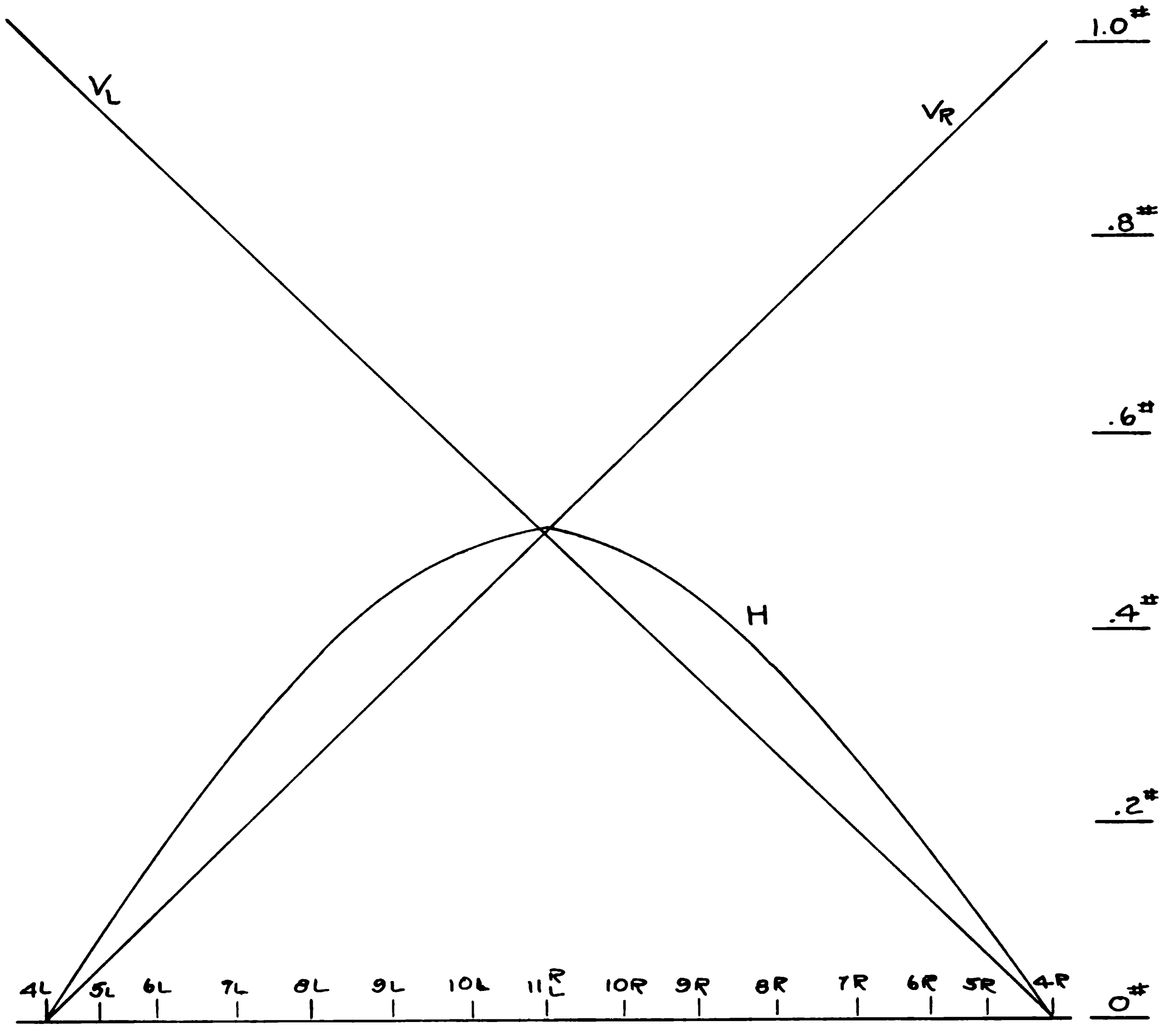
-*-

FRAME CONSTANTS

PT.	t	ds	I	$\frac{ds}{I}$	y	$y^2 \frac{ds}{I}$
1	1.79	5.0	.61	8.20	2.50	51.0
2	2.38	4.0	1.40	2.86	7.00	140.0
3	2.90	4.0	2.48	1.61	11.00	195.0
4	3.25	4.0	3.36	1.15	14.85	262.0
5	2.99	4.0	2.70	..85	15.47	203.0
6	2.61	4.0	1.83	2.19	15.67	537.0
7	2.20	4.0	1.03	3.88	15.88	977.0
8	1.88	4.0	.69	5.80	16.05	1492.0
9	1.67	4.0	.49	8.16	16.18	2136.0
10	1.54	4.0	.42	9.52	16.25	2514.0
11	1.50	4.0	.39	10.27	16.28	2720.0
						11227.0

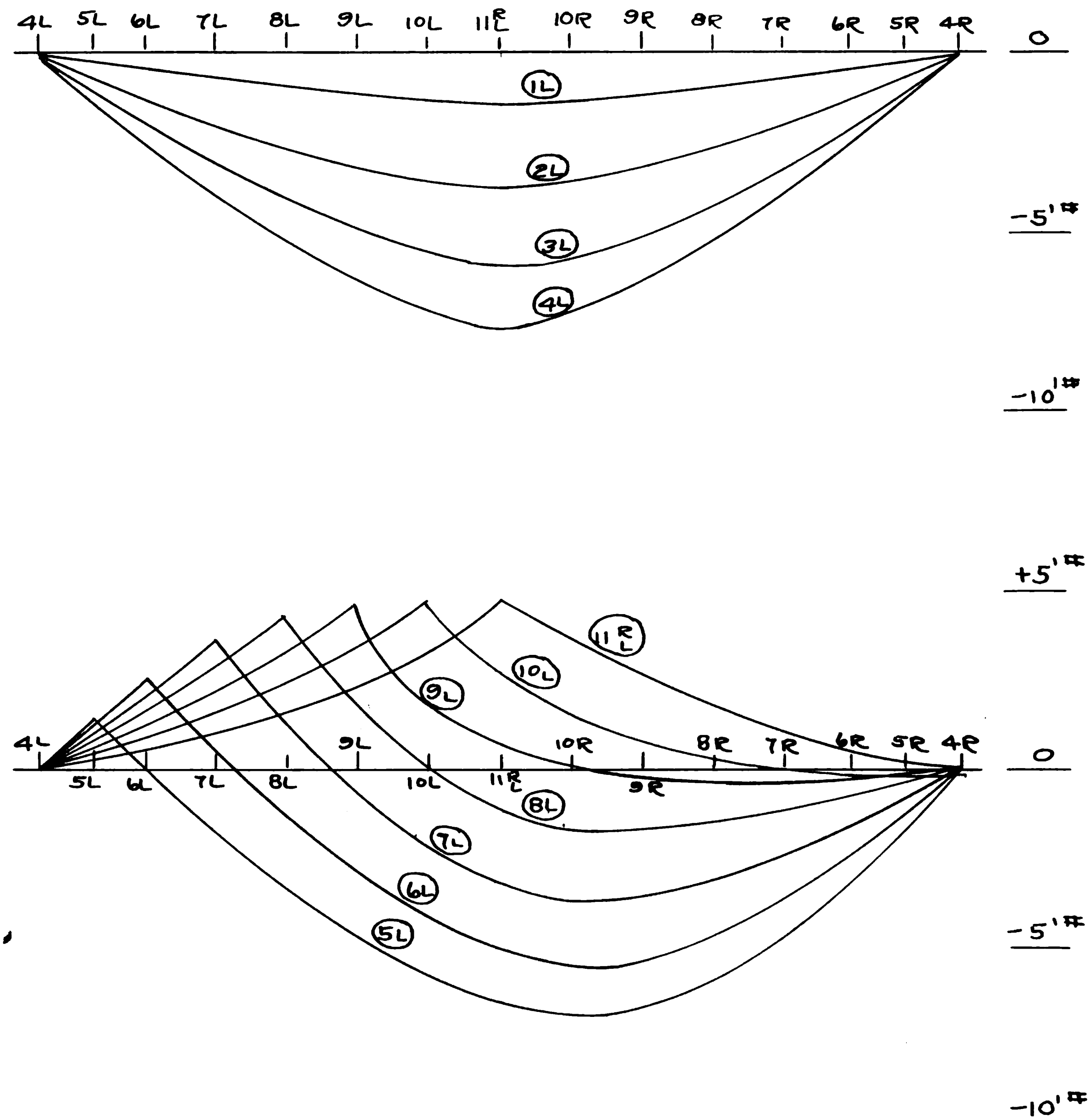
For 1/2 Frame - $\Sigma y^2 \frac{ds}{I}$ = 11,227.0 - 1/2 x 2720.0 = 9,867.0

For Full Frame - $\Sigma y^2 \frac{ds}{I}$ = 9,867.0 x 2 = 19,734.0



INFLUENCE LINES FOR H, V_R, & V_L

HORIZ. SCALE:- 1" = 10'
VERT. SCALE:- 1" = .2#



INFLUENCE LINES FOR MOMENTS

HORIZ. SCALE:- 1" = 10'

VERT. SCALE:- 1" = 5'#

DEAD LOAD MOMENTS (in'Kips)

Pt.	Load	Pt. 1L MF	Pt. 1L M	Pt. 2L MF	Pt. 2L M	Pt. 3L MF	Pt. 3L M
4L	2.6	- .1	- .3	- .4	-1.0	- .6	-1.6
5L	1.3	- .4	- .5	- .9	-1.2	-1.5	-2.0
6L	2.0	- .6	-1.2	- 1.5	-3.0	-2.4	-4.8
7L	1.8	- .8	-1.4	- 2.3	-4.1	-3.6	-6.5
8L	1.6	-1.0	-1.6	- 2.9	-4.6	-4.5	-7.2
9L	1.4	-1.2	-1.7	- 3.4	-4.8	-5.3	-7.4
10L	1.4	-1.3	-1.8	- 3.7	-5.2	-5.8	-8.1
11LR	1.3	-1.4	-1.8	- 3.8	-4.9	-5.9	-7.7
10R	1.4	-1.3	-1.8	- 3.6	-5.0	-5.7	-8.0
9R	1.4	-1.1	-1.5	- 3.2	-4.5	-5.0	-7.0
8R	1.6	-1.0	-1.6	- 2.7	-4.3	-4.2	-6.7
7R	1.8	- .7	-1.3	- 2.0	-3.6	-3.1	-5.6
6R	2.0	- .4	- .8	- 1.2	-2.4	-1.9	-3.8
5R	1.3	- .2	- .3	+ .6	+ .8	- .9	-1.2
4R	2.6	0	0	.1	.3	.1	.3
			-17.6		-49.1		-77.3

Pt.	Load	Pt. 4L MF	Pt. 4L M	Pt. 5L M	Pt. 5L MF	Pt. 6L MF	Pt. 6L M
4L	2.6	- .2	- .5	- .5	- .2	- .2	- .5
5L	1.3	-1.5	-2.0	1.8	1.4	1.0	1.5
6L	2.0	-2.8	-5.6	- .4	- .2	2.6	5.2
7L	1.8	-4.3	-7.8	-3.8	-2.1	.5	.9
8L	1.6	-5.7	-9.1	-5.9	-3.7	-1.5	-2.4
9L	1.4	-6.8	-9.5	-7.3	-5.2	-3.2	-4.5
10L	1.4	-7.5	-11	-8.4	-6.0	-4.3	-6.0
11LR	1.3	-7.7	-10	-8.4	-6.5	-5.0	-6.5
10R	1.4	-7.4	-10	-9.0	-6.4	-5.2	-7.3
9R	1.4	-6.7	-9.4	-8.4	-6.0	-5.0	-7.0
8R	1.6	-5.5	-8.8	-7.9	-4.9	-4.2	-6.7
7R	1.8	-4.1	-7.4	-6.7	-3.7	-3.1	-5.6
6R	2.0	-2.5	-5.0	-4.4	-2.2	-1.9	-3.8
5R	1.3	-1.2	-1.6	-1.6	-1.2	-1.0	-1.3
4R	2.6	.2	.5	.5	.2	.2	.5
			-97.1	-70.4			-43.7

DEAD LOAD MOMENTS (Con'd)

		Pt. 7L		Pt. 8L		Pt. 9L	
4L	2.6	- .1	- .3	- .1	- .3	- .1	- .3
5L	1.3	- .9	-1.2	.7	.9	.5	.7
6L	2.0	2.1	4.2	1.6	3.2	1.1	2.2
7L	1.8	3.6	6.5	2.7	4.9	2.0	3.6
8L	1.6	1.4	2.2	4.3	6.9	3.1	5.0
9L	1.4	- .6	- .8	2.0	2.8	4.4	6.2
10L	1.4	-2.1	-2.9	.1	.1	2.4	3.4
11LR	1.3	-3.1	-4.0	-1.2	-1.6	.7	.9
10R	1.4	-3.6	-5.0	-2.0	-2.8	- .4	- .6
9R	1.4	-3.7	-5.2	-2.3	-3.2	-1.0	-1.4
8R	1.6	-3.2	-5.1	-2.2	-3.5	-1.1	-1.8
7R	1.8	-2.5	-4.5	-1.7	-3.1	-1.0	-1.8
6R	2.0	-1.5	-3.0	-1.1	-2.2	- .7	-1.4
5R	1.3	- .7	- .9	- .6	- .8	- .4	- .5
4R	2.6	.1	.3	.1	.3	.1	.3
			-19.7		+1.6		+14.5

		Pt. 10L		Pt. 11L	
4L	2.6	0	0	0	0
5L	1.3	.2	.3	.1	.1
6L	2.0	.7	1.4	.2	.4
7L	1.8	1.3	2.3	.5	.9
8L	1.6	2.0	3.2	1.0	1.6
9L	1.4	3.1	4.3	1.7	2.4
10L	1.4	4.6	6.4	3.0	4.2
11LR	1.3	2.7	3.5	4.7	6.1
10R	1.4	1.3	1.8	3.0	4.2
9R	1.4	.4	2.0	1.7	2.4
8R	1.6	- .1	- .2	1.0	1.6
7R	1.8	- .3	- .5	.5	.9
6R	2.0	- .2	- .4	.2	.4
5R	1.3	- .1	- .1	.1	.1
4R	2.6	.1	.3	0	0
			+24.3		+25.3

DEAD LOAD THRUSTS (in Kips)

Pt.	Load	Pt. 1L NF	Pt. 1L N	Pt. 2L NF	Pt. 2L N	Pt. 3L NF	Pt. 3L N	Pt. 4L NF	Pt. 4L N	5L-11L NF	5L-11L N
1L	1.3	1.00	1.3								
2L	1.4	1.01	1.4		1.4						
3L	1.7	1.01	1.7		1.7		1.7				
4L	2.6	1.01	2.6		2.6		2.6	.71	1.8	-.01	0
5L	1.3	.95	1.2					.72	.9	.07	.1
6L	2.0	.89	1.8					.75	1.5	.16	.3
7L	1.8	.81	1.5					.77	1.4	.27	.5
8L	1.6	.73	1.2					.77	1.2	.36	.6
9L	1.4	.65	.9					.77	1.1	.44	.6
10L	1.4	.58	.8					.76	1.1	.49	.7
11LR	1.3	.50	.7					.71	.9	.50	.7
10R	1.4	.42	.6					.65	.9	.49	.7
9R	1.4	.35	.5					.56	.8	.44	.6
8R	1.6	.27	.4					.45	.7	.36	.6
7R	1.8	.19	.3					.33	.6	.27	.5
6R	2.0	.11	.2					.19	.4	.16	.3
5R	1.3	.05	.1					.09	.1	.07	.1
4R	2.6	-.01	0					0	0	-.01	0
3R	1.7	-.01	0					0	0	0	0
2R	1.4	-.01	0					0	0	0	0
1R	1.3	0	0					0	0	0	0
			+17.2		+15.9		+14.5		+13.4		+6.3

Points 1L - 3L incl.:- $NF = V_L$

Point 4L :- $NF = 0.71\ (H + V_L)$

Points 5L - 11L incl.:- $NF = H$

LIVE LOADS

Loading on 1' strip;

Cooper's E-72 loading.

Allowance for two tracks;

90% of load.

Allowance for impact;

60% of load.

No allowance made for wind or side-sway.

LIVE LOAD MOMENTS & THRUSTS

Load	Point 1L				Point 2L			
	MF	M	NF	N	MF	M	NF	N
2.6	-0.7	-1.8	.85	2.2	-1.9	- 5.0		
5.2	-1.1	-5.7	.70	3.6	-3.2	-16.7		
5.2	-1.3	-6.8	.60	3.1	-3.7	-19.3		
5.2	-1.3	-6.8	.50	2.6	-3.8	-19.8		
5.2	-1.3	-6.8	.40	2.1	-3.6	-18.7		
3.4	-0.9	-3.1	.23	0.8	-2.3	- 7.8		
3.4	-0.5	-1.7	.10	0.3	-1.2	- 4.1		
		-32.7		+14.7		-91.4		+14.7

Load	Point 3L				Point 4L			
2.6	-3.0	- 7.8			-3.5	- 9.1	.76	2.0
5.2	-5.0	-26.0			-6.3	-32.8	.78	4.1
5.2	-5.8	-30.2			-7.3	-38.0	.77	4.0
5.2	-5.9	-30.6			-7.5	-39.0	.71	3.7
5.2	-5.5	-28.6			-7.2	-37.4	.62	3.2
3.4	-3.7	-12.6			-4.9	-16.7	.39	1.3
3.4	-2.0	- 6.8			-3.7	-12.6	.18	.6
		-142.6		+14.7		-185.6		+18.9

Load	Point 5L				Point 5L			
5.2	1.3	6.8	.08	.4	-1.1	- 5.7	.22	1.1
3.4					-5.0	-17.0	.43	1.5
3.4					-6.1	-20.8	.49	1.7
3.4					-6.5	-22.1	.50	1.7
3.4					-6.0	-20.4	.44	1.5
2.6					-4.0	-10.4	.28	.7
5.2					-1.0	- 5.2	.06	.3
		+6.8		+.4		-101.6		+8.5

Load	Point 6L				Point 6L			
5.2	.2	1.0	.02	.1				
3.4					-4.0	-13.6	.47	1.6
3.4					-5.0	-17.0	.52	1.8
3.4					-5.2	-17.7	.47	1.6
3.4					-4.6	-15.6	.40	1.4
2.6					-2.3	- 6.0	.20	.5
5.2	2.5	13.0	.30	1.6				
		+14.0		+1.7		-69.9		+6.9

Load	Point 7L				Point 7L			
5.2	1.7	8.9	.14	.8				
5.2	3.5	18.2	.28	1.5				
5.2	.6	3.2	.40	2.1				
3.4					-2.8	- 9.4	.50	1.7
3.4					-3.8	-12.8	.48	1.6
3.4					-3.5	-11.8	.40	1.4
3.4					-2.8	- 9.4	.30	1.0
2.6					- .8	- 2.1	.08	.2
		+30.3		+4.4		-45.5		+5.9

LIVE LOAD MOMENTS & THRUSTS ([illegible]K'S)

Load	MF	M	NF	H	MF	M	NF	H
		Point 8L				Point 8L		
5.2	.8	4.2	.10	.5				
5.2	2.5	13.0	.26	1.4				
5.2	4.2	21.8	.36	1.9				
3.4					-1.8	-6.1	.50	1.7
3.4					-2.2	-7.4	.44	1.5
3.4					-2.0	-5.7	.32	1.1
3.4					-1.3	-4.4	.20	1.2
2.6	1.5	7.8	.46	2.4				
		+45.8		+5.2		-24.6		+5.5
		Point 9L				Point 9L		
5.2	1.5	7.8	.22	1.2				
5.2	2.8	14.6	.35	1.8				
5.2	4.3	22.4	.44	2.3				
5.2	2.0	10.4	.52	2.7				
3.4					- .8	-2.7	.47	1.6
3.4					-1.2	-4.1	.36	1.2
3.4					-1.0	-3.4	.22	.8
3.4					- .3	-1.0	.10	.4
		+55.2		+8.0		-11.2		+4.0
		Point 10L				Point 10L		
5.2	1.6	8.3	.32	1.7				
5.2	2.8	14.6	.43	2.3				
5.2	4.7	24.5	.49	2.6				
5.2	2.0	10.4	.52	2.7				
3.4			.43	1.5				
3.4					- .2	- .7	.32	1.1
3.4					- .2	- .7	.16	.6
2.6	.3	.8	.[illegible]1	.3				
		+5[illegible].6		+11.1		-1.4		+1.7
		Point 11L						
2.6	.3	.8	.21	.6				
5.2	1.2	6.3	.40	2.3				
5.2	2.6	10.5	.48	2.5				
5.2	4.8	25.0	.52	2.7				
5.2	2.5	13.0	.48	2.5				
3.4	.6	2.7	.32	1.1				
3.4	.2	.7	.16	.6				
		+[illegible].0		+12.[illegible]				

NOTE:- Loads are placed to give max. "[illegible]"; thrusts are determined from loads in same positions.

Points 1L-3L :- NF = V
Point 4L :- NF = 0.71(H-V)
Points 5L-11L :- NF = H

EARTH PRESSURES FROM LEFT

Pt.	M_A	X	M_B	Total M_A+M_B	$\frac{yds}{I}$	Total $(M_A+M_B)y\frac{ds}{I}$	H_y	M
1L	11.4	-.15	.1	11.5	20.50	236	- 2.5	9.0
2L	24.4	-.44	.3	24.7	20.02	495	- 7.1	17.6
3L	29.9	-.70	.4	30.3	17.71	536	-11.1	19.2
4L	31.5	-.40	.3	31.8	17.67	562	-15.0	16.8
5L	31.5	2.60	- 1.6	29.9	13.15	393	-15.6	14.3
6L	31.5	5.75	- 3.5	28.0	34.32	960	-15.8	12.2
7L	31.5	9.75	- 6.0	25.5	61.61	1570	-16.0	9.5
8L	31.5	13.75	- 8.4	23.1	93.09	2150	-16.2	6.9
9L	31.5	17.75	-10.8	20.7	132.03	2735	-16.3	4.4
10L	31.5	21.75	-13.3	18.2	154.70	2830	-16.4	1.8
11LR	31.5	25.75	-15.7	15.8	167.20	2640	-16.5	- .7
10R	31.5	29.75	-18.1	13.4	154.70	2075	-16.4	- 3.0
9R	31.5	33.75	-20.6	10.9	132.03	1440	-16.3	- 5.4
8R	31.5	37.75	-23.0	8.5	93.09	790	-16.2	- 7.7
7R	31.5	41.75	-25.5	6.0	61.61	370	-16.0	-10.0
6R	31.5	45.75	-27.9	3.6	34.32	124	-15.8	-12.2
5R	31.5	48.90	-29.8	1.7	13.15	22	-15.6	-13.9
4R	31.5	51.90	-31.7	- .2	17.67	4	-15.0	-15.2
3R	31.5	52.20	-31.8	- .3	17.71	5	-11.1	-11.4
2R	31.5	51.94	-31.7	- .2	20.02	4	- 7.1	- 7.3
1R	31.5	51.65	-31.5	0	20.50	0	- 2.5	- 2.5
						+19915		

$$H = \frac{-\Sigma M y \frac{ds}{I}}{\Sigma y^2 \frac{ds}{I}} = \frac{-19{,}915}{19{,}734} = -1.01\,K$$

THRUSTS ** EARTH FROM LEFT

Points 1L - 3L incl.:-	$N = V_L$ =	- .6 K.
Point 4L:-	$-N = .71(H-V_L) = .71(1.01-.61)$	+ .3 K.
Points 5L - 5R incl.:-	N = H =	+1.0 K.
Point 4R:-	$N = .71(H - V_L)$ =	+1.2 K.
Points 3R -1R incl.:-	$N = V_R$ =	+ .6 K.

THRUSTS ** EARTH FROM RIGHT

Points 1R - 3R incl.:-	N =	- .6 K.
Point 4R:-	N =	+ .3 K.
Points 5R - 5L incl.:-	N =	+1.0 K.
Point 4L:-	N =	+1.2 K.
Points 3L - 1L incl.:-	N =	+ .6 K.

RIB SHORTENING (From D. L. only)

(Refer to p. 120 of McCullough & Thayer's
Elastic Arch Bridges)

Approximate method

Sec.	N	Conc.	Area of Sec. Steel x 15	A	Unit Stress N ÷ A Kips/ft.²
1 R&L	16.3	1.79	.29	2.08	7.83
2 R&L	15.0	2.38	.29	2.67	5.62
3 R&L	13.6	2.90	.29	3.19	4.26
4 R&L	12.3	3.25	.25	3.50	3.51
5 R&L	5.6	2.99	.29	3.28	1.71
6 R&L	5.6	2.61	.29	2.90	1.93
7 R&L	5.6	2.20	.17	2.37	2.36
8 R&L	5.6	1.88	.25	2.13	2.63
9 R&L	5.6	1.67	.25	1.92	2.92
10 R&L	5.6	1.54	.37	1.91	2.94
½11 R&L	2.8	1.50	.37	1.87	1.50
					+37.21

$$F_{Ave} = \frac{37.21}{10.5} = 3.54 \text{ Kips/sq. ft.}$$

$$\frac{3540}{144} = \underline{24.6} \ \#/in^2$$

Rib shortening approximates temp. drop of t_{RS}.

$$T_{RS} = \frac{F}{E_c} = \frac{24.6}{2,000,000 \times .0000067} = \underline{1.84^\circ}$$

TEMPERATURE DROP

$$H = \frac{-E_c t L}{\Sigma y^2 \frac{ds}{I}} = \frac{-2,000,000 \times .0000067 \times (-40) \times 51.5 \times 144}{19,734.0} =$$

$t = -40°$

202 # = +.2 K.

MOMENTS FOR TEMPERATURE, RIB SHORTENING & SHRINKAGE

PT.	Temp Drop. 40°		Temp. Rise	R.S.	Shrink.
	y	M	M	M	M
1R&L	2.50	.5	- .5	0	.2
2R&L	7.00	1.4	-1.4	.1	.7
3R&L	11.00	2.2	-2.2	.1	1.1
4R&L	14.85	3.0	-3.0	.1	1.5
5R&L	15.47	3.1	-3.1	.1	1.5
6R&L	15.67	3.2	-3.2	.1	1.6
7R&L	15.88	3.2	-3.2	.1	1.6
8R&L	16.05	3.2	-3.2	.1	1.6
9R&L	16.18	3.3	-3.3	.2	1.6
10R&L	16.25	3.3	-3.3	.2	1.6
11R&L	16.28	3.3	-3.3	.2	1.6

THRUSTS FOR TEMPERATURE, RIB SHORTENING & SHRINKAGE

PT.	Temp. Drop.	Temp. Rise	R.S.	Shrink.
1R&L	0	0	0	0
2R&L	0	0	0	0
3R&L	0	0	0	0
4R&L	-.1	.1	0	0
5R&L	-.2	.2	0	-.1
6R&L	-.2	.2	0	-.1
7R&L	-.2	.2	0	-.1
8R&L	-.2	.2	0	-.11
9R&L	-.2	.2	0	-.1
10R&L	-.2	.2	0	-.1
11R&L	-.2	.2	0	-.1

DEAD LOAD SHEARS

Points 1L - 3L incl.	-6.2 K
Point 4L	2.8 K
Point 5L	10.2 K
Point 6L	8.9 K
Point 7L	66.9 K
Point 8L	5.1 K
Point 9L	3.5 K
Point 10L	2.1 K
Point 11L	.7 K

LIVE LOAD SHEARS

Points 1L - 3L incl.	-12.0 K
Point 4L	10.2 K
Point 5L	17.0 K
Point 6L	20.3 K
Point 7L	17.9 K
Point 8L	20.1 K
Point 9L	17.8 K
Point 10L	17.3 K
Point 11L	15.0 K

SHEARS FROM EARTH FROM LEFT

Point 1L,	$J = H_e - H - (.556 - .484)1.25 =$	+2.9 K
Point 2L,	J =	+1.0 K
Point 3L,	J =	- .2 K
Point 4L,	J =	-1.1 K
Point 5L-5R,	J =	- .6 K
Point 4R,	J =	+ .3 K
Point 3R-1R,	J =	+1.0 K

SHEARS FROM EARTH FROM RIGHT

Point 1L-3L incl.,	J =	-1.0 K
Point 4L,	J =	- .3 K
Point 5L-5R, incl.,	J =	+ .6 K
Point 4R,	J =	+1.1 K
Point 3R,	J =	+ .2 K
Point 2R,	J =	-1.0 K
Point 1R,	J =	-2.9 K

SHEARS FROM TEMPERATURE DROP

Points 1L - 3L incl.	J = H =	+ .2 K
Point 4L	J = .71H =	+ .2 K
Points 5L - 5R incl.	J = 0 =	0
Point 4R	J = -.71H =	- .2 K
Points 3R - 1R incl.	J = -H =	- .2 K

SHEARS FROM TEMPERATURE RISE

Points 1L - 3L,	J =	- .2 K
Point 4L,	J =	- .2 K
Points 5L - 5R,	J =	0
Point 4R,	J =	+ .2 K
Points 3R - 1R,	J =	+ .2 K

SHEARS FROM RIB SHORTENING

J = .046 x (Shears from temp. drop) = 0

SHEARS FROM SHRINKAGE

Points 1L - 3L	J =	+ .1 K
Point 4L	J =	+ .1 K
Points 5L - 5R	J =	0
Point 4R	J =	- .1 K
Points 3R - 1R	J =	- .1 K

DESIGN OF STIRRUPS

Pt.	Total shear +#	-#	d inches	v #/□"	v_s #/□"
1L		19,300	19.0	96.8	6.8
2L		19,300	26.1	70.5	0
3L		19,300	32.3	57.0	0
4L	13,600		36.5	35.5	0
5L	27,800		33.4	79.2	0
6L	29,800		28.8	81.8	0
7L	25,400		23.9	101.2	10.2
8L	25,800		20.0	122.5	32.5
9L	21,900		17.5	119.0	29.0
10L	20,000		16.0	119.0	29.0
11L	16,300		15.5	100.0	10.0

Shear to be taken by stirrups = Total unit shear - 90#/in^2

The allowable unit shear of 90#/in^2 for concrete was obtained from the table on page 401 of "Reinforced Concrete Structures" by Peabody using a 3,000 lb. concrete.

Total unit shear = $v = \frac{V}{bjd}$, Use $j = 7/8$.

$$A_s = \frac{V \times s}{f_s jd} = \frac{v_s bs}{f_s}, \qquad v_s = v - 90$$

$s = 12"$

$b = 12"$

$$A_s = \frac{v_s \times 12 \times 12}{18,000} = \frac{v_s}{125}$$

It may be seen from the above tabulated results that the unit shears are rather high and should be lowered.

CALCULATIONS FOR STEEL REINFORCEMENT

Pt.	Mom. Ft. Lb.	Mom. In. Lb.	N Lb.	e $\frac{M}{N}$	t in.	d t-2
1L	- 53,100	- 636,000	32,500	19.6	21	19
2L	-148,400	-1,780,000	31,200	57.2	29	27
3L	-232,300	-2,790,000	29,800	93.5	35	33
4L	-299,300	-3,590,000	33,900	105.8	39	37
5L	-187,400	-2,250,000	17,300	130.0	36	34
6L	-127,300	-1,530,000	17,000	90.0	32	30
7L	- 77,400	- 928,000	14,300	65.0	27	25
7L	- 43,000	- 516,000	12,800	40.4	27	25
8L	- 60,200	- 722,000	14,600	49.4	23	21
8L	- 35,500	- 426,000	13,900	30.6	23	21
9L	- 79,200	- 950,000	19,200	49.5	20	18
10L	- 89,800	-1,078,000	20,000	53.8	19	17
11L	- 89,400	-1,070,000	20,500	52.3	18	16

Pt.	e' $e-\frac{t}{2}-2$	$\frac{e'}{d}$	K $\frac{Ne'}{bd^2}$	f_c	f_s	Req. p	Req. A_s
1L	28.1	1.5	210	1150	18,000	.0055	1.25
2L	69.7	2.6	248	1240	18,000	.0110	3.56
3L	108.0	3.4	246	1290	18,000	.0115	4.56
4L	123.3	3.3	254	1320	18,000	.0120	5.32
5L	146.0	4.3	182	1060	18,000	.0093	3.79
6L	104.0	3.5	164	996	18,000	.0074	2.66
7L	76.5	3.1	146	935	18,000	.0062	1.86
7L	51.9	2.1	89	675	18,000	.0031	.90
8L	58.9	2.8	163	990	18,000	.0068	1.72
8L	40.1	1.9	105	765	18,000	.0034	.86
9L	57.5	3.2	284	1390	18,000	.0140	3.03
10L	61.3	3.6	354	1640	18,000	.0180	3.68
11L	59.3	3.7	395	1790	18,000	.0200	3.84

The above results show that the allowable f_c of 1200 is greatly exceeded in several instances and that, therefore, the first trial is unsatisfactory and an increase in design sections is required.

FINAL DESIGN

DATA

FINAL TRIAL

For the final trial the sections were increased in thickness to the values listed below.

Pt. #1 -	2.68'
Pt. #2 -	3.57'
Pt. #3 -	4.35'
Pt. #4 -	4.87'
Pt. #5 -	4.48'
Pt. #6 -	3.92'
Pt. #7 -	3.30'
Pt. #8 -	2.82'
Pt. #9 -	2.50'
Pt.#10 -	2.31'
Pt.#11 -	2.25'

Repeating the computations as in the preliminary trial using these new values for "t", new results were obtained. These results are shown in tabulated form on the following pages.

DESIGN OF STIRRUPS

Pt.	Total shear +#	-#	d inches	v	v_s	A_s Req.
1L		22,300	31	68.6	0	0
2L		22,300	41	51.8	0	0
3L		22,300	51	41.7	0	0
4L	14,900		57	24.9	0	0
5L	32,600		52	59.8	0	0
6L	34,000		45	72.0	0	0
7L	28,600		38	71.8	0	0
8L	28,200		32	84.1	0	0
9L	23,500		28	80.0	0	0
10L	20,600		26	75.6	0	0
11L	16,600		25	63.4	0	0

These results are satisfactory and show that stirrups are not needed in the frame reinforcement.

CALCULATIONS FOR STEEL REINFORCEMENT

Pt.	Mom. Ft. Lb.	Mom. In. Lb.	N Lb.	e $\frac{M}{N}$	t in.	d t-2
1L	- 61,500	- 740,000	41,800	17.7	33	31
2L	-172,400	-2,070,000	39,500	52.5	43	41
3L	-269,000	-3,230,000	37,000	87.4	53	51
4L	-343,200	-4,120,000	40,800	100.8	59	57
5L	-221,100	-2,540,000	20,800	124.0	54	52
6L	-148,400	-1,780,000	20,500	86.8	47	45
7L	- 43,600	- 525,000	16,300	32.2	40	38
7L	- 83,100	- 996,000	17,800	55.0	40	38
8L	- 62,100	- 746,000	17,400	42.8	34	32
8L	- 36,100	- 433,000	18,100	24.0	34	32
9L	- 87,100	-1,050,000	23,900	44.0	30	28
10L	- 97,900	-1,175,000	24,700	47.6	28	26
11L	-102,300	-1,230,000	24,200	53.0	27	25

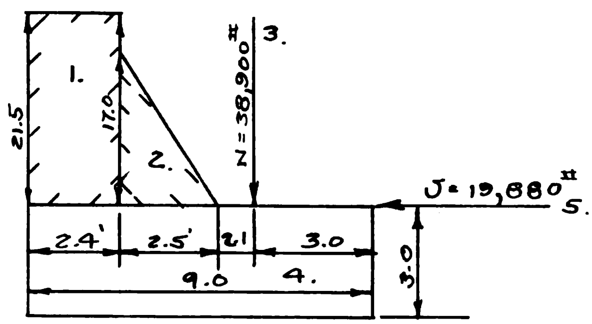
Pt.	e' $e-\frac{t-2}{2}$	$\frac{e'}{d}$	K $\frac{Ne'}{bd^2}$	f_c	f_s	Req. p	Req. A_s
1L	32.2	1.0	116	1150	18,000	.0007	.28
2L	72.0	1.8	141	890	18,000	.0043	2.12
3L	111.9	2.2	132	870	18,000	.0046	2.82
4L	128.3	2.3	135	860	18,000	.0050	3.42
5L	149.0	2.9	96	690	18,000	.0040	2.50
6L	108.3	2.4	92	650	18,000	.0035	1.90
7L	50.2	1.3	47	550	18,000	.0007	.34
7L	73.0	1.9	75	615	18,000	.0025	1.14
8L	57.8	1.8	84	640	18,000	.0026	1.00
8L	39.0	1.2	57	640	18,000	.0007	.29
9L	57.0	2.0	145	910	18,000	.0050	1.68
10L	59.6	2.3	182	1050	18,000	.0068	2.12
11L	64.5	2.6	208	1100	18,000	.0085	2.55

These results are satisfactory.

DESIGN

OF

ABUTMENT FOOTINGS



			Wt.	Arm.	Mom.'#
1.	21.5x2.4x100	=	5150	1.20	6,200
2.	17.0x2.5x½x100	=	2120	3.24	6,880
3.	N	=	38900	6.00	233,000
4.	3.0x9.0x150	=	4050	4.50	18,250
	Direct load P	=	50220		264,330
5.	J	=	-19,880x3.00		- 59,600
					+204,730'#

Sliding -- $\frac{19,880}{50,220} = \underline{.396}$ O.K.

Position of Resultant ---

$\frac{M}{P} = \frac{204,730}{50,220} = \underline{4.1'}$ to rt. of **A**

Eccentricity ----

$4.50 - 4.10 = \underline{.40}$

$\frac{P}{A} = \frac{50,220}{9} =$		-5,580	-5,580
$\frac{M}{s} = \frac{50,220x.4x6}{9x9} =$		+1,490	-1,490
		-4,090	-7,070

Design of Heel ---

$M = 52,260'\#$

$d = 26"$ Use 1" @ 8" $A_s = 1.50 in^2$

$p = \frac{1.50}{12 \times 26} = .0048$ $K = .315$

$J = .895$

$f_s = \frac{52,260 \times 12}{1.5x.315x.895} = 14,800\ \#/in.^2$ O.K.

$f_c = 2x14,800x = \frac{.0048}{.315} = 450\ \#/in.^2$ O.K.

Shear ---

$V = 21,630\ \#$

$v = \frac{21,630}{12x.895x26} = 77\ \#/in.^2$ O.K.

Bond ---

$u = \frac{21,630}{6x.895x26} = 154\ \#/in.^2$ O.K.

Toe design comes under the values of the heel design so the same steel is used.

Bearing of Shaft on Footing ---

$N = 38,900$ #

$$\frac{38,900}{144} = 270 \text{ \#/in}^2 \qquad \text{O.K.}$$

Dowels at top of footing ---

Total shear to be taken by dowels

$$A_s = \frac{19,880 \times 141}{18,000} = 1.50 \text{ in}^2$$

Use 1" ∅ @ 6" $A_s = 1.57 \text{in}^2$

WINGWALL DESIGN

The cantilever type of retaining wall was used in this design as the wingwalls.

The assumed dimensions were as follows:

heigth	21.5'
stem thickness	1.33'
base thickness	3.00'

Design ----

Base = 65%h = .65 x 21.5' = 14'

Earth pressure = $C_e \frac{wh^2}{2}$ = 4620#

Wt. of earth = 17,300#

Wt. of foundation = 6,300#

Live load surcharge ---

For Cooper's E-72 loading the side P is 300#/in.^{2}

This value combined with the earth pressure gives a total P of 5220#/in.^{2} acting at a point 7.15' above the base.

Point of application of vertical forces --

$$x = \frac{17,300 \times 9.33 \quad - \quad 6300 \times 7}{17,300 - 6300}$$

$$x = \underline{8.76'}$$

$$y = 7.15 \frac{5220}{23,600} = 1.58'$$

$$z = 8.76 - 1.58 = 7.18'$$

$$e = 7.18 - 7.00 = \underline{\quad .2' \quad}$$

$$p = \frac{23,600}{14} \left(1 \pm \frac{6x.2}{14}\right) = \begin{matrix} 1830^{\#} \text{ toe} \\ 1540^{\#} \text{ heel} \end{matrix}$$

$$f = \frac{23,600 \times .4}{5220} = 1.8$$

Stem ----

$$EP = \frac{0.27 \times 100 \times (18.5)^2}{2} = 4620\# \;+\; \text{Surcharge}$$

$$BM = 5220\ (6.2) = 32,400'\#$$

$$d = \frac{32,400 \times 12}{12 \times 164} = 14'' \quad \text{Add } 3'' = \underline{17}'' = D$$

$$v = \frac{5220}{12 \times 7/8 \times 14} = \underline{35}\ \#/in^2 \qquad \text{O.K.}$$

$A_s = .0094 \times 12 \times 12 = 1.35$ in.^{2}

Use 7/8" ∅ bars @ 5" $A_s = 1.44$ in.^{2}

$$u = \frac{5220}{(2.75 \times \frac{12}{5})7/8 \times 14} = \underline{65} \ \#/\text{in.}^2 \qquad \text{O.K.}$$

The heel and toe sections were also checked in the usual manner and the assumed dimensions were found to be satisfactory.

This concludes the basic design features of this problem and general views of the structure are shown in the accompanying drawings.

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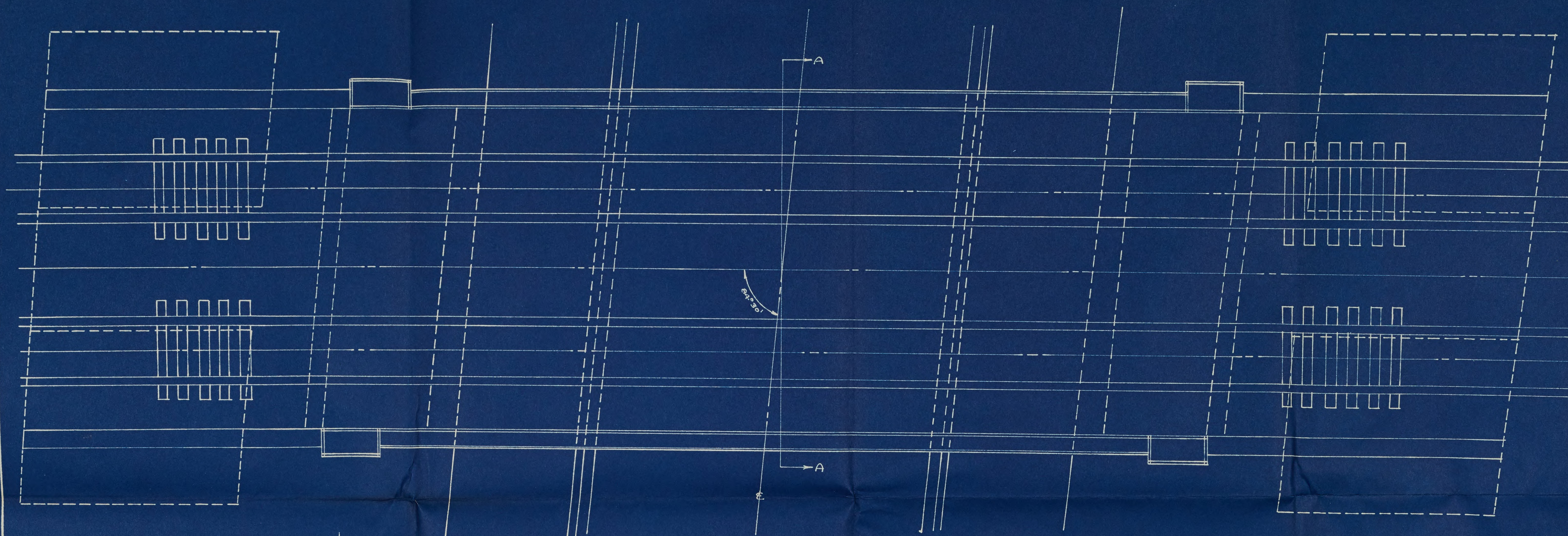
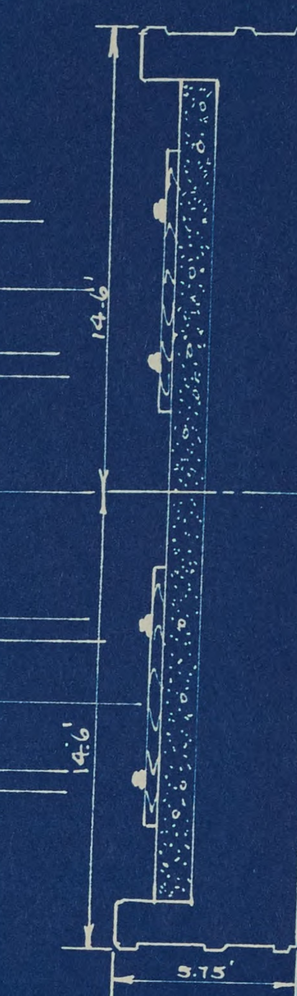
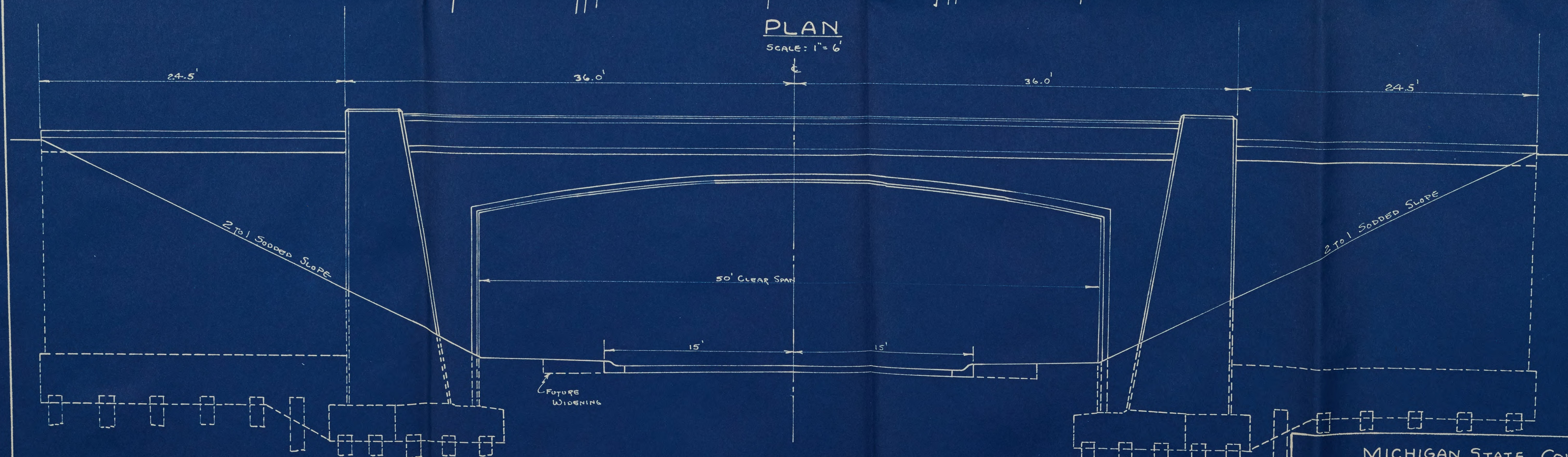


PLAN
SCALE: 1" = 6'



SECTION A-A



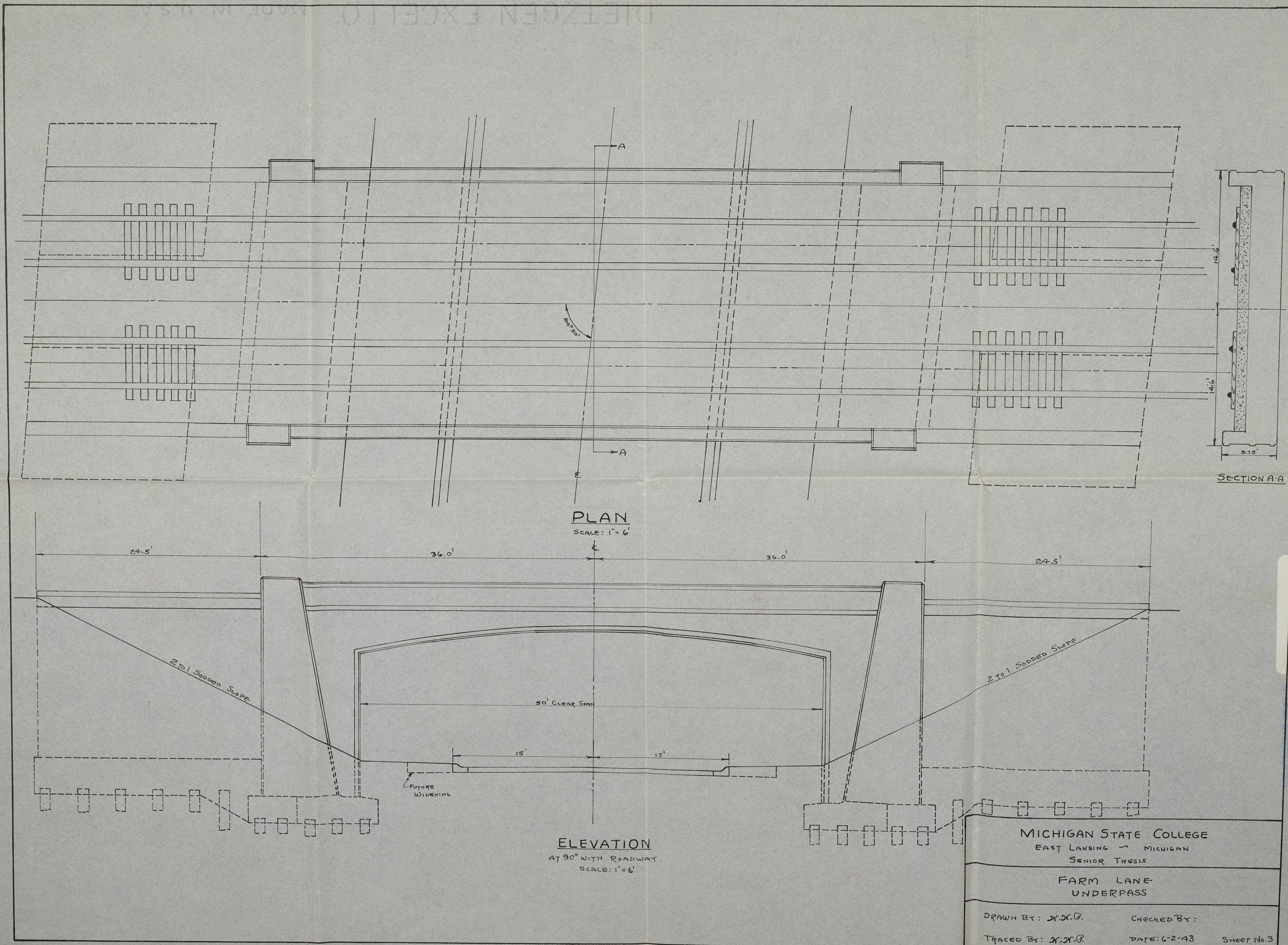
ELEVATION
AT 90° WITH ROADWAY
SCALE: 1" = 6'

MICHIGAN STATE COLLEGE
EAST LANSING — MICHIGAN
SENIOR THESIS

FARM LANE
UNDERPASS

DRAWN BY: N.N.P. CHECKED BY:

TRACED BY: N.N.P. DATE: 6-2-43 SHEET No. 3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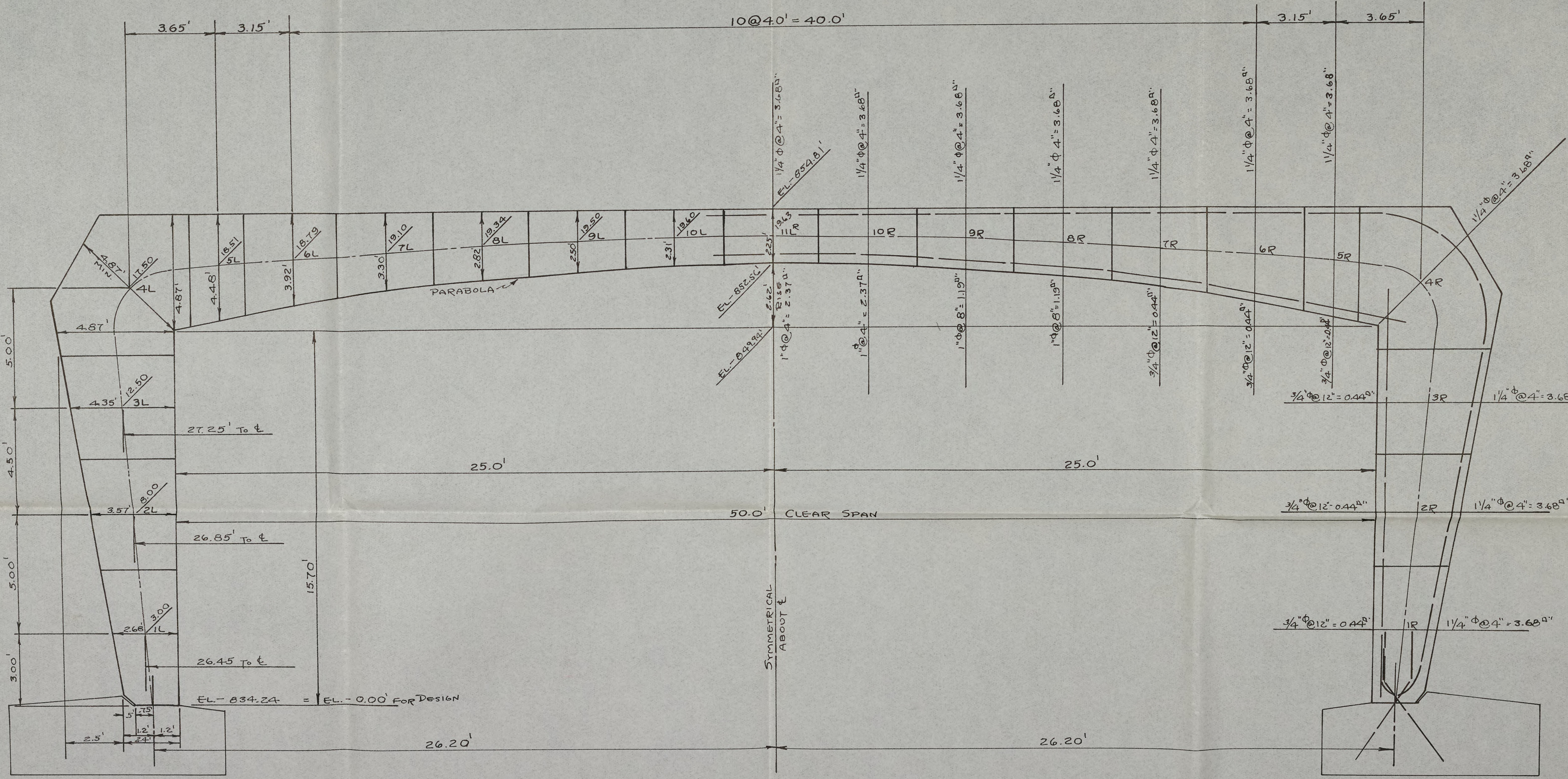
℄
14.6'
14.6'
5.75'
SECTION A-A
PLAN
SCALE: 1"=6'
℄
24.5'
36.0'
36.0'
24.5'
2 TO 1 SODDED SLOPE
2 TO 1 SODDED SLOPE
50' CLEAR SPAN
15'
15'
FUTURE WIDENING
ELEVATION
AT 90° WITH ROADWAY
SCALE: 1"=6'
MICHIGAN STATE COLLEGE
EAST LANSING — MICHIGAN
SENIOR THESIS
FARM LANE
UNDERPASS
DRAWN BY: H.H.B.
CHECKED BY:
TRACED BY: H.H.B.
DATE: 6-2-43
SHEET No. 3



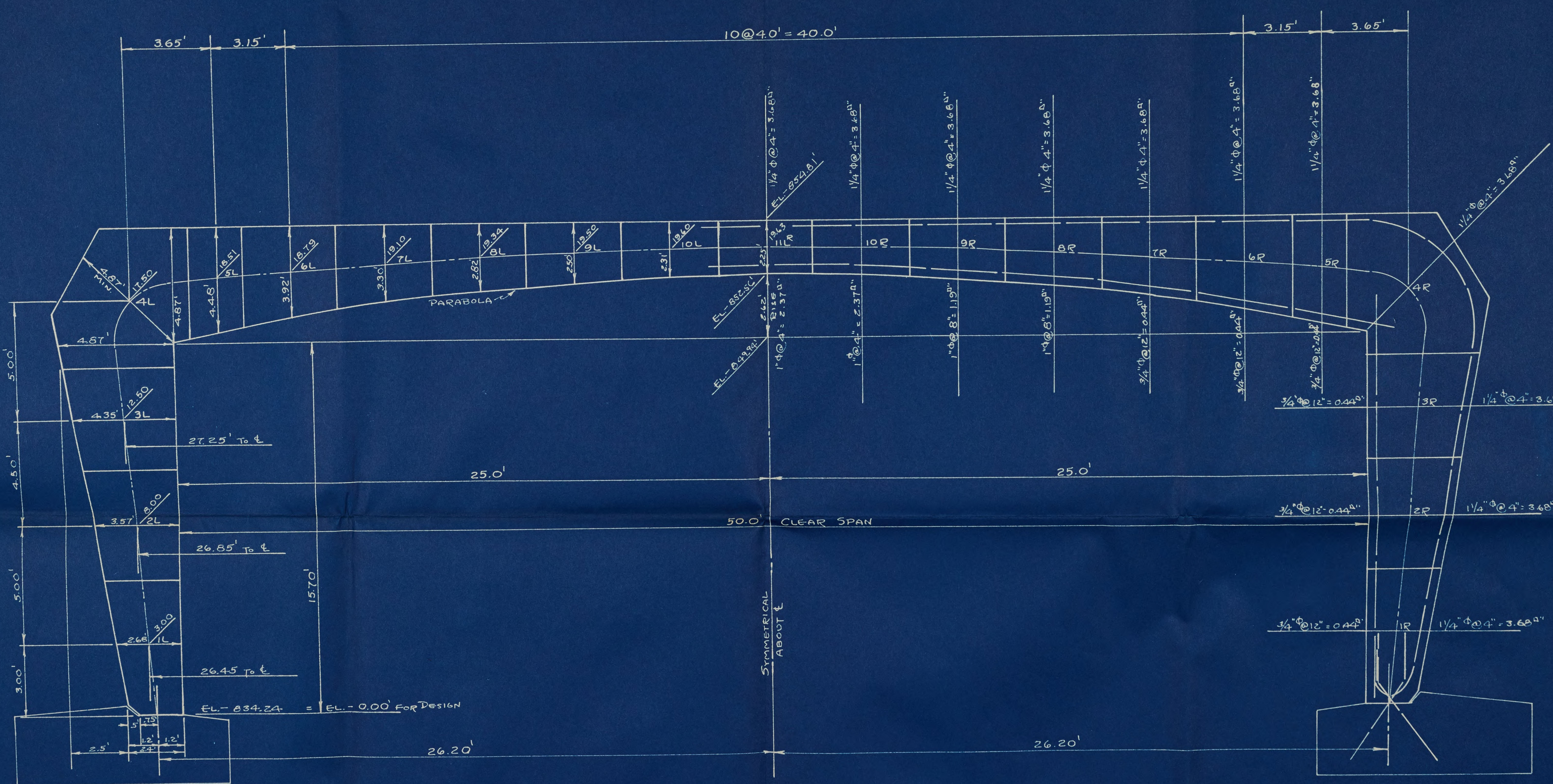
FRAME DESIGN

SCALE: 1" = 3'

MICHIGAN STATE COLLEGE
E. LANSING – MICHIGAN
SENIOR THESIS

FARM LANE
UNDERPASS

DRAWN BY – H. S. P.	CHECKED BY –
TRACED BY – H. S. P.	DATE – 6-2-43 SHEET No. 2



FRAME DESIGN

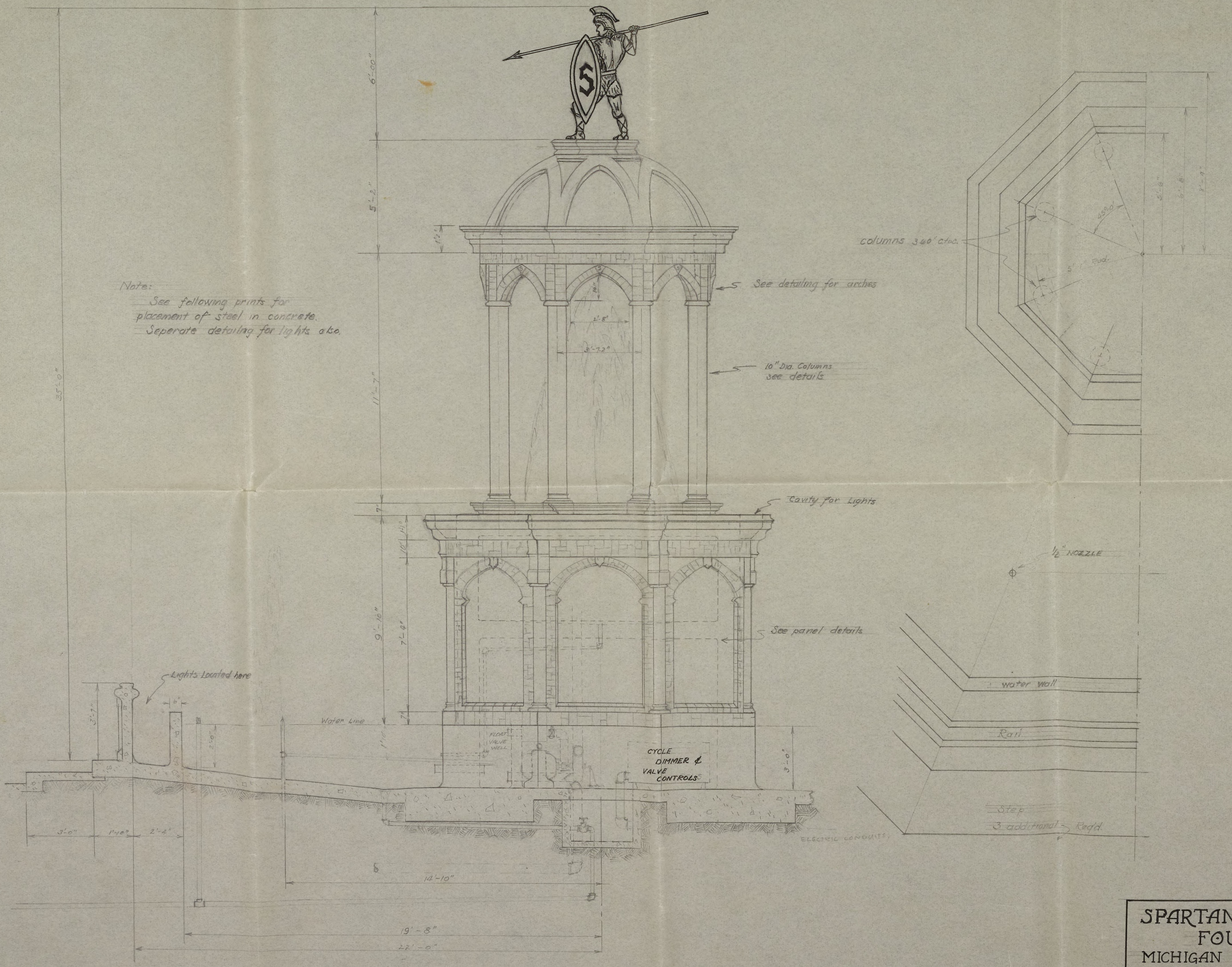
SCALE: 1" = 3'

MICHIGAN STATE COLLEGE
E. LANSING — MICHIGAN
SENIOR THESIS

FARM LANE
UNDERPASS

DRAWN BY - R.R.P. CHECKED BY -

TRACED BY - R.R.P. DATE - 6-2-43 SHEET No. 2



SPARTAN MEMORIAL FOUNTAIN

MICHIGAN STATE COLLEGE
EAST LANSING, MICH.

Leo V. Nothstine — December 1938

Scale 1" = 3'-0"	Sheet No. 1