DESIGN OF CONCRETE ARCH FOR CHILDSDALE ROAD ROCKFORD, MICHIGAN

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

Alan G. Davis

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DESIGN OF CONCRETE ARCH FOR CHILDSDALE ROAD

ROCKFORD, MICHIGAN

A Thesis Submitted to

The Faculty of

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of

AGRICULTURE AND APPLIED SCIENCE

by

Alan G. Davis

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DESIGN OF CONCRETE ARCH FOR CHILDSDALE ROAD

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This particular problem was choosen for a thesis because of the variety of design problems which must be dealt with. The wooden bridge which is being used at present is very unsafe for modern, or any traffic, as part of the timbers have started to decay. The bridge is only 16 feet wide between railings, thus making it a one way bridge. The floor has been patched in numerous places. The wooden railing is in very poor condition and gone entirely in some places. The floor slants making it very dangerous when slippery. The bridge is 160 feet long, and slopes slightly upward from the north end to a point just past the center where it dips sharply to the south end. A car coming on the bridge from either direction cannot see the road ahead until reaching the center of the bridge. It can be seen from this description that the bridge should be replaced before some accident takes place. The bridge passes over a Penna. Railroad track which is the main line between Grand Rapids and Mackinaw City. The angle of intersection formed by the road and the track is 27½ degrees. This means that the road runs nearly parallel to the railroad. The topography of the location makes a natural grade separation. The bridge is located 1 mile west and ½ mile south of Rockford on a township gravel road.

The bridge which was choosen to replace the present one is a segmental circular arch. This was choosen because of the beauty of its design and of its adaptability to this particular topography. The arch has a 14 foot rise and a 66 foot span. The approaches are nearly 60 feet long. These dimensions were arrived at after various designs had been tried in which the stresses developed were to high. The strength of the concrete to be developed in 28 days is 2500 lbs. per sq. in. This gives a working stress of 1000 lbs. per sq. in. The working stress of the steel is 20,000 lbs. per sq. in. The n for 2500 lb. concrete is 12. There is 4 feet of earth between the crown of the arch and the pavement. The pavement is of the same strength concrete and 1 foot thick. The live load used was 200 lbs. per sq. ft. In the stress analysis a temperature rise of 20 degrees and a fall of 60 degrees were allowed for. The highest stresses developed in the bridge under the worst possible conditions were 968 lbs. per sq. in. for the concrete and 18,480 lbs. per sq. in. for the steel. These stresses are within the allowable.

The retaining walls for the approaches are of two kinds; cantilever, and counterfort. At the end of the approaches wing walls run out parallel to the track. The wings are cantilever retaining walls. The railing is of metal with concrete posts and pilasters. There are two drains on each side of the bridge, one opposite each pilaster adjacent to the arch proper. The clear roadway is 18 feet. The sidewalks are $2\frac{1}{2}$ feet wide. The soil is sandy, the angle of internal friction 41 degrees and the bearing capacity 5 tons per sq. ft.

The calculations for this project appear in the following pages in blue-line prints. The drawings are in the folder in the back.

COMPUTATIONS OF CONCRETE ARCH
FOR CHILDSDALE ROAD

ROCKFORD — MICHIGAN

BY: A. G. D.

TRIAL ARCH

SPAN-66 FT.
RISE-14 FT.

CROWN SECTION -1.5 FT.
SPRINGING SECTION - 3 FT.

INTRADOS:

$$R = \frac{X^2 + Y^2}{2Y} = \frac{(33)^2 + (14)^2}{2 \times 14} = 45.90 \text{ FT.}$$

EXTRADOS:

$$R = \frac{(35.16)^2 + (13.41)^2}{2 \times 13.41} = 52.83 \text{ FT.}$$

ARCH AXIS:

$$R = \frac{(34.08)^2 + (13.70)^2}{2 \times 13.70} = 49.24 \text{ FT.}$$

REDUCED LOAD CONTOUR:

$4(.8)+1 = 4.2'$
$4.14(.8)+1 = 4.31'$
$4.62(.8)+1 = 4.70'$
$5.47(.8)+1 = 5.38'$
$6.63(.8)+1 = 6.30'$
$8.20(.8)+1 = 7.56'$
$10.17(.8)+1 = 9.14'$
$12.62(.8)+1 = 11.10'$
$15.60(.8)+1 = 13.48'$

WEIGHTS:

$$\frac{5.71+5.84}{2} \times 4.125 \times 150 = 3576\#$$

$$\frac{5.84+6.31}{2} \times 4.125 \times 150 = 3762\#$$

$$\frac{6.31+7.10}{2} \times 4.125 \times 150 = 4152\#$$

$$\frac{7.10+8.22}{2} \times 4.125 \times 150 = 4740\#$$

$$\frac{8.22+9.79}{2} \times 4.125 \times 150 = 5575\#$$

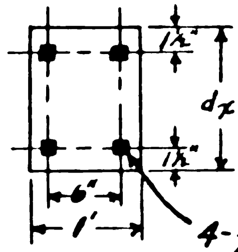
$$\frac{9.79+11.75}{2} \times 4.125 \times 150 = 6664\#$$

$$\frac{11.75+14.21}{2} \times 4.125 \times 150 = 8031\#$$

$$\frac{14.21+17.38}{2} \times 4.125 \times 150 = 9776\#$$

ARCH

$f'_c = 2500$ #/□"
$f_c = 1000$ #/□"
$n = 12$
$f_s = 20000$ #/□"
$p = 1\%$



4-$\frac{3}{4}$"# BARS
TOTAL AREA = 2.25 □"

AREA = $d_x + .1719$ □'

$I = \frac{d_x^3}{12} + .0430(d_x - .25)^2$

REDUCED LOAD CONTOUR:

4(.8)+1 = 4.20'	5.61(.8)+1 = 5.49'	11.23(.8)+1 = 9.98'
4.01(.8)+1 = 4.21'	6.66(.8)+1 = 6.33'	13.19(.8)+1 = 11.55'
4.29(.8)+1 = 4.44'	7.95(.8)+1 = 7.36'	15.34(.8)+1 = 13.27'
4.81(.8)+1 = 4.85'	9.50(.8)+1 = 8.60'	

WEIGHTS: SEE DRAWING

R (ARCH AXIS) = 49.24' $\theta = 43°53'$

Length of arch axis = 37.72'

Length of parts = 3.77'

SECT	Z_o	d_x	$d_x^3/12$	$.043(d_x-.25)^2$	I	Z_o/I	$1/I$
1	13.66	1.51	.2869	.06827	.35518	38.458	2.8155
2	13.38	1.54	.3044	.07156	.37592	35.592	2.6601
3	12.80	1.60	.3413	.07837	.41970	30.497	2.3826
4	11.94	1.69	.4022	.08917	.49140	24.297	2.0350
5	10.80	1.82	.5024	.10599	.60837	17.752	1.6437
6	9.39	1.97	.6371	.12721	.76433	12.285	1.3083
7	7.72	2.14	.8167	.15360	.97029	7.956	1.0306
8	5.80	2.37	1.1093	.19326	1.30260	4.453	.7677
9	3.63	2.60	1.4647	.23747	1.70214	2.133	.5875
10	1.23	2.87	1.9700	.29517	2.26516	.543	.4415
						173.966	15.6725

$$t = \frac{\Sigma \frac{Z_o}{I}}{\Sigma \frac{1}{I}} = \frac{173.966}{15.673} = 11.10'$$

SECT	X	$y = Z_o - t$	X^2/I	Y^2/I	$1/A$
1	1.89	2.56	10.057	18.451	.5945
2	5.64	2.28	84.617	13.828	.5841
3	9.37	1.70	209.189	6.886	.5643
4	13.04	.84	346.034	1.436	.5370
5	16.64	-.30	455.133	.148	.5020
6	20.13	-1.71	530.150	3.826	.4668
7	23.51	-3.38	569.640	11.774	.4325
8	26.75	-5.30	549.334	21.565	.3933
9	29.84	-7.47	523.121	32.783	.3607
10	32.75	-9.87	473.504	43.007	.3286
			3750.779	153.704	4.7638

DEAD STRESSES

SECT	$m_L + m_R$	$\frac{m_L + m_R}{I}$	$\left(\frac{m_L + m_R}{I}\right) Y$
1	1489	8384	21463
2	13667	72712	165783
3	38470	183322	311647
4	76214	310192	260561
5	127666	419698	-125909
6	192952	504892	-863365
7	272884	562480	-1901182
8	367399	564102	-2989741
9	476349	559706	-4181004
10	598327	528286	-5214183
		3713774	-14515930

$M_o = \frac{3713.774}{31.34} = 118.499^{k.ft.}$

$H_o = \frac{14515.930}{316.936} = 45.801^{k.}$

$M_c = 118.499 - 45.801 \times 2.60 = -.584^{k.ft.}$

$e = \frac{584 \times 12}{45801} = .153'' \text{ or } .0127'$ below axis

$M_s = -659.867 - 45.801 \times 13.69$
$= -30.851^{k.\ ft.}$

$T_s = 45.801 \times \cos 43°53' + 51.268 \times \sin 43°53'$
$= 68.549^{k.}$

$e = \frac{30851 \times 12}{68549} = 5.40''$ below axis

TEMPERATURE STRESSES:

$H_o = \frac{\phi t n E}{\Sigma \frac{Y^2}{I} + \Sigma \frac{1}{A}}$

FOR 60° FALL

$H_o = \frac{6 \times 10^{-6} \times 60 \times 10 \times 2.5 \times 10^6 \times 144}{158.468} = -8178^{\#}$

$M_c = 8178 \times 2.60 = 21263'^{\#}$

$T_s = 8178 \times .72075 = -5894^{\#}$

$M_s = 8178 \times 11.10 = -90776'^{\#}$

FOR 20° RISE

Divide by (-3)

UNIT LOAD AT A_L

SECT	$m_L = (m_L+m_R) = (m_L-m_R)$	$(m_L+m_R)\frac{1}{I}$	$(m_L-m_R)\frac{x}{I}$	$(m_L+m_R)\frac{y}{I}$
2	3.44	9.15	51.61	20.86
3	7.17	17.08	160.04	29.04
4	10.84	22.06	287.66	18.53
5	14.44	23.74	395.03	-7.12
6	17.93	23.46	472.25	-40.12
7	21.31	21.96	516.28	-74.22
8	24.55	18.85	504.24	-99.91
9	27.64	16.24	484.60	-121.31
10	30.55	13.49	441.80	-133.15
		166.03	3313.51	-407.40

UNIT LOAD AT B_L

3	2.77	6.60	61.84	11.22
4	6.44	13.11	170.95	11.01
5	10.04	16.50	274.56	-4.95
6	13.53	17.70	356.30	-30.27
7	16.91	17.43	409.78	-58.91
8	20.15	15.47	413.82	-81.99
9	23.24	13.65	407.32	-101.97
10	26.15	11.55	378.26	-114.00
		112.01	2472.83	-369.86

UNIT LOAD AT C_L

4	2.04	4.15	54.17	3.49
5	5.64	9.27	154.25	-2.78
6	9.13	11.94	240.35	-20.42
7	12.51	12.89	303.04	-43.57
8	15.75	12.09	323.41	-64.08
9	18.84	11.07	330.33	-82.69
10	21.75	9.60	314.40	-94.75
		71.01	1719.95	-304.80

UNIT LOAD AT D_L

5	1.24	2.04	33.95	-.61
6	4.73	6.19	124.60	-10.58
7	8.11	8.36	196.54	-28.26
8	11.35	8.71	232.99	-46.16
9	14.44	8.48	253.04	-63.35
10	17.35	7.66	250.87	-75.60
		41.44	1091.99	-224.56

UNIT LOAD AT E_L

6	.33	.43	8.66	-.74
7	3.71	3.82	89.81	-12.91
8	6.95	5.34	142.85	-28.30
9	10.04	5.90	176.06	-44.07
10	12.95	5.72	187.33	-56.46
		21.21	604.71	-142.48

UNIT LOAD AT F_L

8	2.55	1.96	52.43	-10.39
9	5.64	3.31	98.77	-24.73
10	8.55	3.77	123.47	-37.21
		9.04	274.67	-72.33

UNIT LOAD AT G_L

9	1.24	.73	21.78	-5.45
10	4.15	1.83	59.93	-18.06
		2.56	81.71	-23.51

INFLUENCE TABLE

Unit Load at	A_L	B_L	C_L	D_L	E_L	F_L	G_L
M_o	5.298	3.574	2.265	1.322	.677	.288	.081
H_o	1.285	1.167	.962	.708	.450	.228	.074
$V_o=V_R$	.442	.329	.229	.146	.081	.037	.011
V_L	.558	.671	.771	.854	.919	.963	.989
$-2.60H_o$	3.341	3.034	2.500	1.841	1.170	.593	.192
M_C	1.957	.540	-.235	-.519	-.493	-.305	-.111
$11.10H_o$	14.264	12.954	10.678	7.859	4.995	2.531	.821
$34.08V_o$	15.063	11.212	7.804	4.976	2.760	1.261	.375
	34.625	27.740	20.747	14.157	8.432	4.080	1.277
K_L	31.88	27.48	23.08	18.68	14.28	9.88	5.48
M_S(left)	2.745	.260	-2.333	-4.523	-5.848	-5.800	-4.203
M_S(Right)	4.499	5.316	5.139	4.205	2.912	1.558	.527
$H_o \cos\phi$	.926	.841	.693	.510	.324	.164	.053
$V_L \sin\phi$	.387	.465	.534	.592	.637	.668	.686
T_S (left)	1.313	1.306	1.227	1.102	.961	.832	.739
$H_o \cos\phi$	.926	.841	.693	.510	.324	.164	.053
$V_R \sin\phi$	.306	.228	.159	.101	.056	.026	.008
T_S (Right)	1.232	1.069	.852	.611	.380	.190	.061

$M_C = M_o - 2.60 H_o$

$M_S(\text{Left}) = M_o + 11.10 H_o + 34.08 V_o - K_L$

$T_S = V \sin\phi + H \cos\phi$

$M_S(\text{Right}) = M_o + 11.10 H_o - 34.08 V_o$

LIVE PANEL LOAD = 200 × 4.40 = 880#

MAXIMUM LIVE THRUST & MOMENT			
	LOADING	UNIT LOAD VALUES	LIVE LOAD STRESSES
MOMENT +	A_L, B_L, A_R, B_R	4.994	4395
AT CROWN -	C, D, E, F, G (R & L)	3.326	2927
H_o WITH $+M_c$		4.904	4316
H_o WITH $-M_c$		4.844	4263
MOMENT +	$A_L, B_L, A_R, B_R, C_R, D_R, E_R, F_R$ & G_R	27.161	23902
AT SPRINGING -	C_L, D_L, E_L, F_L, G_L	22.707	19982
THRUST $+M_s$		7.014	6172
THRUST $-M_s$		4.861	4278

STRESS SUMMARY & UNIT STRESSES								
CROWN		THRUST = H_c	MOMENT = M_c	e	e/h	L	f_c	f_s
MAX $+M_c$	DEAD	+45801	-584					
	LIVE	+4316	+4395					
		+50117	+3811	.91"	.051		255	
	TEMP	-8178	+21263					
	(FALL)	+41939	+25074	7.17"	.398	.132	586	
MAX $-M_c$	DEAD	+45801	-584					
	LIVE	+4263	-2927					
		+50064	-3511	.84"	.047		250	
	TEMP	+2726	-7088					
	(RISE)	+52790	-10599	2.41"	.134		362	

$P_o = .0104$

SPRINGING		THRUST = T_s	MOMENT = M_s	e	e/h	L	f_c	f_s
MAX $+M_s$	DEAD	+68549	-30851					
	LIVE	+6172	+23902					
		+74721	-6949	1.12"	.031		190	
	TEMP	+1965	+30259					
	(RISE)	+76686	+23310	3.65"	.101		261	
MAX $-M_s$	DEAD	+68549	-30851					
	LIVE	+4278	-19982					
		+72827	-50833	8.37"	.232	.110	356	
	TEMP	-5894	-90776					
	(FALL)	+67933	-141609	25.00"	.695	.1125	968	18480

$P = .0052$

EQUATIONS:

$$M_0 = \frac{\sum \frac{m_L + m_R}{I}}{2\sum \frac{1}{I}} \qquad H_0 = \frac{-\sum \frac{(m_L + m_R)y}{I}}{2\sum \frac{y^2}{I} + 2\sum \frac{1}{A}}$$

$$V_0 = \frac{\sum \frac{(m_L - m_R)X}{I}}{2\sum \frac{X^2}{I}} \qquad f_c = \frac{NK}{bt}$$

$$f_c = \frac{M}{Lbt^2} \qquad f_s = n f_c\left(\frac{d}{Kt} - 1\right)$$

ABUTMENT

WEIGHTS:

$$\frac{20.33 + 32.33}{2} \times 18 \times 120 = 56873^{\#}$$

$$\frac{22.50 \times 2.81}{2} \times 150 = 4742^{\#}$$

$$\frac{22.50 \times 7.18}{2} \times 150 = 12116^{\#}$$

$$\frac{20.28 \times 6.60}{2} \times 150 = 10039^{\#}$$

$$\frac{17.50 \times 1.90}{2} \times 150 = 2494^{\#}$$

EARTH PRESSURE

$$P_e = C_e \frac{wh^2}{2} \qquad C_e = .21 - \phi = 41^\circ \text{ (Rankin's)}$$

$$P_e = C_e w \frac{(H^2 - h_1^2)}{2} \qquad C_e w = .21 \times 120 = 25$$

$$= 25 \frac{(34.33^2 - 20.33^2)}{2} = 8566^{\#}$$

$$X = \frac{h^2 + 3hh_1}{3(h + 2h_1)} = \frac{14^2 + 3 \times 14 \times 20.33}{3(14 + 2 \times 20.33)} = 6.40'$$

SOIL STRESSES

Bearing Capacity = 5 tons/sq. ft.

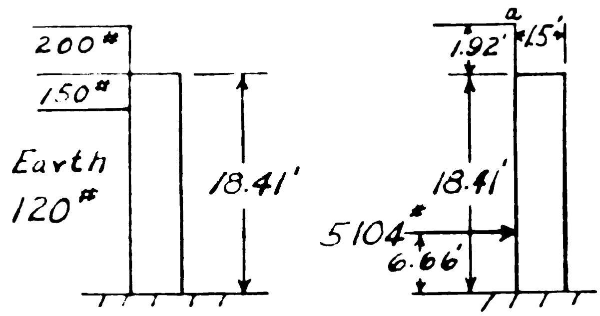
$$S = \frac{P}{A} \pm \frac{Mc}{I}$$

$$S = \frac{151300}{17} = 8900^{\#}/\square'$$

$$S = \frac{145700}{17} \pm \frac{145700 \times .40 \times 8.5}{410}$$

$$= 9768^{\#}/\square' - 7352^{\#}/\square'$$

ARCH RETAINING WALL



$C_e = .21 \quad C_w = 25$

$P = \frac{25 \times 20.33^2}{2} = 5150^{\#}$

$P_0 = \frac{25 \times 1.92^2}{2} = \frac{46^{\#}}{5104^{\#}}$

Mom about (a)

$5150 \times 13.55 = 46 \times 1.28 + 5104\, y$

$y = 13.67'$

$d = \sqrt{\frac{5104 \times 6.66}{164}} = 14.4''$ say $= 15''$ $D = 18''$

$A_s = .0094 \times 12 \times 15 = 1.70^{\square''}$ $\frac{7}{8}''\phi$ bars $4''$ C-C $A = 1.80^{\square''}$

$v = \frac{V}{b \cdot j \cdot d} = \frac{5104}{12 \times .875 \times 15} = 33^{\#}/^{\square''}$ OK $50^{\#}/^{\square''}$ allowable

$u = \frac{V}{\Sigma o \cdot j \cdot d} = \frac{5104}{8.25 \times .875 \times 15} = 47^{\#}/^{\square''}$ Use plain rods

Anchorage $= 40\,d = 35''$

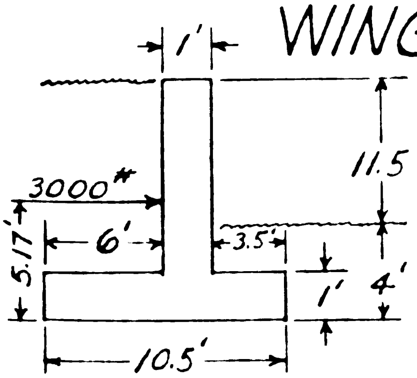
Temp. Steel

$.003 \times 18 \times 12 = .54^{\square''}$

$.2\%$ in front $= .36^{\square''}$ $\frac{1}{2}''\phi$ bars $6''$ C-C

$.1\%$ in back $= .18^{\square''}$ $\frac{1}{2}''\phi$ bars $12''$ C-C

WING WALLS



base $= .65 \times 15.5 = 10.1'$ say $10\frac{1}{2}'$

Toe $= \frac{1}{3} \times 10.5 = 3.5'$

$P = \frac{25 \times 15.5^2}{2} = 3000^{\#}$

Wt of earth $= 14.5 \times 6 \times 120 = 10440^{\#}$

Wt of stem $= 1 \times 14.5 \times 150 = 2175^{\#}$

Wt of base $= 1 \times 10.5 \times 150 = \underline{1573^{\#}}$

$14188^{\#}$

Pt. of application

$14188\,x = 10440 \times 7.5 + 2175 \times 4 + 1573 \times 5.25$

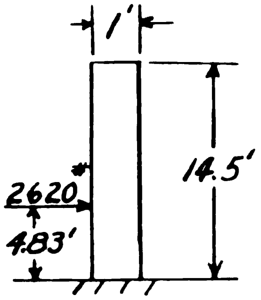
$x = 6.74'$

$\bar{x} = \frac{5.17 \times 3000}{14188} = 1.10'$ $\quad 6.74 - 1.10 = 5.64'$

$e = 5.25 - 5.64 = -.39'$ (to left of center)

$p = \frac{14188}{10.5}\left(1 \pm \frac{6 \times .39}{10.5}\right) = \begin{matrix} 1650 \text{ heel} \\ 1052 \text{ toe} \end{matrix}$

$f_s = \frac{14188 \times .4}{3000} = 1.9$



STEM

$P = \frac{25 \times 14.5^2}{2} = 2620^{\#}$

$d = \sqrt{\frac{2620 \times 4.83}{164}} = 8.8''$ say $9''$ $D = 12''$

$A_s = .0094 \times 12 \times 9 = 1.02^{\square''}$ $\frac{3}{4}''\phi$ bars $5''$ C-C $A = 1.06^{\square''}$

$v = \frac{2620}{12 \times .875 \times 9} = 28^{\#}/^{\square''}$ OK

$\mu = \frac{2620}{2.36 \times \frac{12}{5} \times .875 \times 9} = 60^{\#}/^{\square''}$ Use plain rods

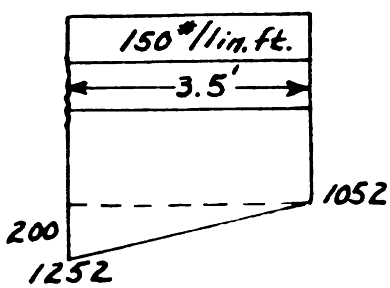
Anchorage = $40d = 30''$ in base

Temp. Steel

.2% in front – $\frac{1}{2}''\phi$ bars $6''$ C-C

.1% in back – $\frac{1}{2}''\phi$ bars $12''$ C-C

TOE



$BM = -\frac{150 \times 3.5^2}{2} + \frac{1052 \times 3.5^2}{2} + \frac{100 \times 3.5^2}{3} = 5938'^{\#}$

$d = \sqrt{\frac{5938}{164}} = 6.0''$ $D = 9''$

$V = 1000 \times 3.5 = 3500^{\#}$

$v = \frac{3500}{12 \times .875 \times 6} = 56^{\#}/^{\square''}$ Use $D = 12''$, $d = 9''$

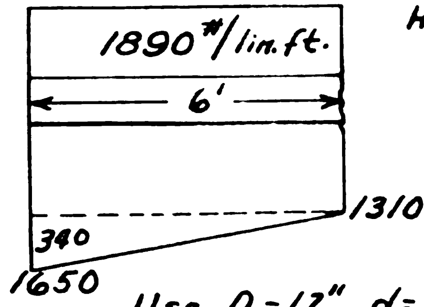
$v = \frac{3500}{12 \times .875 \times 9} = 37^{\#}/^{\square''}$ OK

$A_s = .0094 \times 12 \times 9 = 1.02^{\square''}$ $\frac{3}{4}''\phi$ bars $5''$ C-C $A = 1.06^{\square''}$

$\mu = \frac{3500}{2.36 \times \frac{12}{5} \times .875 \times 9} = 79^{\#}/^{\square''}$ Use plain rods

Temp. Steel – $\frac{1}{2}\phi$ bars $12''$ C-C Top & Bottom

HEEL



$BM = 580 \times 6 \times 3 - 340 \times 3 \times 4 = 6350'^{\#}$

$d = \sqrt{\frac{6350}{164}} = 6.2''$ say $7''$ $D = 10''$

$V = 410 \times 6 = 2460^{\#}$

$v = \frac{2460}{12 \times .875 \times 7} = 33^{\#}/^{\square''}$ OK

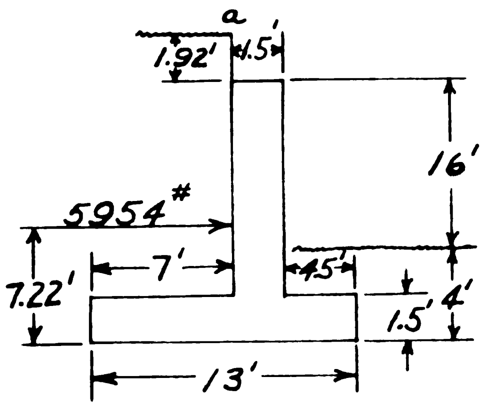
Use $D = 12''$, $d = 9''$ to make same as toe

$A_s = .0094 \times 12 \times 9 = 1.02^{\square''}$ $\frac{3}{4}''\phi$ bars $5''$ C-C $A = 1.06^{\square''}$

$\mu = \frac{2460}{2.36 \times \frac{12}{5} \times .875 \times 9} = 55^{\#}/^{\square''}$ Use plain rods

Temp. Steel – $\frac{1}{2}''\phi$ bars $12''$ C-C Top & Bottom

APPROACH WALLS
CANTILEVER WALL



$base = .65h = .65 \times 20 = 13.00'$

$Toe = \frac{1}{3} base = \frac{13}{3} = 4\frac{1}{3}'$ say $4.5'$

$P = \frac{25 \times 21.92^2}{2} = 6000^{\#}$

$P_{①} = \frac{25 \times 1.92^2}{2} = \underline{46^{\#}}$

$5954^{\#}$

Wt of base $= 13 \times 1.5 \times 150 = 2920^{\#}$

Wt of stem $= 18.5 \times 1.5 \times 150 = 4160^{\#}$

Wt of earth $= 20.42 \times 7 \times 120 = \underline{14300^{\#}}$

$21380^{\#}$

Mom. about (a)

$6000 \times 14.61 = 46 \times 1.28 + 5954\,y$

$y = 14.70'$

Pt. of application

$2920 \times 6.5 + 4160 \times 5.25 + 14300 \times 9.5 = 21380\,x$

$x = 8.25'$

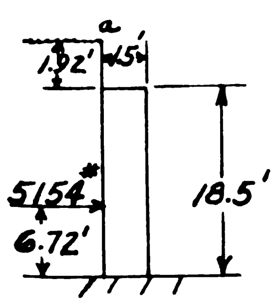
$\bar{X} = \frac{7.22 \times 5954}{21380} = 2.01'$ $\quad 8.25 - 2.01 = 6.24'$

$e = 6.50 - 6.24 = .26'$

$p = \frac{21380}{13}\left(1 \pm \frac{6 \times .26}{13}\right) = \begin{matrix} 1842^{\#/\square'} \text{ Toe} \\ 1448^{\#/\square'} \text{ Heel} \end{matrix}$

$f_s = \frac{21380 \times .4}{5954} = 1.5$ OK

STEM



$p = \frac{25 \times 20.42^2}{2} = 5200^{\#}$

$P_{①} = \underline{46^{\#}}$

$5154^{\#}$

Mom. about (a)

$46 \times 1.28 + 5154\,y = 5200 \times 13.61$

$y = 13.70'$

$d = \sqrt{\frac{6.72 \times 5154}{764}} = 14.51''$ say $15''$ $\quad D = 18''$

$A_s = .0094 \times 15 \times 12 = 1.70^{\square''}$ $\quad \frac{7}{8}''\phi$ bars $4''$ C-C $\quad A = 1.80^{\square''}$

$v = \frac{5154}{12 \times .875 \times 15} = 33^{\#/\square''}$ OK $\quad u = \frac{5154}{8.26 \times .875 \times 15} = 47^{\#/\square''}$ Use plain rods

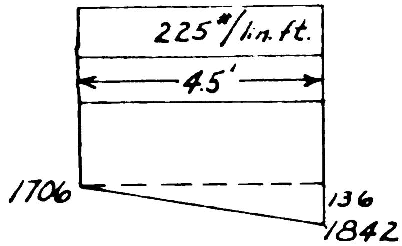
Anchorage $= 40d = 35''$ in base

Temp. Steel

$.2\%$ in front $= .36^{\square''}$ $\quad \frac{1}{2}\phi$ bars $6''$ C-C

$.1\%$ in back $= .18^{\square''}$ $\quad \frac{1}{2}\phi$ bars $12''$ C-C

TOE



$BM = 1481 \times 4.5 \times 2.25 + 68 \times 4.5 \times 3 = 15918'^{\#}$

$d = \sqrt{\frac{15918}{164}} = 9.85''$ say $10''$ $D = 13''$

$V = 1481 \times 4.5 + 68 \times 4.5 = 6966^{\#}$

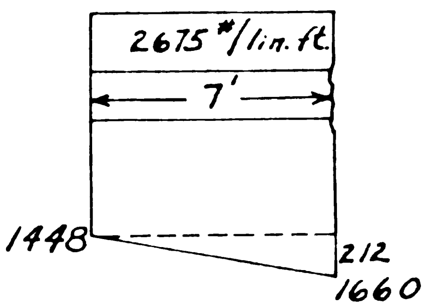
$v = \frac{6966}{12 \times .875 \times 10} = 66^{\#}/\square''$ but using $D = 18''$ $d = 15''$ $v = 44^{\#}/\square''$ OK

$A_s = .0094 \times 12 \times 15 = 1.70^{\square''}$ $\frac{7}{8}''\phi$ bars $4''$ C-C $A = 1.80^{\square''}$

$u = \frac{6966}{8.25 \times .875 \times 15} = 64^{\#}/\square''$ Use plain rods

Temp. Steel $\frac{1}{2}''\phi$ bars $12''$ C-C top & bottom

HEEL



$BM = 1227 \times 7 \times 3.5 - \frac{106 \times 7^2}{3} = 28370'^{\#}$

$d = \sqrt{\frac{28370}{164}} = 13.1''$ say $14''$ $D = 17''$

$V = 1227 \times 7 - 106 \times 7 = 7847^{\#}$

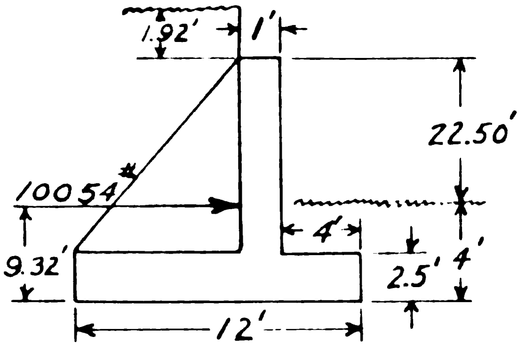
$v = \frac{7847}{12 \times .875 \times 14} = 53^{\#}/\square''$ but using $D = 18''$ $d = 15''$ $v = 50^{\#}/\square''$ OK

$A_s = .0094 \times 12 \times 15 = 1.70^{\square''}$ $\frac{7}{8}''\phi$ bars $4''$ C-C $A = 1.80^{\square''}$

$u = \frac{7847}{8.25 \times .875 \times 13} = 73^{\#}/\square''$ Use plain rods

Temp. Steel $\frac{1}{2}''\phi$ bars $12''$ C-C top & bottom

COUNTER-FORT WALL



Thickness of C.F. $\geq \frac{1}{20}h = \frac{24}{20} = 1.2'$

Say 15"

Spacing of C.F.

$s \geq 2.46 + .216h = 2.46 + .216 \times 24 = 7.64'$

Say 8'-0"

Breadth of base

$b = \frac{h}{2} = \frac{24}{2} = 12'$

$P = \frac{25 \times 28.42^2}{2} = 10100^{\#}$

$P_{1} = \frac{25 \times 1.92^2}{2} = \frac{46^{\#}}{10054^{\#}}$

Mom. about (a)

$10100 \times 18.95 = 46 \times 1.28 + 10054\,y$

$y = 19.1'$

Wt. of wall per lin. ft.

$12 \times 2.5 \times 150 + 24 \times 150 + \frac{24 \times 7 \times 1.25 \times 150}{2 \times 8} = 10070^{\#}$

Wt. of earth

$7 \times 25.92 \times 120 = 21800^{\#}$

Pt. of application

$31870\,x = 4.5 \times 3600 + 6 \times 4500 + 1970 \times 7.33 + 21800 \times 8.50$

$x = 7.63'$

$\bar{x} = \frac{9.32 \times 10054}{31870} = 2.94'$ $\quad 7.63 - 2.94 = 4.69'$

$e = 6 - 4.69 = 1.33'$ $\quad p = \frac{31870}{12}\left(1 \pm \frac{6 \times 1.33}{12}\right) = \begin{matrix} 4420^{\#}/\square' \text{ Toe} \\ 905^{\#}/\square' \text{ Heel} \end{matrix}$

$f_s = \frac{31870 \times .4}{10054} = 1.27$ - Use key

STEM

$m = 25 \times 25.42 = 635^{\#}$/lin. ft.

$BM = \frac{wl^2}{10} = \frac{635 \times 64}{10} = 4060'^{\#}$

$d = \sqrt{\frac{4060}{164}} = 4.98''$ say 5" Use d = 9", D = 12" minimum

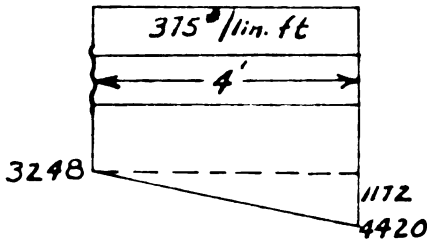
$A_s = .0094 \times 9 \times 12 = 1.01\square''$ $\frac{3}{4}''\phi$ bars 5" C-C $A = 1.06\square''$

$V = \frac{wl}{2} = \frac{635 \times 8}{2} = 2540^{\#}$

$v = \frac{2540}{12 \times .875 \times 9} = 27^{\#}/\square''$ OK

$u = \frac{2540}{2.36 \times \frac{12}{5} \times .875 \times 9} = 57^{\#}/\square''$ Use deformed bars

TOE



$BM = 2873 \times 4 \times 2 + \frac{586 \times 4 \times 8}{3} = 29215'^{\#}$

$d = \sqrt{\frac{29215}{164}} = 13.35''$ say $14''$ $D = 17''$

$A_s = .0094 \times 14 \times 12 = 1.58^{\square''}$ $1''^{\phi}$ bars $7''$ C-C $A = 1.71^{\square''}$

$V = 2873 \times 4 + 586 \times 4 = 13836^{\#}$

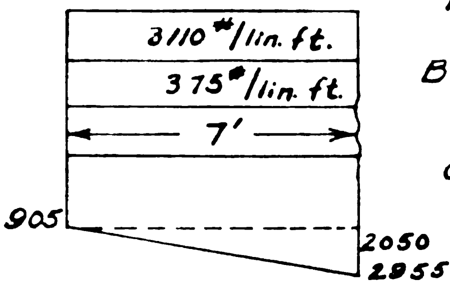
$v = \frac{13836}{12 \times .875 \times 14} = 94^{\#}/^{\square''}$ $\quad \frac{94}{50} \times 14 = 27''$ $D = 30''$

$u = \frac{13836}{4 \times \frac{13}{7} \times .875 \times 14} = 164^{\#}/^{\square''}$ $\quad \frac{164}{125} \times 14 = 19''$

$A_s = .0094 \times 12 \times 27 = 3.04^{\square''}$ $1\frac{1}{8}''^{\phi}$ bars $5''$ C-C $A = 3.04^{\square''}$

deformed bars

HEEL



$BM = \frac{2580 \times 64}{10} = 16500^{\#}$

$d = \frac{16500}{164} = 10'' + D = 14''$ but use $D = 30''$

Wall is poor in sliding & key will have to be used.

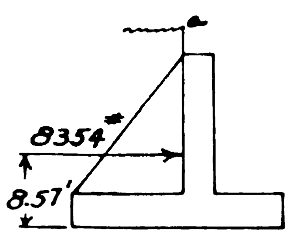
$A_s = .0094 \times 12 \times 27 = 3.04^{\square''}$ $1\frac{1}{8}''^{\phi}$ bars $5''$ C-C $A = 3.04^{\square''}$

$V = 2580 \times 4 = 11320^{\#}$

$v = \frac{11320}{12 \times .875 \times 27} = 41^{\#}/^{\square''}$ OK

$u = \frac{11320}{12 \times .875 \times 27} = 45^{\#}/^{\square''}$ Use deformed bars

COUNTER-FORT



$P = \frac{25 \times 25.92^2}{2} = 8400^{\#}$

$P_{\phi} = \frac{46^{\#}}{8354^{\#}}$

Mom. about (a)

$8400 \times 17.28 = 46 \times 1.28 + 8354y, \quad y = 17.35'$

$P = 8354 \times 8 = 66832^{\#}$

$BM = 66832 \times 8.57 \times 12 = 6880000''^{\#}$ $\quad K = \frac{6880000}{15 \times (81)^2} = 70$

$A_s = .0068 \times 15 \times 81 = 8.26^{\square''}$ $6 - 1\frac{1}{4}''^{\phi}$ bars $A = 9.38^{\square''}$

Placed in two rows – 2" apart

$v = \frac{66832}{15 \times .875 \times 79} = 64^{\#}/^{\square''}$ taken care of later

$u = \frac{66832}{30 \times .875 \times 79} = 32^{\#}/^{\square''}$ Use deformed bars

Steel to Connect Stem to Counter-fort

assume $\frac{3}{4}$"ϕ bars   Tensile Strength $= \frac{9}{16} \times 20{,}000 = 11250^{\#}$

Anchorage $= 40\,d = 30$"

Earth pressure on lowest foot of stem $= 25 \times 25.42 \times 8 = 5080^{\#}$

Spacing $= \frac{11250}{5080} = 2.21'$ Use 18" - max. allowable

Shear $= 25.92 \times 7 \times 8 \times 120 = 174000^{\#}$ $\frac{174000}{15000} = 11.60^{\square}$"

$\frac{11.60}{9/16} = 21$ bars

$$\frac{66832}{11250} = \begin{array}{l} 6 \text{ bars needed for tension} \\ \underline{21 \quad " \quad\quad " \quad\quad " \quad \text{Shear}} \\ 27 \text{ bars-Total} \end{array}$$

Spacing

16 bars at 18" starting 9" from bottom

11 bars at 18" starting 18" from bottom

Steel to Connect Counter-Fort to Base

Placed in pairs   Tensile Strength $= \frac{9}{16} \times 2 \times 20{,}000 = 22500^{\#}$

Overturning mom. $= 66{,}832 \times 8.57 = 573000'^{\#}$

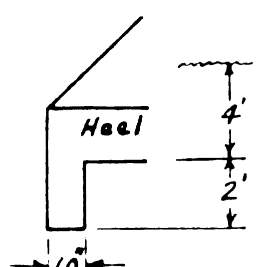
Resisting mom. $= \frac{22500}{6}\left(1^2 + 2^2 + 3^2 + 3.5^2 + 4^2 + 4.5^2 + 5^2 + 5.5^2 + 6^2\right) = 576000'^{\#}$

Shear $= 66{,}832^{\#}$ no of pairs $\frac{66832}{22500} = 3$

Spacing - 24 - $\frac{3}{4}$"ϕ bars at .5', 1, 1.5', 2', 2.5', 3', 3.5', 4', 4.5', 5', 5.5', 6'

from stem, running all way up in C.F.

KEY



$$P = 4.9\,\frac{120 \times 36}{2} = 10600^{\#}$$

$$P_{\textcircled{1}} = 4.9\,\frac{120 \times 16}{2} = \frac{4700^{\#}}{5900^{\#}}$$

$$f_s = \frac{31870 \times .4 + 5900}{10054} = 1.86 \text{ OK}$$

$$10600 \times 2 = 4700 \times \frac{10}{3} + 5900\,y$$

$$y = .94'$$

$$BM = 5900 \times 1.06 = 6250'^{\#}$$

$$d = \sqrt{\frac{6250}{164}} = 6.18" \text{ say } 7" \quad D = 10"$$

$A_s = .0094 \times 12 \times 7 = .79^{\square}$" $\frac{3}{4}$"ϕ bars $6\frac{1}{2}$" C-C $A = .82^{\square}$"

Anchorage $= 40d = 30$"   Use deformed bars

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