THESIS

INVESTIGATION OF A TWO SPAN REINFORCED CONCRETE ARGH HIGHWAY BRIDGE

C. E. FOSTER & E. E. PETERSON

1915

THESIS

AN INVESTIGATION OF A 2-SPAN REINFORCED CONCRETE ARCH HIGHWAY BRIDGE OVER SHIAWASSEE RIVER. HENDERSON, MICH.

A THESIS SUBMITTED TO

THE FACULTY OF

MICHIGAN AGRICULTURAL COLLEGE

BY

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THESIS

FOREWORD.-

THE PURPOSE OF THIS THESIS IS TO ENABLE US TO BECOME MORE FAMILIAR WITH THE ANALYSIS OF A REINFORCED CONCRETE ARCH.

INTRODUCTION.

THE WRITERS OF THIS THESIS CAME IN TOUCH WITH THIS ARCH BRIDGE THROUGH THE AGENCY OF THE MICHIGAN STATE HIGHWAY DEPARTMENT. THE BRIDGE WAS BUILT IN 1914 BY THE ILLINOIS BRIDGE COMPANY, OF CHICAGO. THE ORIGANAL DESIGN WAS SUBMITTED BY AN INDEPENDENT BRIDGE COMPANY. THE ENGINEERS OF THE STATE HIGHWAY DEPARTMENT SAW FIT TO CHANGE THE SECTION OF THE ARCH, MAKING IT HEAVIER THROUGH-OUT. FOR THIS REASON THE WRITERS HAVE INVESTIGATED THE ARCH IN AN ENDEAVOR TO DETERMINE THE STRESSES INDUCED IN A STRUCTURE OF THIS TYPE WHEN SUBMITTED TO THE LOADINGS PRESCRIBED IN THE STATE SPECIFICATIONS.

THE ARCH BEING UNSYMMETRICAL AND FIXED AT THE SUPPORTS IT WAS NECESSARY TO DETERMINE REACTIONS BY THE ANALYTICAL METHOD. HAVING THE REACTIONS THE THRUSTS, MOMENTS AND SHEARS WERE DETERMINED GRAPHICALLY. STRESSES WERE COMPUTED BY THE USE OF INFLUENCE LINES.

WE WISH TO THANK THE STATE HIGHWAY DEPARTMENT; MR. C.W. DEWART AND MR. H.L. BRIGHTMAN, ESPECIALLY, FOR THEIR KIND ASSISTANCE IN PROVIDING DRAWINGS, PICTURES AND INFORMATION. WE ARE DEEPLY INDEBTED TO PROF. C.A. MELICK, FOR THE METHODS USED AND THE CARE TAKEN IN CHECKING THE WORK.

E.E.P.
C.E.F.

POSITION OF LINEAR ARCH

POINT	A_c h × 3'	y DISTANCE OF STEEL FROM INTRADOS	A_s $\frac{.785 \times 3 \times 15}{144}$	M_s $A_s \times 2y$	M_c $A_c \times \frac{h}{2}$	M_{total} $M_s + M_c$	A_{total} $A_s + A_c$	Z DISTANCE OF LINEAR ARCH FROM INTRADOS
0	7.50	2.23 2.23 2.22	0.246	0.563	9.31	9.938	7.746	1.283
1	6.36	2.11 2.11 2.11	"	0.518	8.04	8.558	7.206	1.188
2	6.33	1.90 1.90 1.90	"	0.467	6.66	7.127	6.576	1.086
3	5.82	1.73 1.73 1.73	"	0.426	5.64	6.066	6.066	1.000
4	5.40	0.21 0.21 1.59	"	0.165	4.86	5.025	5.646	0.888
5	5.13	1.50 0.75 0.21	"	0.206	4.38	4.586	5.376	0.852
6	5.01	1.46 0.21 0.21	"	0.1455	4.17	4.315	5.256	0.820
7	4.83	0.21 0.21 0.21	"	0.0516	3.84	3.892	5.076	0.777
8	4.80	0.21 0.21 0.21	"	0.0516	3.84	3.892	5.046	0.777
9	4.80	0.21 0.21 0.21	"	0.0516	3.84	3.892	5.046	0.777
10	4.80	0.21 0.21 0.21	"	0.0516	3.84	3.892	5.046	0.777
11	4.80	0.21 0.21 0.21	"	0.0516	3.84	3.892	5.046	0.777
12	4.86	0.21 0.21 0.21	"	0.0516	3.93	3.982	5.106	0.780
13	5.01	0.21 0.21 0.21	"	0.0516	4.17	4.222	5.256	0.810
14	5.13	1.50 0.21 0.21	"	0.157	4.38	4.537	5.376	0.844
15	5.52	1.63 0.80 0.21	"	0.221	5.07	5.291	5.766	0.916
16	6.00	1.19 1.19 0.21	"	0.311	6.00	6.311	6.246	1.010
17	6.75	2.02 2.04 2.04	"	0.506	7.56	8.066	6.996	1.150
18	7.50	2.29 2.29 2.29	"	0.563	9.39	9.953	7.746	1.280
19	8.46	2.61 2.61 2.61	"	0.644	11.91	12.554	8.776	1.440
20	9.00	2.79 2.79 2.79	"	0.686	13.50	14.186	9.246	1.460

MOMENT OF INERTIA OF TRANSFORMED SECTIONS

POINT	h	w	A_c	A_s	A_t	I_c	nI_s	I_t
1	2.38	2.17 2.17 2.17	7.14	0246	7.386	3.37	.2460	3.616
3	2.18	1.97 1.97 1.97	6.54	"	6.786	2.59	.1930	2.783
5	2.00	1.79 1.79 1.79	6.00	"	6.246	2.00	.1480	2.148
7	1.84	1.63 1.63 1.63	5.52	"	5.776	1.58	.1170	1.697
9	1.75	1.54 1.54 021	525	"	5496	1.346	.1040	1452
11	1.65	144 021 021	495	"	5.196	1.123	.1010	1291
13	1.61	122 021 021	483	"	5.076	1.043	.0700	1.130
15	1.60	021 021 021	480	"	5.046	1.024	.0860	1.112
17	1.60	021 021 021	480	"	5.046	1.024	.0860	1.112
19	1.60	021 021 021	480	"	5.046	1.024	.0860	1.112
21	1.60	021 021 021	480	"	5.046	1.024	.0860	1.112
23	1.60	021 021 021	480	"	5.046	1.024	.0860	1.112
25	1.63	021 021 021	489	"	5.136	1.083	.0920	1.175
27	1.67	196 021 021	501	"	5.256	1.164	.0960	1.262
29	1.72	146 021 021	516	"	5.406	1.272	.1130	1.385
31	1.90	169 169 021	570	"	5.946	1.715	.1300	1.845
33	2.10	189 189 021	630	"	6.546	2.315	.1660	2481
35	2.43	021 221 221	729	"	7.536	3.587	.1910	3.778
37	2.61	240 240 240	783	"	8.076	4.445	.2710	4.716
39	2.90	169 169 169	870	"	8.946	6.097	.3790	6476

CALCULATIONS FOR ΔS

(Values of x & y Scaled)

Δx	228 1	424 11	482 21	380 31
Δy	1.30	0.64	-0.24	-1.52
Δx^2	51984	179776	232324	14440
Δy^2	1.6900	.4096	.0576	2.3104
Sum	6.5884	18.3872	23.2900	16.7504
LogSum	0.8381184	1.2645156	1.3671695	1.2240252
LogΔS	0.4190592	0.6322578	0.6835848	0.6120126
Δx	384 3	440 13	380 23	404 33
Δy	1.64	0.76	-0.60	-1.48
Δx^2	147456	19.36	144400	163216
Δy^2	2.6896	0.5776	.3600	2.1904
Sum	17.4352	19.9376	14.80	18.5120
LogSum	1.2414270	1.2996729	1.1702617	1.2674533
LogΔS	0.6207135	0.6498365	0.5851308	0.6337267
Δx	420 5	420 15	486 25	396 35
Δy	1.80	0.40	-0.74	-2.18
Δx^2	1764	17.6400	23.6196	15.6816
Δy^2	3.24	.1600	.5476	4.7524
Sum	20.88	17.80	24.1672	20.4340
LogSum	1.3197305	1.2504200	1.3832243	1.3103634
ΔS(Log)	0.6598652	0.6252100	0.6916132	0.6551767
Δx	400 7	462 17	370 27	368 37
Δy	1.18	0.70	-1.00	-2.00
Δx^2	16.00	21.3444	136900	13.5424
Δy^2	1.3924	0.0400	1.0000	4.0000
Sum	17.2424	21.3844	14.6900	17.5424
LogSum	1.2403595	1.3300971	1.1670218	1.2440840
ΔS(Log)	0.6201798	0.6650486	0.5835109	0.6220445
Δx	444 9	402 19	476 29	168 39
Δy	1.36	-0.12	-1.22	-1.26
Δx^2	197136	161604	226576	28224
Δy^2	1.8496	.0144	1.4884	1.5876
Sum	26.5632	16.1748	24.1460	4.4100
LogSum	1.3337132	1.2088389	1.3828452	0.6444386
ΔS(Log)	0.6668566	0.6044195	0.6914226	0.3222193

Coordinates of Linear Arch

Point	x	y	Δx	Δy	φ	sin φ	cos φ
1	1.1400	0.6500	2.2800	1.3000	27° 10′	0.4566	0.8897
2	4.2000	2.1200	3.8400	1.6400	24° 45′	0.4213	0.9069
3	8.2200	3.8400	4.2000	1.8000	31° 30′	0.3665	0.9304
4	12.3200	5.3300	4.0000	1.1800	18° 00′	0.3090	0.9511
5	16.5400	6.6000	4.4400	1.3600	14° 50′	0.2560	0.9667
6	20.8800	7.6000	4.2400	0.6400	11° 50′	0.2051	0.9788
7	25.2000	8.3000	4.4000	0.7600	8° 25′	0.1454	0.9872
8	29.5000	8.8800	4.2000	0.4000	5° 25′	0.0944	0.9955
9	33.9100	9.1800	4.6200	0.2000	2° 05′	0.0364	0.9993
10	38.2300	9.2200	4.0200	−0.1200	− 0° 30′	− 0.0145	0.9999
11	42.6500	9.0400	4.8200	− 0.2400	− 3° 55′	− 0.0683	0.9977
12	46.9600	8.6200	3.8000	− 0.6000	− 6° 35′	− 0.1146	0.9934
13	51.2900	7.9500	4.8600	−0.7400	− 9° 55′	− 0.1742	0.9851
14	55.5700	7.0800	3.7000	− 1.0000	− 13° 05′	− 0.2264	0.9740
15	59.8000	5.9700	4.7600	− 1.2200	− 16° 10′	− 0.2784	0.9605
16	64.0800	4.6000	3.8000	− 1.5200	− 18° 45′	−0.3214	0.9469
17	68.0000	3.1000	4.0400	− 1.4800	−22° 10′	− 0.3773	0.9261
18	72.0000	1.2700	3.9600	− 2.1800	−26° 30′	− 0.4462	0.8945
19	75.8200	− 0.8200	3.6800	− 2.0000	− 30° 05′	− 0.5013	0.8653
20	78.5000	− 2.4500	1.6800	− 1.2600	−37° 40′	− 0.6098	0.8418

ARCH PROPERTIES

①	⑪	㉑	㉛
0.4100592	0.6327578	0.6833848	0.6120126
0.5582284	0.112 9400	0.0461048	0.2654964
9.8608308-0.72582	0.5193178 - 33061	0.6374800-43349	0.3460162 - 22183
9.9177357 0.87410	1.8390483 - 69.032	2.2673440 - 18510	2.1527387- 14215
9.9676406 0.94328	3.1587788 - 14414	3.8973180 - 78944	3.9544612 - 91088
9.7294431-0.53659	7.7198619 - 52.644	3.2235674 - 16833	2.8154965 - 65388
9.6737442 - 0.47179	1.4001314 - 25126	1.5936481 - 39323	1.0087740 - 10284
9.4866816-0.30666	2.2809450 - 19096	2.5498168 - 35466	1.6715318 - 46934
②	⑫	㉒	㉜
0.6868566	0.6044195	0.6914226	0.3222193
0.1613666	0.0461048	0.1414498	0.8113068
0.5048900 - 31381	0.5583148 - 36177	0.5949728-3.5479	9.5109125 - 0.3242
1.7234255 - 52886	2.1407190 - 1.3827	2.3266790 - 2.1217	1.4057822 - 2.5456
2.9419610 - 87491	3.7231233 - 5.2860	4 1033752 - 12.685	3.3006519 - 1.9983
2.9429209 - 3.4912	3.1054499 - 1.2748	3.1026483 - 12.666	1.7949483 - 6.2366
1.3244339 - 2.1101	1.5230456 - 3.3346	1.3259471 - 2.1811	9.9000786 - 0.79447
2.1438778 - 1.3931	2.4877665 - 3.0745	2.1019214 - 1.2645	0.2842447 - 1.9465
③	⑬	㉓	
0.6650486	0.5835109	0.6220945	
0.0461046	0.1010594	0.6735738	
0.6189438 - 4.1586	0.4824.516 - 30.370	9.9484707 - 0.8881	
2.1492716 - 14.102	2.2272918 - 16.877	1.8282542 - 67.337	
3.6795394 - 47.819	3.9721323 - 93.785	3.7080383 - 510.55	
3.1121143 - 12945	3.0773283 - 11949	1.7420684 - 55.216	
1.5817785 - 38.176	1.3324848 - 21.502	9.8622846 - 0.7283	
2.5446792 - 3.5045	2.1825181 - 15.224	9.7960985 - 0.5977	
④	⑭	㉔	
0.6916192	0.6551767	0.6201798	
0.7003719	0.5772620	0.2296818	
0.6215753 - 41838	0.0779147 - 11965	0.3404780 - 2.4576	
2.3316080 - 2.1459	1.9362472 - 86148	1.4811087 - 3.9277	
4.0416407 - 11.063	3.7025797 - 6.2027	2.5717194 - 3.7301	
3.2315751 - 17.060	2.0330509 - 10.941	2.2078369 - 1.6137	
1.5213424 - 3.3262	0.1817184 - 1.5146	1.1172252 - 1.3099	
2.4223095 - 2.6443	0.2855221 - 1.9298	1.8433524 - 6.9816	
⑤	⑮	㉕	
0.6337267	0.6508452	0.6252100	
0.3946268	0.3320343	0.0461048	
0.2390999 - 1.7342	0.3278309 - 2.1273	0.5791052 - 3.7941	
2.0716088 - 1.1743	1.2427028 - 1.7487	2.0489272 - 1.1193	
3.9041177 - 5.0150	2.1575746 - 1.4374	3.8187492 - 3.3018	
2.5629705 - 3.6557	1.8270340 - 6.7.148	2.2073402 - 9.9389	
0.7304616 - 5.376	0.9121621 - 8.1689	1.3275182 - 3.3691	
1.2218322 - 16.666	1.4764933 - 3.1369	2.4752312 - 2.9918	
⑥	⑯	㉖	
0.6270135	0.6428365	0.5851308	
0.4451132	0.0530784	0.0461043	
0.1760003 - 1.5004	0.5967581 - 3.9515	0.5340260 - 3.4596	
0.7994496 - 6.3016	1.9781586 - 9.9577	2.2107541 - 1.6246	
1.4228989 - 2.6467	3.3995591 - 2.5093	3.8224822 - 7.6293	
1.1257856 - 13.359	2.9172367 - 8.2699	3.1462614 - 1.4004	
0.5015362 - 3.1308	1.5158362 - 32.798	1.4745333 - 2.4822	
0.8288721 - 6.7433	2.4343143 - 2.7222	2.4100406 - 2.5706	

SUMMATION OF ARCH PROPERTIES

POINT	$\frac{\Delta s}{I}$	$x\frac{\Delta s}{I}$	$x^2\frac{\Delta s}{I}$	$xy\frac{\Delta s}{I}$	$y\frac{\Delta s}{I}$	$y^2\frac{\Delta s}{I}$	$\frac{\Delta x}{A}\sin\phi$ Σ_A^1	$\frac{\Delta y}{A}\sin\phi$ Σ_A^1	$\frac{\Delta x}{A}\cos\phi$	$\frac{\Delta y}{A}\cos\phi$
1	0.72.58	0814	0.92	0.53	0.4717	0.31	0.14 -0.29	0.08 1.09	0.27	0.16
3	1.5004	6.301	26.46	13.35	3.1808	6.74	0.24	0.10	0.51	0.22
5	2.1273	17.487	143.74	67.14	8.169	31.37	0.25 -0.67	0.11 0.91	0.63	0.27
7	2.4576	30.277	373.01	161.37	13.099	69.82	0.21	0.06	0.66	0.19
9	3.1981	52.896	874.91	349.12	21.107	139.31	0.21 -0.13	0.06 0.74	0.78	0.24
11	3.3061	69.032	1441.40	524.64	25.126	190.96	0.17	0.03	0.80	0.12
13	3.9515	94.577	2.50430	826.49	32.798	272.22	0.13 -1.51	0.02 0.65	0.86	0.15
15	3.7441	111.93	3301.80	943.89	33.691	299.18	0.08	0.01	0.83	0.08
17	4.1580	141.02	4781.90	1244.50	38.176	350.45	0.03 -1.72	0.00 0.62	0.91	0.04
19	3.6167	138.270	5286.00	1274.80	33.346	307.45	0.01	0.00	0.80	-0.02
21	4.3399	185.100	7894.40	1673.30	33.233	359.66	-0.07 -1.74	0.00 0.62	0.95	-0.05
23	3.4596	162.46	7629.30	1400.40	29.822	257.06	-0.09	0.01	0.75	-0.12
25	4.1838	214.59	11006.30	1706.00	33.262	264.43	-0.16 -1.58	0.02 0.61	0.93	-0.14
27	3.0370	168.770	9378.50	1194.40	21.502	152.44	-0.16	0.04	0.69	-0.18
29	3.5479	212.17	12681.50	1266.60	21.181	126.25	-0.25 -1.26	0.06 0.55	0.85	-0.22
33	2.2183	142.15	9108.80	658.88	10.204	46.94	-0.21	0.08	0.61	-0.24
35	1.7342	117.93	8104.00	365.57	5.316	16.67	-0.23 -0.80	0.09 0.41	0.51	-0.21
36	1.1465	86.148	6202.70	104.41	1.520	1.93	-0.24	0.13	0.47	-0.26
37	0.88617	67.337	5105.50	-5.522	-0.728	0.60	-0.23 -0.33	0.12 0.19	0.40	-0.21
39	0.32427	25.456	1948.30	-62.37	-0.794	1.95	-0.10	0.07	0.16	-0.12
Σ	53.7688	2049.716	9776976	13758.33	369.741	2830.72			13.43	-0.30

ARCH CONSTANTS

	Log
$a_1 = 53.7658$	1.7305061
$a_2 = 369.741$	2.5678976
$a_3 = 2049.716$	3.3116937
$b_1 = 2049.716$	3.3116937
$b_2 = 13758.62$	4.1385744
$b_3 = -9777.085$	4.9902044
$c_1 = 369.741$	2.5678976
$c_2 = -2984.15$	3.4730191
$c_3 = 13758.63$	4.1385744
$\frac{a_1}{c_1} = -.14541$	-9.1626085
$\frac{b_1}{c_1} = -.54436$	5-0.7437961
$\frac{a_2}{c_2} = -.127315$	9.1048785
$\frac{b_2}{c_2} = -4.7375$	7 0.6755558
$\frac{a_3}{c_3} = -.14897$	7 9.1731188
$\frac{b_3}{c_3} = -7.1061$	5 0.8516345
$A_1 = +.003562$	7.5516939
$A_2 = +.021662$	8.3356986
$B_1 = -1.56250$	0.1938200
$B_2 = -2.36855$	0.3744880
$D_1 = -329.315$	2.5176115

	Log
$\frac{B_1}{A_1} = -438.658$	2.6421261
$\frac{B_2}{A_2} = -109.343$	2.0387894

ARCH PROPERTIES DUE TO LOADING

LOAD AT 1	5	9	13	17
(x−a) 306 5015	1110	1134	1130	1132
Log (x−a) 0.4857214	0.6127834	0.6374841	0.6334686	0.6334837
" (x−a) ^{A_5} 0.6619217 - 9.5912	1.0032819 - 1.0076	1.1568075 - 1.4348	1.2125737 - 1.6314	1.1937454 - 1.5624
" (x−a)$^{x\ A_5}$ 1.2851710 - 19.283	2.0938926 - 12.413	2.4765360 - 299.60	2.6823957 - 481.28	2.7762027 - 597.31
" (x−a)$^{y\ A_5}$ 0.4822576 - 9.7332	1.7300091 - 53.104	2.0376211 - 109.05	2.1609867 - 144.81	2.1585293 - 144.06
(x−a) 708	832	866	871	874
Log (x−a) 0.8500333	0.9201233	0.9375179	0.9400182	0.9415114
" (x−a) ^{A_5} 1.1778642 - 1.5061	1.4250133 - 2.6608	1.5342760 - 34.220	1.5589620 - 36.221	1.5789914 - 37.931
" (x−a)$^{x\ A_5}$ 2.0927361 - 12.380	2.6435488 - 44.010	2.9356765 - 862.34	3.0842898 - 1228.3	3.2089104 - 1617.7
" (x−a)$^{y\ A_5}$ 1.7621954 - 57.86	2.2455772 - 175.61	2.4533541 - 284.02	2.5218047 - 332.51	2.5331598 - 342.89
(x−a) 1118	1266	1296	1303	1305
Log (x−a) 1.0484418	1.1024337	1.1126050	1.1149444	1.1156105
" (x−a) ^{A_5} 1.4389398 - 2.7475	1.6217515 - 41.885	1.6917107 - 49.171	1.6732591 - 47.166	1.6816365 - 45.148
" (x−a)$^{x\ A_5}$ 2.5295605 - 33.849	2.9419820 - 844.10	3.1615322 - 1450.6	3.2556634 - 1801.6	3.3263646 - 2120.1
" (x−a)$^{y\ A_5}$ 2.1656670 - 14.644	2.5026651 - 318.10	2.6401232 - 436.4	2.6379900 - 434.50	2.5901438 - 389.17
(x−a) 1540	1698	1737	1745	1738
Log (x−a) 1.1875207	1.2299377	1.2397498	1.2417954	1.2400443
" (x−a) ^{A_5} 1.6924107 - 49.251	1.8266953 - 67.096	1.8587436 - 72.234	1.8792754 - 75.731	1.8616251 - 72.715
" (x−a)$^{x\ A_5}$ 2.9109462 - 81.960	3.2280963 - 169.03	3.3890714 - 244.95	3.5091944 - 322.99	3.5716578 - 372.96
" (x−a)$^{y\ A_5}$ 2.5119546 - 32.505	2.7457739 - 556.40	2.8215863 - 663.11	2.8354436 - 684.61	2.7619922 - 578.09
(x−a) 1974	2128	2169	2176	2166
Log (x−a) 1.2953471	1.3278716	1.3362596 - 78.447	1.3376589	1.3356585
" (x−a) ^{A_5} 1.8146649 - 68263	1.9070768 - 80.738	1.9345743 - 78.447	1.8766849 - 75.281	1.8181100 - 65.782
" (x−a)$^{x\ A_5}$ 3.1343954 - 13627	3.3763883 - 2381.8	3.4769786 - 24940	3.5484130 - 35352	3.5629604 - 36455
" (x−a)$^{y\ A_5}$ 2.4954785 - 4960	2.8854898 - 716.95	2.8893052 - 72328	2.8121922 - 648.92	2.6681433 - 465.74
(x−a) 2406	2569	2611	2609	2589
Log (x−a) 1.3815926	1.4097641	1.4163089	1.4164741	1.4131321
" (x−a) ^{A_5} 1.9780537 - 4.5072	2.0287079 - 106.83	2.0542869 - 113.32	2.0380404 - 109.16	1.9631049 - 98.55
" (x−a)$^{x\ A_5}$ 3.3794542 - 23958	3.5590357 - 3622.7	3.6842059 - 4821.9	3.7480321 - 5598.6	3.7398061 - 5493.0
" (x−a)$^{y\ A_5}$ 2.8471318 - 7810	2.9815506 - 960.73	3.0104553 - 1024.4	2.9384165 - 867.79	2.7390792 - 549.38

ARCH PROPERTIES DUE TO LOADING (Continued)

LOAD AT 1		5		9		13		17 - 37	
$(x-a)$	28.36	15	30.01	19	30.42	23	30.37	27	30.17	31
$\log(x-a)$	1.4527062		1.4772660		1.4831542		1.4824448		1.4795753	
" $(x-a)^{\frac{5}{2}}$	2.0318114 - 10760		2.0365807 - 10854		2.0221382 - 10524		1.9648963 - 92235		1.8255915 - 66926	
" $(x-a)x^{\frac{5}{2}}$	3.0516334 - 31742		3.0617850 - 41494		3.0436133 - 49421		3.7047367 - 51755		3.6323140 - 42886	
" $(x-a)y^{\frac{5}{2}}$	2.7467244 - 95544		2.8003116 - 10007		2.7957925 - 90718		2.8142496 - 65307		2.4883493 - 30786	
$(x-a)$	32.77	17	34.43	21	34.75	25	34.60	29	34.04	33
$\log(x-a)$	1.5154764		1.5369370		1.5409548		1.5390761		1.5326270	
" $(x-a)^{\frac{5}{2}}$	2.1344202 - 13628		2.1744170 - 14942		2.1625301 - 14539		2.0890489 - 122.76		1.7717269 - 59119	
" $(x-a)x^{\frac{5}{2}}$	3.6647480 - 46211		3.8043360 - 63729		3.7725623 - 74570		3.8651501 - 73409		3.6033358 - 4010.8	
" $(x-a)y^{\frac{5}{2}}$	3.2472629 - 12510		3.3136584 - 13508		3.2628972 - 11558		2.8650232 - 732.86		2.2630886 - 18221	
$(x-a)$	37.89	19	38.74	23	39.03	27	38.88	31	38.09	35
$\log(x-a)$	1.5792568		1.5881596		1.5912986		1.5897263		1.5808110	
" $(x-a)^{\frac{5}{2}}$	2.1275715 - 13414		2.1271856 - 13404		2.0738501 - 11854		1.9357425 - 86247		1.6587257 - 45575	
" $(x-a)x^{\frac{5}{2}}$	3.7099738 - 51283		3.7989137 - 62933		3.8186905 - 65871		3.7424650 - 55267		3.5053682 - 32738	
" $(x-a)y^{\frac{5}{2}}$	3.0923024 - 12368		3.0626929 - 11553		2.9238834 - 83423		2.5485003 - 39673		1.7625244 - 57880	
$(x-a)$	41.51	21	42.07	25	42.26	29	42.80	33	41.91	37
$\log(x-a)$	1.5692568		1.6241749		1.6260865		1.6314438		1.6223177	
" $(x-a)^{\frac{5}{2}}$	2.2555231 - 18011		2.2657502 - 18020		2.1860593 - 15248		1.8705437 - 74224		1.5707884 - 37221	
" $(x-a)x^{\frac{5}{2}}$	2.8884471 - 76815		3.9657829 - 92424		3.9627605 - 91780		3.7036526 - 58472		3.4505722 - 28221	
" $(x-a)y^{\frac{5}{2}}$	3.2116965 - 16287		3.1661173 - 14326		2.9620336 - 91624		2.3619064 - 23010		1.4846023 - 30521	
$(x-a)$	45.82	23	47.35	27	47.54	31	47.80	35	44.51	39
$\log(x-a)$	1.6610581		1.6752200		1.6770547		1.6792459		1.6484576	
" $(x-a)^{\frac{5}{2}}$	2.2000811 - 15852		2.1577715 - 143.81		2.0230754 - 10546		1.7481606 - 55496		1.1593701 - 14434	
" $(x-a)x^{\frac{5}{2}}$	3.3813092 - 74441		3.4024119 - 79912		3.3829479 - 67577		3.2654931 - 40317		2.4505722 - 11330	
" $(x-a)y^{\frac{5}{2}}$	3.1255884 - 13664		3.0078038 - 10181		2.6838372 - 48510		1.8519643 - 71116		1.5485367 - 35367	
$(x-a)$	50.15	25	51.58	29	51.46	33	50.62	37	268 LOAD AT 37	
$\log(x-a)$	1.7002709		1.7124813		1.7139799		1.7043221		0.4281348	
" $(x-a)^{\frac{5}{2}}$	2.3213462 - 20982		2.2624541 - 183.00		1.8218946 - 66358		1.4527928 - 44956		9.9390473 - 86906	
" $(x-a)x^{\frac{5}{2}}$	4.0318789 - 107615		4.0239563 - 109435		3.6792271 - 47778		3.5323766 - 34086		1.8339170 - 68221	
" $(x-a)y^{\frac{5}{2}}$	3.2222133 - 16681		3.0384254 - 10925		1.9256983 - 84275		1.5666067 - 36864		0.2821234 - 2129	

ARCH PROPERTIES DUE TO LOADING (Continued)

		9 – 25		13 – 21		33	
(x-a)	.5443	27	55.86	31	5.146	33	5330	35	4.00	35
Log (x-a)	1.7358383		1.7471009		1.7114648		1.7267272		0.6020600	
" (x-a)$^{\frac{3}{2}}$	2.2182898 - 16531		2.0931171 - 12391		1.9505697 - 89242		1.8376397 - 17284		0.6799747 - 47860	
" (x-a)x$^{\frac{3}{2}}$	2.9631302 - 9186.1		3.8983796 - 79403		3.7830786 - 60685		3.7325094 - 13568		2.5373072 - 344.59	
" (x-a)y$^{\frac{3}{2}}$	2.0683231 - 11704		2.7558749 - 570.00		2.4419314 - 27665		1.6268058 - 42.345		0.7837784 - 60782	
(x-a)	.5866	29	5978	33	5928	33	A.31 LOAD AT 21	25	7.82	37
Log(x-a)	1.7683421		1.7765559		1.7726082		0.6244773		0.8932068	
" (x-a)$^{\frac{3}{2}}$	2.2183149 - 208.12		2.0756558 - 10367		1.9213784 - 52647		1.7750333 - 14911		0.8416735 - 69451	
" (x-a)x$^{\frac{3}{2}}$	4.0950161 - 12.4170		3.8481647 - 70496		3.6011627 - 39917		2.8452314 - 700.22		2.7214613 - 52658	
" (x-a)y$^{\frac{3}{2}}$	3.0942892 - 12.425		2.8070175 - 321.38		1.6351928 - 43171		2.1090106 - 12853		0.7454994 - 56950	
(x-a)	6294	31	62.78	35	61.96	34	8.64	26	10.50	39
Log (x-a)	1.7489267		1.8046845		1.7921114		0.9365137		1.0211893	
" (x-a)$^{\frac{3}{2}}$	2.1449429 - 13962		1.8825992 - 76313		1.8030239 - 20092		1.6580890 - 36148		0.5321018 - 34049	
" (x-a)x$^{\frac{3}{2}}$	3.9516654 - 89441		3.7399317 - 54996		3.1978936 - 15772		3.2681217 - 18541		2.4269715 - 26728	
" (x-a)y$^{\frac{3}{2}}$	2.8077007 - 64215		1.9684029 - 96.918		1.6921400 - 49276		2.4584561 - 28738		0.9212679 - 83419	
(x-a)	66.86	33	67.60	37	428 LOAD AT 25	27	1242	21		
Log(x-a)	1.8251664		1.8299467		0.6319238		1.1172625			
" (x-a)x$^{\frac{3}{2}}$	2.0642663 - 11595		1.7784174 - 60031		1.1138555 - 12999		1.5831140 - 38239			
" (x-a)y$^{\frac{3}{2}}$	3.8967752 - 78445		3.6582012 - 45520		2.8587357 - 722.33		3.3385544 - 21804			
" (x-a)x$^{\frac{3}{2}}$	2.5556280 - 35944		1.6922313 - 49.232		1.9639286 - 92.030		2.4437473 - 27781			
(x-a)	70.86	35	7028	37	8.51	29	17.15	29		
Log(x-a)	1.8504011		1.8468318		0.9299296		1.2342641			
" (x-a)	1.9383158 - 84784		1.8577443 - 22790		1.9799024 - 30193		1.7842369 - 60874			
" (x-a)x$^{\frac{3}{2}}$	3.7856483 - 61095		3.7326140 - 17830		3.2566036 - 15055		3.5609381 - 36386			
" (x-a)y$^{\frac{3}{2}}$	2.0321195 - 10768		1.7469104 - 55836		2.2558767 - 18025		2.5602112 - 36326			
(x-a)	74.68	37	428 LOAD AT 29	31	12.79	31	2143	31		
Log (x-a)	1.8732043		0.6314438		1.1068750		1.3310222			
" (x-a)$^{\frac{3}{2}}$	1.8216750 - 66325		0.9774600 - 9494		1.4528867 - 28372		1.6770384 - 47538			
" (x-a)x$^{\frac{3}{2}}$	3.7014888 - 50287		2.7841825 - 60839		3.2596972 - 18181		3.4837609 - 30462			
" (x-a)y$^{\frac{3}{2}}$	1.7354889 - 54386		1.6402178 - 43673		2.1156445 - 13061		2.3297762 - 21861			

ARCH PROPERTIES DUE TO LOADING (Continued)

LOAD AT 1	2.0	2.5	2.1
(x-a) 7.736 [39]	8.20 [33]	1.671 [33]	2.535 [33]
Log (x-a) 1.8885165	0.9138139	1.2229764	1.4039780
" (x-a) $\frac{\Delta S}{I}$ 1.3944290 - 25086	1.1529138 - 14.22	1.4620763 - 28.978	1.6430779 - 43.962
" (x-a)x $\frac{\Delta S}{I}$ 3.2942987 - 19692	2.0854227 - 966.99	3.2945852 - 1970.5	3.4745868 - 2982.5
" (x-a)y $\frac{\Delta S}{I}$ 1.7885951 - 61960	1.6442755 - 44.083	1.9534380 - 89833	2.1344396 - 136.18
(x-a)	12.20 [35]	2.071 [35]	2.935 [33]
Log (x-a)	1.0863598	1.3161801	1.4676081
" (x-a) $\frac{\Delta S}{I}$	1.1642745 - 14.597	1.3446948 - 24.730	1.5455228 - 35.118
" (x-a)x $\frac{\Delta S}{I}$	3.0216070 - 1051.0	3.2514273 - 1784.1	3.4028553 - 2528.4
" (x-a)y $\frac{\Delta S}{I}$	1.2680782 - 18538	1.4978985 - 31470	1.6493265 - 44599
(x-a)	1.602 [37]	2.453 [37]	3.317 [37]
Log (x-a)	1.2046625	1.3896975	1.5207455
" (x-a) $\frac{\Delta S}{I}$	1.1531332 - 14.228	1.3381682 - 21.875	1.4692162 - 29.459
" (x-a)x $\frac{\Delta S}{I}$	3.0329170 - 1078.7	3.2178520 - 1658	3.3490000 - 2236
" (x-a)y $\frac{\Delta S}{I}$	1.0669471 - 11667	1.2519821 - 17864	1.3830301 - 24157
(x-a)	1.570 [39]	2.221 [39]	3.085 [39]
Log (x-a)	1.7718416	1.4347285	1.5514892
" (x-a) $\frac{\Delta S}{I}$	0.7827541 - 60639	0.9456410 - 8.8235	1.0653997 - 11.625
" (x-a)x $\frac{\Delta S}{I}$	2.6775238 - 475.91	2.8405107 - 692.65	2.9602714 - 912.58
" (y-a)y $\frac{\Delta S}{I}$	1.1719202 - 14857	1.3348071 - 21618	1.4545678 - 28482

ARCH PROPERTIES DUE TO LOADING (Continued)

LOAD AT 1	29	25	21	
$(x-a)$	77.36	820	16.71	25.35
Log $(x-a)$	1.8885165	0.9138139	1.2229764	1.4039780
" $(x-a)\ \frac{\Delta s}{I}$	1.3944290 - 25086	1.1529138 - 14.22	1.4620763 - 28.978	1.6430779 - 43.962
" $(x-a) \times \frac{\Delta s}{I}$	3.2942987 - 1969.2	2.9854227 - 966.99	3.2945852 - 1970.5	3.4745868 - 2982.5
" $(x-a)\ y\ \frac{\Delta s}{I}$	1.7885951 - 61.460	1.6442755 - 44.083	1.9534380 - 89.833	2.1344396 - 136.28
$(x-a)$	12.20	20.71	29.35
Log $(x-a)$	1.0863598	1.3161801	1.4676081
" $(x-a)\ \frac{\Delta s}{I}$	1.1642745 - 14.597	1.3940948 - 24.780	1.5455228 - 35.118
" $(x-a) \times \frac{\Delta s}{I}$	3.0216070 - 1051.0	3.2514273 - 1784.1	3.4028553 - 2528.4
" $(x-a)\ y\ \frac{\Delta s}{I}$	1.2680782 - 18.538	1.4978985 - 31.470	1.6493265 - 44.599
$(x-a)$	16.02	24.53	33.17
Log $(x-a)$	1.2046625	1.3896975	1.5207455
" $(x-a)\ \frac{\Delta s}{I}$	1.1531332 - 14.228	1.3381682 - 21.875	1.4692162 - 29.459
" $(x-a) \times \frac{\Delta s}{I}$	3.0329170 - 1078.7	3.2174520 - 1651.8	3.3490000 - 2233.6
" $(x-a)\ y\ \frac{\Delta s}{x}$	1.0669471 - 1166.7	1.2519821 - 17.864	1.3830301 - 24.157
$(x-a)$	18.70	27.21	35.85
Log $(x-a)$	1.2718416	1.4347285	1.5544892
" $(x-a)\ \frac{\Delta s}{I}$	0.7827541 - 6.0639	0.9456410 - 8.8235	1.0653997 - 11.625
" $(x-a) \times \frac{\Delta s}{I}$	2.6775238 - 475.91	2.8405107 - 692.65	2.9602714 - 912.58
" $(y-a)\ y\ \frac{\Delta s}{I}$	1.1719202 - 14.857	1.3348071 - 21.618	1.4545678 - 28.482

SUMMATION OF ARCH PROPERTIES DUE TO LOADING

POINT	$(x-a)\frac{\Delta s}{I}$	$(x-a)\times\frac{\Delta s}{I}$	$(x-a)y\frac{\Delta s}{I}$	$(x-a)\times\frac{\Delta s}{I}$	$(x-a)\times\frac{\Delta s}{I}$	$(x-a)y\frac{\Delta s}{I}$	$(x-a)\frac{\Delta s}{I}$	$(x-a)\times\frac{\Delta s}{I}$	$(x-a)y\frac{\Delta s}{I}$
3	LOAD AT ③ 4.591	19.28	9.73	LOAD AT ③ .86906	68.221	-42.129 [35]	LOAD AT ⑤ 4.7860	344.59	607.82 [45]
5	15.061	123.80	57.84	Σ 86906	68221	-42.129	6.9451	526.58	-569.50 [37]
7	24.475	338.44	146.44	LOAD AT ⑦ 10.08	124.13	53.70	3.4049	267.28	-834.19 [39]
9	49.251	814.60	325.05	26.61	440.10	175.61	Σ+15.1360	+ 1138.45	- 7.9587
11	65.263	1362.7	496.00	41.85	873.94	318.10	LOAD AT ⑨ 14.348	299.60	109.25
13	95.072	2395.8	789.10	67.10	1690.8	556.90	34.220	862.34	284.02
15	107.600	3174.2	955.49	80.74	2381.8	716.95	49.171	1450.60	436.64
17	136.280	4621.1	1251.00	106.83	3622.7	980.73	72.234	2449.50	663.11
19	134.140	5128.3	1236.80	108.54	4149.4	1000.70	78.447	2999.00	723.28
21	180.110	7681.5	1628.20	149.42	6372.9	1350.80	113.320	4832.90	1024.40
23	158.520	7444.1	1366.40	134.03	6293.8	1155.30	105.240	4942.10	907.18
25	209.82	10761.5	1668.10	180.20	9242.4	1432.60	145.390	7457.00	1155.80
27	165.310	9186.1	1170.40	143.81	7991.2	1018.10	118.540	6587.10	839.23
29	208.120	12417.0	1242.50	183.00	10943.5	1092.50	153.480	9178.30	916.29
31	139.620	8444.7	642.25	123.91	7940.3	570.00	105.460	6757.70	485.10
33	115.950	7884.5	359.44	103.67	7049.6	321.38	89.240	6068.50	276.65
35	84.784	6104.5	107.68	76.31	5499.6	96.92	66.358	4777.80	84.27
37	66.325	5028.7	-54.39	60.31	4552.0	-43.23	52.647	3991.70	- 43.17
39	25.086	1969.2	-61.46	22.79	1784.0	-55.84	20.092	1577.20	- 49.23
Σ	+1988.378	+ 95400.1	+ 13336.59	+1618.92	+ 80452.0	+10735.22	+ 1218.189	+ 64231.34	+7812.62

Summation of Arch Properties Due to Loading (Continued)

Point	$(x-a)\frac{\Delta s}{I}$	$(x-a)x\frac{\Delta s}{I}$	$(x-a)y\frac{\Delta s}{I}$	$(x-a)\frac{\Delta s}{I}$	$(x-a)x\frac{\Delta s}{I}$	$x-ay\frac{\Delta s}{I}$	$(x-a)\frac{\Delta s}{I}$	$(x-a)x\frac{\Delta s}{I}$	$(x-a)y\frac{\Delta s}{I}$
3				Load at 25 9494 31	6084	43673	Load at 25 12992	722.3	92.03 27
5				1422 33	967.0	44.083	30.193	1805.5	180.25 29
7				1460 35	1051.0	18.538	28.372	1818.1	130.51 31
9				14.23 37	1078.1	- 11.667	28.978	1970.5	89.83 33
11				6.064 39	475.9	- 14.857	24.780	1784.1	31.47 35
13				+58.603 Σ	+ 4181.0	+ 79.77	21.785	1651.8	- 17.86 37
15	Load at 19 16.314	481.28	144.87				8.873	692.65	- 21.62 39
17	36.221	1228.3	332.51				Σ + 155.33	+ 10446.0	+ 484.61
19	47.126	1801.6	434.50	Load at 11 15.624	597.31	144.06			
21	75.731	3229.9	689.61	37.931	1617.7	342.89			
23	75.281	3535.2	648.92	95.148	2120.1	382.17	Load at 21 14.911	700.2	128.53
25	109.160	5598.6	867.69	72.715	3729.6	578.09	36.148	1854.1	287.38
27	92.235	5125.5	653.12	65.782	3655.5	465.74	30.239	2180.4	277.81
29	122.760	7342.9	732.86	91.885	5493.0	548.38	60.847	3638.6	363.26
31	86.247	5526.7	396.73	66.926	4288.6	307.86	47.538	3046.2	218.67
33	74.224	5047.2	230.10	54.119	4010.6	183.27	43.962	2982.5	136.28
35	55.996	4031.7	71.116	45.815	3273.8	57.88	35.118	2528.4	44.60
37	44.956	3408.6	- 36.864	37.221	2822.1	- 30.521	29.459	2233.6	- 24.157
39	17.284	1356.8	- 42.34	14.434	1133.0	- 35.362	11.625	912.6	- 28.84
Σ	+853.555	+47723	+ 5117.82	+552330	+32741.5	+2951.46	+318.847	+20076.6	+14 03.89

COMPUTATIONS FOR $V_L - M_L - H_L - M_R$

POINT	d_1	d_2	d_3	LOG d_1	LOG d_2	LOG d_3	LOG $\frac{d_1}{C_1}$	$\frac{d_1}{C_1}$	LOG $\frac{d_2}{C_2}$
1	-1988.378	-1336.88	954012	3.2984990	4.1250543	4.9795538	0.7306014	5.37776	0.6620352
5	-1018.923	-1073.89	809531	3.2092262	4.0308380	4.9082334	0.6413286	4.37853	0.5678189
9	-1218.189	-781.375	642320	3.0857147	3.8928595	4.8077514	0.5178171	3.29471	0.4298404
13	-853.535	-511.933	477130	2.9312213	3.7092131	4.6786367	0.3633237	2.30347	0.2461940
17	-552.330	-295.818	327421	2.7421986	3.4708900	4.5151065	0.1743010	1.49383	0.0072709
21	-318.847	-140.563	200772	2.5035823	3.1478710	4.3027031	9.9356847	0.862352	9.6848519
25	-155.930	-48.619	104456	2.1929297	2.6868060	4.0189334	9.6250321	0.421728	9.2237869
29	-58.603	-8.103	41816	1.7679198	1.9086453	3.6213425	9.2000222	0.15850	8.8456267
33	-15.1360	+7.16	113886	1.1800111	0.8549130	3.0564704	8.6121135	0.040937	7.3918939
37	-0.88806	+41.80	6841	9.9390498	1.6245833	1.8339181	7.3711522	0.0023505	8.1115642

POINT	$\frac{d_2}{C_2}$	LOG $\frac{d_3}{C_3}$	$\frac{d_3}{C_3}$	C_1	C_2	LOG C_1	LOG C_2	LOG $\frac{C_2}{A_1}$	$\frac{C_2}{A_1}$
1	-4.59235	0.8409789	6.93392	1.55616	2.34157	0.1920642	0.3695072	2.6403603	436.878
5	-3.69674	0.7696585	5.88381	1.50528	2.18707	0.1776173	0.3398626	2.6259134	422.594
9	-2.69055	0.6691765	4.66849	1.37378	1.97794	0.1379172	0.2962131	2.5862233	386.677
13	-1.76276	0.5400618	3.46786	1.15939	1.70510	0.0642296	0.2317244	2.5125357	325.488
17	-1.01688	0.3765316	2.37475	0.88592	1.36287	9.9473945	0.1344544	2.3951006	248.714
21	-0.484007	0.1641282	1.45425	0.59690	0.97524	9.7759016	0.9891115	2.2242077	167.574
25	-0.167412	9.8803585	0.759204	0.337476	0.591792	9.5282480	9.7721676	1.9765541	94.7445
29	-0.0279014	9.4827676	0.303926	0.14543	0.276025	9.1626540	9.4409406	1.6109601	40.828
33	-0.0024654	8.9178955	0.082774	0.0418 37	0.080309	8.6215605	8.9047642	1.0698666	11.745
37	-0.0014507	7.6953332	0.0049583	0.0026078	0.006404	7.4162743	7.8867903	9.8645804	0.73212

COMPUTATIONS FOR V_L - M_L - H_L & M_R

POINT	LOG $\frac{C_1}{A_1}$	$\frac{C_1}{A_2}$	F_1	LOG F_1	LOG $\frac{E_1}{D}$ = V_L	LOG $\frac{B_2 V_L}{A_2}$	$\frac{B_2}{A_2} V_L$	M_L
1	2.0338086	108.096	- 328.782	2.5169080	9.9992965	+.998381	2.0380859	- 109.166	-1.070
5	2.0041640	100.963	- 321.631	2.5073579	9.9847464	.976667	2.0285358	- 106.791	- 5.828
9	1.9605145	91.309	- 294.368	2.4688906	9.9512791	.893380	1.9900685	- 97.539	- 6.430
13	1.8960258	78.709	- 246.779	2.3923082	9.8746967	.749311	1.9134861	- 81.938	- 3.229
17	1.7987558	62.915	- 186.799	2.2690434	9.7514319	.564198	1.7902213	- 61.691	+ 1.224
21	1.6534129	46.021	- 122.553	2.0883239	9.5707124	.372145	1.6095018	- 40.691	+ 4.330
25	1.4364690	27.319	- 67.925	1.8288210	9.3112095	.204743	1.3499989	- 22.387	+ 4.432
29	1.1062420	12.742	- 28.086	1.4484899	8.9308784	.082286	0.8696678	- 9.325	+ 3.417
33	0.5690656	3.7074	- 8.038	0.9051480	8.3875365	.024408	0.4263259	- 2.6688	+ 1.038
37	8.6383984	-0.04349	+ 0.4361	9.6395861	7.1219646	.001324	9.1607540	- 0.0448	+ 0.1586

POINT	LOG M_L	LOG $\frac{a}{c} M_L$	$\frac{a}{c} M_L$	LOG $\frac{b}{c} V_L$	$\frac{b}{c} V_L$	H_L	$V_L L$	1000(L-a)	$H_L \Sigma \Delta y$	M_R
1	0.0273339	9.1919923	+ 0.155594	0.7430926	- 5.53468	0.01333	+74.2115	+78.14	+ 0.04106	+ 0.084
5	0.7659195	9.9281280	+ 0.847477	0.7335425	- 5.41430	+ 0.18829	77.4887	+ 71.06	+ 0.57993	+ 1.209
9	0.8082110	9.9708195	+ 0.935017	0.6950152	- 4.95536	+ 0.72563	70.9204	+ 62.74	+ 2.2349	+ 3.9249
13	0.5096680	9.6716765	+ 0.469544	0.6184928	- 4.15425	+ 1.37624	59.4551	+ 54.08	+ 4.23882	+ 6.3238
17	0.0771814	9.2503899	- 0.177988	0.4952280	- 3.12772	+ 1.81198	44.7635	+ 45.37	+ 5.5808	+ 6.1372
21	0.6364879	9.7990964	- 0.629646	0.3145025	- 2.06301	+ 1.83031	25.5760	+ 36.63	+ 5.63735	+ 2.8022
25	0.6933231	9.8556316	- 0.717186	0.0550056	- 1.13502	+ 1.43048	16.2443	+ 27.99	+ 4.40588	- 2.4676
29	0.6451274	9.8062541	- 0.636883	9.6746683	- 0.47279	+.081118	6.7666	+ 19.48	+ 2.49843	- 6.7977
33	0.0161974	9.1788059	- 0.150941	9.1313326	- 0.13531	+ .24531	1.9366	+ 11.28	+ 0.76555	- 7.6095
37	9.1794369	8.3420474	- 0.021981	7.8710531	- 0.0074311	+ 0.0450	0.10505	+ 0.78	+ 0.1386	- 3.3367

REACTIONS FOR 30000# LOAD.

POINT	M_L	H_L	$\frac{M_L}{H_L}$	V_L	M_R	$\frac{M_R}{H_L}$
1	-29560	+400	- 7390	+29958	+ 2520	+ 6.30
5	-174840	+ 5649	- 30.95	+29300	+ 16250	+ 5.953
9	-192900	+21769	- 8.86	+ 26816	+ 50700	+ 5.409
13	- 96870	+41287	- 2.34	+ 22491	+ 62560	+4.595
17	+ 36720	+ 54359	+ 0.675	+ 16925	+ 16740	+ 3.387
21	+ 129900	+ 54909	+ 2.36	+ 11164	- 85020	+ 1.538
25	+ 147960	+ 42914	+ 3.44	+ 6192	-206220	- 1.725
29	+ 102510	+ 24335	+ 4.21	+ 2559	- 264900	- 8.38
33	+ 31140	+ 7359	+ 4.23	+ 732	- 250950	- 34.01
37	+ 5940	+ 1350	+ 4.4	+ 120	-100100	- 74.05

MOMENTS, SHEARS & THRUSTS FOR 30000# LOAD

	LOAD AT 1			AT 5			AT 9		
	THRUST	SHEAR	MOMENT	THRUST	SHEAR	MOMENT	THRUST	SHEAR	MOMENT
1	+14300 + 300	+ 26500 - 300	+12.15 +4860	+18600	+ 23400	- 2530 - 142920	+31800	+13650	- 80 -174150
5	+ 400	- 250	+ 8.00 +3200	+15750 + 5000	+25150 - 2700	+ 8.50 +48000	+ 30200	+17000	- 245 -53300
9	+ 400	- 200	+43.5 +1700	+5300	-2150	+4.83 26190	+27900 + 20200	+20300 - 8650	- 15.38 +11700
13	+ 400	- 100	+ 1.5 +600	+5500	- 1500	+ 174 +9830	+21000	- 6250	+ 2.75 +48980
17	+ 400	0	- 45 -180	+5600	- 950	- 930 1645	+21600	-4940	+ 0.05 1090
21	+ 500	0	- 135 - 540	+5700	- 400	- 130 - 7345	+21700	-1820	+ 1.10 +23450
25	+ 350	+ 100	- 100 - 520	+5700	+ 300	- 134 7550	+22000	+ 650	- 1.34 - 29200
29	+ 380	+ 100	- 0.23 - 132	+5600	+900	- 047 -2655	+21800	+ 2900	- 0.00 - 13060
33	+ 300	+ 200	+ 160 +640	+5800	+1500	+133 +7450	+21400	+ 5450	+ 1.05 + 22890
37	+ 300	+ 300	+495 +1890	+5300	+2100	+ 4.22 23.85	+20500	+7700	+ 3.80 82700

	LOAD AT 13			AT 17			AT 21		
	THRUST	SHEAR	MOMENT	THRUST	SHEAR	MOMENT	THRUST	SHEAR	MOMENT
1	+47200	+750	- 232 - 95780	+56100	- 10200	+ 240 21740	+5400	- 18500	+ 2.8 109800
5	+46650	+5750	-170 -70200	+56300	- 3600	- 0.65 - 35330	+55350	- 9000	+ 0.18 +9880
9	+45700	+11100	+8266 + 0.20	+56880	+2550	- 0.72 - 39150	+55450	- 3150	- 083 -45515
13	+44200 + 39750	- 13800 +16100	+ 3.20 +133130	+56250	+8700	+10830 + 0.80	+56000	+2445	- 080 -43930
17	+40950	-9200	+0.70 28900	+55050 +53800	+14900 - 15200	+ 2.10 +114150	+55350	+8900	+ 015 +8240
21	+41700	-4800	-070 -28800	+55000	-9600	+ 0.10 +5420	+56000 +54000	+15300 +14650	+2.10 115300
25	+41900	- 600	-1.21 -44990	+55750	- 3700	- 040 - 41990	+57250	-9250	+012 +6590
29	+41750	+4150	- 010 -33030	+55750	+2100	- 0.11 -44000	+57900	- 3100	- 080 -43930
33	+41000	+9000	+000 24770	+55200	+8600	+002 1090	+57800	+3600	- 070 - 38440
37	+39000	+13100	+310 +127990	+53700	+14200	+2.10 114150	+57000	+9600	+000 32450

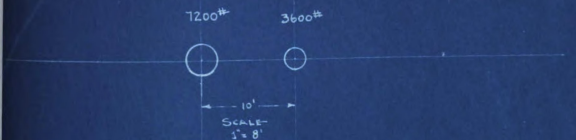
POINT	LOAD AT 29			AT 29		
	THRUST	SHEAR	MOMENT	THRUST	SHEAR	MOMENT
1	+41000	-14500	+30 +128000	+22900	-8700	+370 +49020
5	+42300	-9650	+075 +32200	+23650	-6300	+126 +30420
9	+43150	-5000	-021 -30470	+24200	-3700	-050 -19170
13	+43400	-300	-120 -51600	+24500	-1000	-125 -30420
17	+43200	+4400	-073 -31340	+24500	+1600	-110 -26780
21	+42450	+8800	+075 32200	+24100	+4100	-010 -2435
25	+41400 +43150	+13400 -16200	+310 +133030	+23500	+6700	+217 +51000
29	+47850	-11100	+025 +10730	+22650 +31000	+4190 -19200	+510 +124110
33	+48850	-5550	-145 +622225	+33050	-16100	-150 -36500
37	+49150	-600	-148 -83680	+34800	-12600	-165 -158180

POINT	AT 33			AT 37		
	THRUST	SHEAR	MOMENT	THRUST	SHEAR	MOMENT
1	+6950	-2700	+376 +27600	+1300	-500	+39 +5265
5	+7150	-1400	+125 +9200	+1250	-300	+18 +1620
9	+7500	-1000	-065 -141500	+1350	-200	-065 -870
13	+7800	-500	-150 -11040	+1300	00	-160 -2160
17	+7400	+500	-148 -10400	+1300	+100	-165 -2210
21	+7300	+1250	-048 -3540	+1200	300	-076 -1010
25	+7200	+2050	+160 +11040	+1300	+400	+12 +1620
29	+6900	+2750	+440 +32400	+1200	+550	+40 +5400
33	+18100 +6600	-24150 +3560	+81 59600	+1200	+700	+815 +11000
37	+21000	-21700	-1435 -142420	+16000 +4650	+11000 -26000	+123 +16600

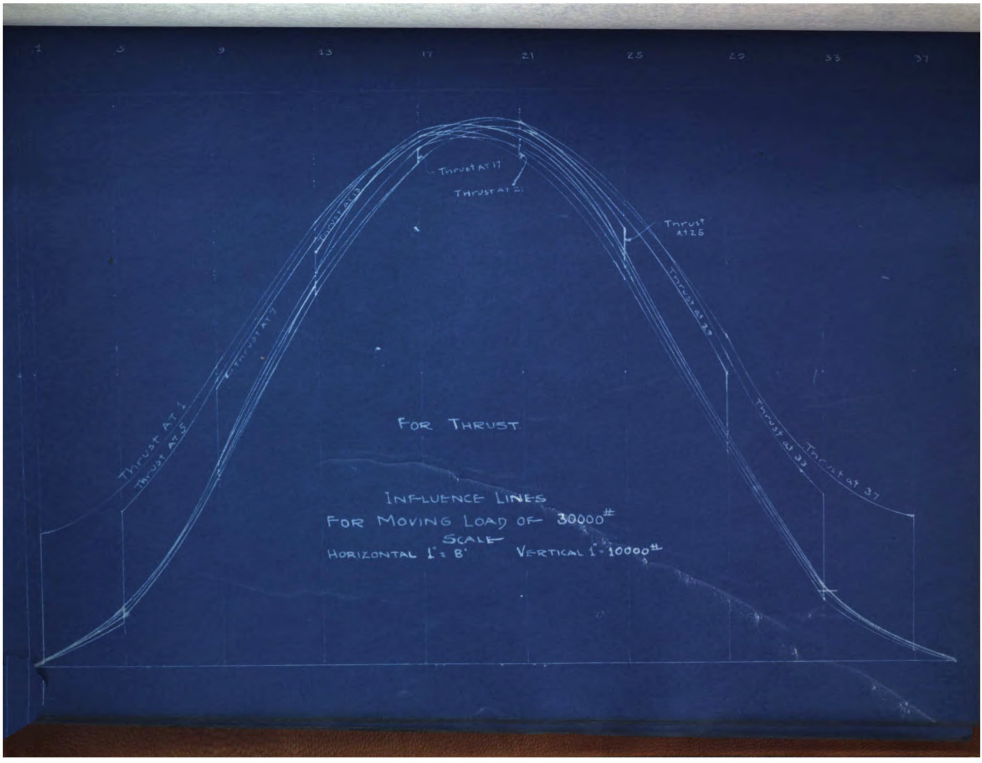
LOADING

LIVE LOAD UNIFORM - 100#/SQ FT.
ROAD ROLLER 18 TON - AS SHOWN
DEAD LOAD - SEE TABLE
WEIGHT OF CONCRETE - 150# CU. FT.
WEIGHT OF BACK FILL - 120# CU FT.

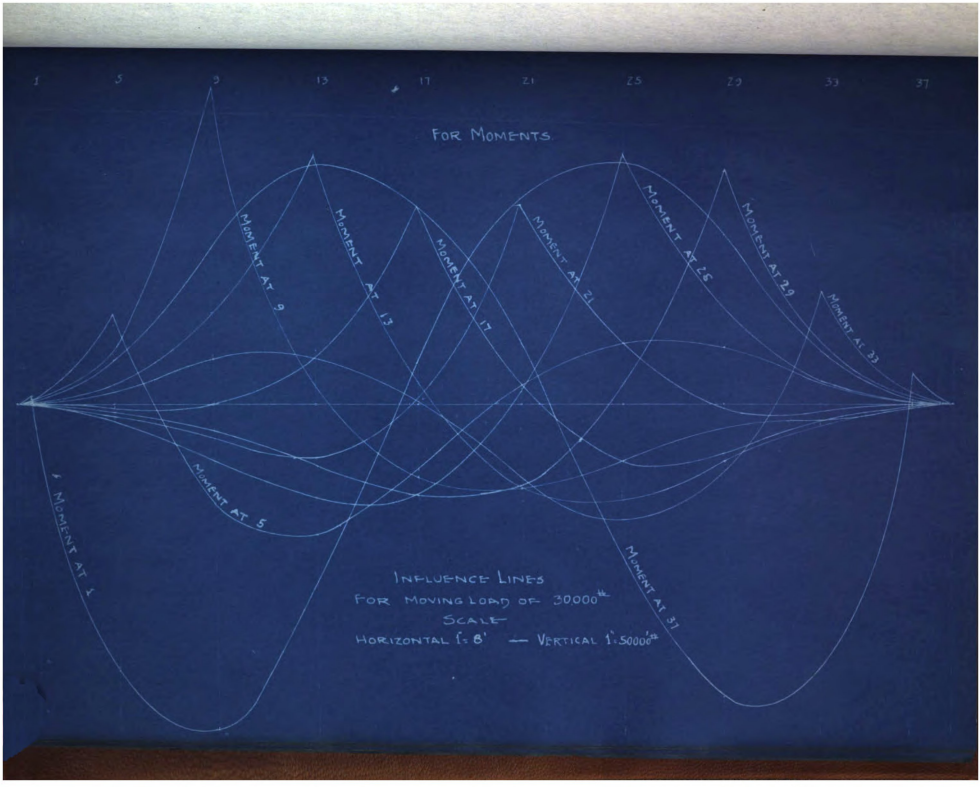
SECT.	DEAD LOAD
1	13840
5	30770
9	16680
13	10860
17	9088
21	8960
25	12280
29	18500
33	27600
37	39950

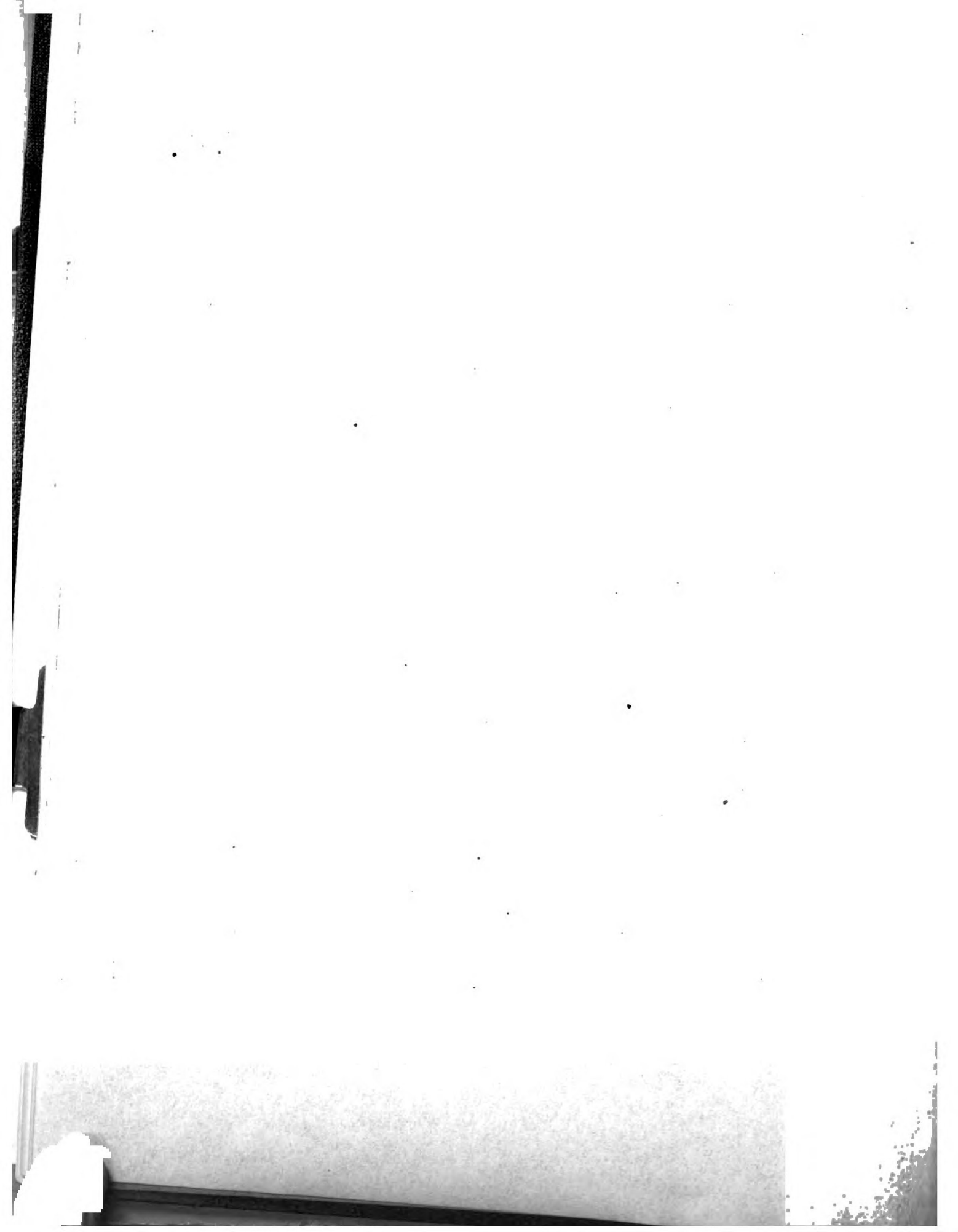


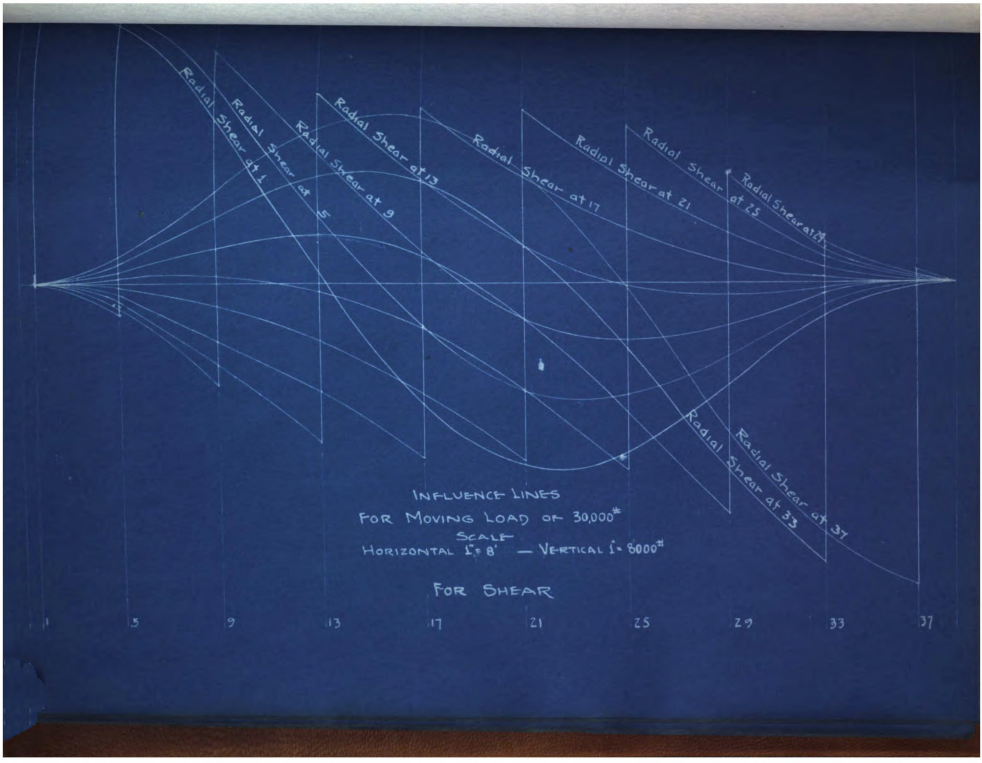
SLIDER FOR INFLUENCE LINES.
(CONCENTRATIONS FOR 3' SECTION)


1
5
9
13
17
21
25
29
33
37
Thrust at 17
Thrust at 21
Thrust at 25
Thrust at 1
Thrust at 5
Thrust at 9
Thrust at 13
Thrust at 29
Thrust at 33
Thrust at 37
For Thrust
Influence Lines
For Moving Load of 30000#
Scale
Horizontal 1" = 8'
Vertical 1" = 10000#

FOR MOMENTS


1
5
9
13
17
21
25
29
33
37
FOR MOMENTS
MOMENT AT 9
MOMENT AT 13
MOMENT AT 17
MOMENT AT 21
MOMENT AT 25
MOMENT AT 29
MOMENT AT 33
MOMENT AT 5
MOMENT AT 1
MOMENT AT 37
INFLUENCE LINES
FOR MOVING LOAD OF 30000#
SCALE
HORIZONTAL 1"=8' — VERTICAL 1"=50000'#s




Radial Shear at 1
Radial Shear at 5
Radial Shear at 9
Radial Shear at 13
Radial Shear at 17
Radial Shear at 21
Radial Shear at 25
Radial Shear at 29
Radial Shear at 33
Radial Shear at 37
INFLUENCE LINES
FOR MOVING LOAD OF 30,000#
SCALE
HORIZONTAL 1" = 8' — VERTICAL 1" = 8000#
FOR SHEAR
1
5
9
13
17
21
25
29
33
37

MOMENTS & THRUSTS (DUE TO MAX LOADING)

SECTION 1

	THRUST	MOM	LOADS
DL(W)	130520	-81120	ALL
LL 1	46655	-6240	"
" 2	4560	+31700	1-5-9-13 17-21-25 29-33-37
" 3	10112	-36200	5-9-13
RR 1	29000	+33580	1°9
" 2	11700	+66200	
" 3	8350	-88300	

SECTION 5

	THRUST	MOM	LOADS
	106880	+21622	ALL
	23730	-3120	"
	10824	+97800	1-5-21-25 29-33-37
	12904	-13020	9-13-17
	29000	-8250	
	13300	+11540	
	6600	-34500	

SECTION 9

	THRUST	MOM	LOADS
DL(W)	110395	+30600	ALL
LL 1	23110	+3280	"
" 2	4800	-14280	1-5-9-13
" 3	18312	-11000	1-5-21-25 33-37
RR 1	29000	-27600	
" 2	11150	+85200	
" 3	30600	-24300	

SECTION 13

	THRUST	MOM	LOADS
	105787	+24846	ALL
	22500	+3500	"
	8720	+15280	1-5-9-13-17
	13832	-11720	21-25-29 33-37
	29000	-7600	
	26000	+50700	
	23000	-27200	

SECTION 17

	THRUST	MOM	LOADS
DL(W)	104827	+336	ALL
LL 1	22110	+5040	"
" 2	12120	+10760	9-13-17-21
" 3	5992	-5720	1-5-25 29-33-37
RR 1	29000	+33800	
" 2	28000	+39600	
" 3	18700	-16800	

SECTION 21

	THRUST	MOM	LOADS
	104771	-13423	ALL
	22350	+3040	"
	12220	+10800	17-21-26
	10112	7760	1-5-9-13 29-33-37
	29000	+25600	
	26800	+45000	
	21600	-13700	

SECTION 25

	THRUST	MOM	LOADS
DL(W)	106682	+41721	ALL
LL 1	22910	+3080	"
2	9432	+15160	33-37 21-25-29 1-5-9-13-17
3	13480	-12080	
RR 1	24000	-13700	
" 2	20250	+56500	
3	26000	-27400	

SECTION 29

	THRUST	MOM	LOADS
	111312	+70070	ALL
	23130	+1000	"
	5840	+11600	25-29-33 37
	17258	-10600	1-5-9 13-17-21
	29000	-25600	
	11500	+47500	
	25200	-28000	

SECTION 33

	THRUST	MOM	LOADS
DL(W)	122483	+49422	ALL
LL 1	23830	-2200	"
2	9776	+8040	1-5-9-13 17-33-37
3	14056	-10240	21-25-29
RR 1	29000	-15700	
2	6660	+22800	
3	25200	-31800	

SECTION 37

	THRUST	MOM	LOADS
	144580	-11600	ALL
	24385	-1800	"
	14056	+32360	21-37 1-5-9-13-17
	10064	-33440	25-29-33
	29000	+30600	
	9550	+64300	
	16500	-82500	

Section	Max f_c #□"	Loading
1	522 Bottom Fibre	Case(a) & RR 3
5	352 Top Fibre	Case(a) & LL 2
9	550 Top Fibre	Case(a) & RR 2
13	550 Top Fibre	Case(a) & RR 2
17	370 Top Fibre	Case(a) & RR 2
21	309 Top Fibre	Case(a) & LL 3
25	665 Top Fibre	Case(a) & RR 2
29	665 Top Fibre	Case(a) & RR 2
33	310 Top Fibre	Case(a) & RR 2
37	246 Top Fibre	Case(a) & RR 3

$$f_c = \frac{T}{A_c} \pm \frac{Mc}{It}$$

Case (a) - Dead Load Moments & Thrusts
L.L.-1 Live Load Thrusts $_{(MAX)}$ with Corresponding Moments
L.L.-2 Max. Live Load Positive Moments & Thrusts
L.L. 3 Max Live Load Negative Moments & Thrusts
R.R. 1-2 & 3 Road Roller Loading Same as LL 1-2 & 3

Conclusion

It is to be noted that the allowed max unit stress of 650 #□" as specified in the State Highway Specifications is slightly exceeded (2%) at two points of the arch section. However, since the backfill was assumed at 120 #/cuft. the above determined unit stresses are conservative.

It is also to be noted that, due to lack of time, the effect of temperature and pier thrust from the opposing arch have been neglected. It is estimated that these would slightly exceed the conservative margin due to the above assumption of the weight of back-fill.

The effect of shortening due to thrust is, however fully considered in the method of analysis. It is found that the max shear at the crown is about 25 #/sq.in. and theoretically requires no stirrups here. Due to a lack of time analysis for shear stresses has not been made.

Finally, it is concluded that this arch is entirely safe, on the assumption of rigid abutments. Since piling has been used to a large extent the effect of unequal settlement should have been considered, but time did not permit.

SECTION	MAX f_c #□"	LOADING.
1	522 Bottom Fibre	Case(a) & RR 3
5	352 Top Fibre	Case(a) & LL 2
9	550 Top Fibre	Case(a) & RR 2
13	550 Top Fibre	Case(a) & RR 2
17	370 Top Fibre	Case(a) & RR 2
21	309 Top Fibre	Case(a) & LL 3
25	665 Top Fibre	Case(a) & RR 2
29	665 Top Fibre	Case(a) & RR 2
33	310 Top Fibre	Case(a) & RR 2
37	246 Top Fibre	Case(a) & RR 3

$$f_c = \frac{I}{Ac} \pm \frac{Mc}{It}$$

Case (a) - DEAD LOAD MOMENTS & THRUSTS
L.L.-1 LIVE LOAD THRUSTS (MAX) WITH CORRESPONDING MOMENTS
L.L.-2 MAX. LIVE LOAD POSITIVE MOMENTS & THRUSTS
L.L. 3 MAX LIVE LOAD NEGATIVE MOMENTS & THRUSTS
R.R. 1-2 & 3 ROAD ROLLER LOADING SAME AS LL 1-2 & 3

CONCLUSION

IT IS TO BE NOTED THAT THE ALLOWED MAX UNIT STRESS OF 650#□" AS SPECIFIED IN THE STATE HIGHWAY SPECIFICATIONS IS SLIGHTLY EXCEEDED (2%) AT TWO POINTS OF THE ARCH SECTION. HOWEVER, SINCE THE BACKFILL WAS ASSUMED AT 120#/CU.FT. THE ABOVE DETERMINED UNIT STRESSES ARE CONSERVATIVE

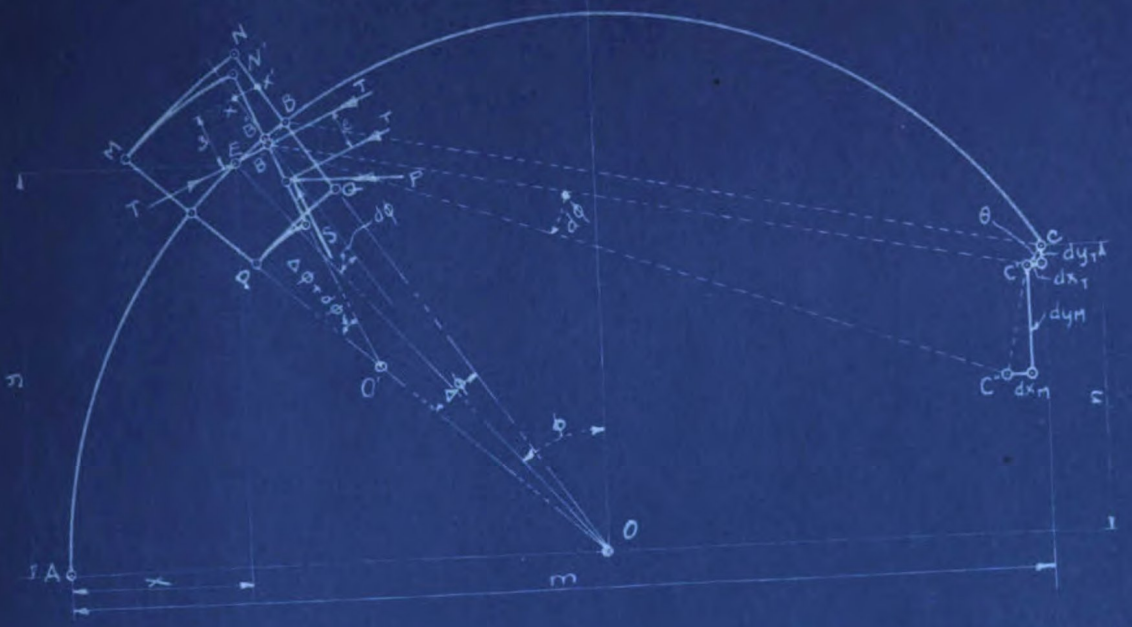
IT IS ALSO TO BE NOTED THAT, DUE TO LACK OF TIME, THE EFFECT OF TEMPERATURE AND PIER THRUST FROM THE OPPOSING ARCH HAVE BEEN NEGLECTED. IT IS ESTIMATED THAT THESE WOULD SLIGHTLY EXCEED THE CONSERVATIVE MARGIN DUE TO THE ABOVE ASSUMPTION OF THE WEIGHT OF BACK-FILL

THE EFFECT OF SHORTENING DUE TO THRUST IS, HOWEVER FULLY CONSIDERED IN THE METHOD OF ANALYSIS. IT IS FOUND THAT THE MAX SHEAR AT THE CROWN IS ABOUT 25#/SQ.IN. AND THEORETICALLY REQUIRES NO STIRRUPS HERE DUE TO A LACK OF TIME ANALYSIS FOR SHEAR STRESSES HAS NOT BEEN MADE.

FINALLY, IT IS CONCLUDED THAT THIS ARCH IS ENTIRELY SAFE, ON THE ASSUMPTION OF RIGID ABUTMENTS. SINCE PILING HAS BEEN USED TO A LARGE EXTENT THE EFFECT OF UNEQUAL SETTLEMENT SHOULD HAVE BEEN CONSIDERED, BUT TIME DID NOT PERMIT.

APPENDIX

THEORETICAL ANALYSIS OF ARCH



FUNDAMENTAL FORMULAE:—

LET ABCD 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, $Te = M$. THESE SHEARS ARE SMALL IN ORDINARY ARCHES AND ARCH THEORIES NEGLECT THEM IN THE THEORY OF STRESSES, JUST AS IS DONE IN THE COMMON THEORY OF FLEXTUR FOR BEAMS. THIS LEAVES THEN FOR THE CONSIDERATION, THE TWO AGENTS, THRUST & BENDING MOMENT ON THE SECTION. THESE BOTH VARY WITH THE DIFFERENT SECTIONS OF THE ARCH RING. T SHORTENS THE SECTION DB UNIFORMLY AN AMOUNT $\frac{T\Delta s}{AE}$. A RISE OF TEMPERATURE LENGTHENS THE SECTION DB BY AN AMOUNT $et\Delta s$ THE RESULTANT LENGTHENING OF THE SECTION $DB = -BB' = et\Delta s - \frac{T\Delta s}{AE}$. A NEGATIVE VALUE OF M WILL CAUSE SECTION DB TO DEFORM IN THE DIRECTION DB" CHANGING $\Delta\phi$ BY AN AMOUNT $d\phi$. ϕ IS MEASURED FROM THE CROWN. POSITIVE TO THE LEFT, NEGATIVE TO THE RIGHT. HENCE THIS CHANGE $d\phi$ IS NEGATIVE AT xx' THE $\Delta\phi = \frac{M\Delta s}{EI}$ BUT xx' $\Delta s = d\phi$. HENCE $d\phi = \frac{M\Delta s}{EI}$ AND SINCE M IS NEGATIVE WHEN $d\phi$ IS NEGATIVE THE EQUATION HOLDS TRUE FOR SIGN

NOW IMAGINE THAT FOR ANY ARCH LOADING, STARTING AT A, EACH SECTION IS TAKEN IN ORDER AND ITS EFFECT ON THE ARCH FOUND SEPARATELY AND IN TURN. THEN MD MAY BE REGARDED AS FIRMLY FIXED TO THE LAST DEFORMED SECTION PRECEDING 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, WHOSE COORDINATES ARE (m n). THE CHANGE IN Δs, BB" DUE TO THRUST AND TEMPERATURE WILL PRODUCE AN EQUAL CHANGE CC' AT C. ALSO THE CHANGE IN $d\phi$ DUE TO M WILL PRODUCE A CHANGE AT C, C'C" SUCH THAT $C'B''C' = d\phi$. THE INCREASE IN THE SPAN m. DUE TO THRUST & TEMPERATURE ON THIS SECTION ALONE $= -dx_T = -CC'\cos\phi = -BB'\frac{\Delta x}{\Delta s} = et\Delta x - T\frac{\Delta x}{AE}$. THE INCREASE IN RISE, n. DUE TO THRUST & TEMPERATURE ON THIS SECTION ALONE $= -dy_T = -CC'\sin\phi = -BB'\frac{\Delta y}{\Delta s} = et\Delta y - T\frac{\Delta y}{AE}$. THE INCREASE IN SPAN M DUE TO A POSITIVE BENDING MOMENT M WILL BE dx_M. BUT $\frac{dx_M}{C'C''} = \frac{dx_M}{B'C'\cdot d\phi}$ HENCE $dx_M = (y-n)d\phi = \frac{My\Delta s}{EI} - n\frac{M\Delta s}{EI}$. THE INCREASE IN RISE, n. DUE TO A POSITIVE BENDING MOMENT M WILL BE dy_M. BUT $\frac{dy_M}{C'C''} = \frac{dy_M}{B'C''d\phi} = \frac{m-x}{BC''}$ OR $dy_M = (m-x)d\phi = \frac{Mx\Delta s}{EI} + \frac{m M\Delta s}{EI}$.

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—

$dx = e t \Delta x - \frac{T \Delta x}{AE} - \frac{M y \Delta s}{I} - \frac{n T \Delta s}{A}$. THE TOTAL INCREASE IN RISE n DUE TO A THRUST T, A RISE IN TEMPERATURE OF $t°$ F, A POSITIVE BENDING MOMENT M ACTING UPON THIS SECTION ALONE WILL BE $dy = e t \Delta y - \frac{T \Delta y}{AE} - \frac{M x \Delta s}{I} + \frac{m M \Delta s}{AE}$

IN A FIXED ARCH THE FOLLOWING CONDITIONS ARE ASSUMED

1. THE RADIAL LINES AT THE SPRINGING REMAIN UNCHANGED IN DIRECTION. THUS SUMMING UP $d\phi$ FOR ALL SECTIONS BETWEEN SPRINGING POINTS $\sum_a^b d\phi = \sum_a^b \frac{M \Delta s}{EI} = 0$
2. THE SUPPORTS ARE FIXED AN IMMOVABLE DISTANCE APART, OR ARE RIGID. THUS $\sum dx = \sum e t \Delta x - \sum \frac{T \Delta x}{AE} + \sum \frac{M y \Delta s}{EI} = 0$ SINCE $\sum \frac{m M \Delta s}{EI}$ BECOMES $0 \sum \frac{M \Delta s}{EI} = 0$
3. THE SUPPORTS ARE RELATIVELY IMMOVEABLE IN ELEVATION. THEN $\sum_a^b dy = \sum_a^b e t \Delta y - \sum_a^b \frac{T \Delta y}{AE} - \sum_a^b \frac{M x \Delta s}{EI} = 0$ SINCE THE TERM $\sum_a^b \frac{m M \Delta s}{EI}$ BECOMES $m \sum_a^b \frac{M \Delta s}{EI}$ AND SINCE $\sum_a^b \frac{M \Delta s}{EI} = 0$

FROM THE FIGURE BELOW $M = M_L + V_L x - H_L y - W_V (x-a) - W_H (y-b)$ $x > a$

$T = H_L \cos\phi + V_L \sin\phi + W_H \cos\phi$ $x > a$ $- W_L \sin\phi$ $x > a$

SUBSTITUTING THESE VALUES IN EQUATIONS 1, 2 & 3 THEY BECOME—

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

REWRITING THESE 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 $M_L \left(\frac{a_1}{c_1} - \frac{a_3}{c_3}\right) = -\frac{b_1}{c_1} V_L - \left(\frac{d_1}{c_1} - \frac{d_3}{c_3}\right)$ 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 $M_L = \frac{B_2}{A_2} V_L + \frac{C_2}{A_2}$

SOLVING THE LAST TWO EQUATIONS GIVES $\left(\frac{B_1}{A_1} - \frac{B_2}{A_2}\right) V_L = \left(\frac{C_2}{A_2} - \frac{C_1}{A_1}\right)$ OR $D_1 V_L = E_1$ OR $V_L = \frac{E_1}{D_1}$

BUT FOR SYMETRICAL ARCHES $A_2 = 0 \quad \therefore V_L = \frac{C_2}{B_2}$

THE FOLLOWING ITEMS ARE CONSTANTS FOR ANY GIVEN ARCH AND ARE INDEPENDENT OF THE LOADING :- $a_1 a_2 a_3 \; b_1 b_2 b_3 \; c_1 c_2 c_3 \; A_2 . B_2 . B_1$

THEIR VALUES FROM ABOVE ARE,

$A_2 = \frac{a_2}{c_2} - \frac{a_3}{c_3}$

$a_1 = \sum_a^b \frac{\Delta s}{I}$ $\quad b_1 = \sum_a^b \frac{x \Delta s}{I}$ $\quad c_1 = -\sum_a^b \frac{y \Delta s}{I}$ $\quad B_1 = \frac{b_1}{c_1} - \frac{b_2}{c_2}$

$a_2 = \sum_a^b \frac{y \Delta s}{I}$ $\quad b_2 = \sum_a^b \frac{x y \Delta s}{I} - \sum_a^b \frac{\Delta x \sin\phi}{A}$ $\quad c_2 = -\sum_a^b \frac{y^2 \Delta s}{I} - \sum_a^b \frac{\Delta x \cos\phi}{A}$ $\quad B_2 = \frac{b_2}{c_2} - \frac{b_3}{c_3}$

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

THE FOLLOWING TERMS ARE DEPENDENT UPON THE LOADING; $d_1 d_2 d_3 \; c_1 c_2 c_3$

THEIR VALUES FROM ABOVE ARE $\quad C_1 = \frac{d_1}{c_1} - \frac{d_3}{c_3} \quad C_2 = \frac{d_2}{c_2} - \frac{d_3}{c_3}$

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

$d_2 = E e t \sum_a^b \Delta x - W_V \left[\sum_a^b \frac{(x-a) y \Delta s}{I} - \sum_a^b \frac{\Delta x \sin\phi}{A}\right] - W_H \left[\sum_a^b \frac{(y-b) y \Delta s}{I} + \sum_a^b \frac{\Delta x \cos\phi}{A}\right]$

$d_3 = E e t \sum_a^b \Delta y - W_V \left[\sum_a^b \frac{(x-a) x \Delta s}{I} + \sum_a^b \frac{\Delta y \sin\phi}{A}\right] - W_H \left[\sum_a^b \frac{(y-b) x \Delta s}{I} - \sum_a^b \frac{\Delta y \cos\phi}{A}\right]$

FROM NOTES ON ELASTIC ARCHES
BY PROF C.A. MELICK.

Outline for Unsymmetrical Arch.

1. Make large scale drawing of full arch

2. Divide intrados into 20 equal parts and locate C.of G. of each radial transformed section. Tabulate:

3 Thru points obtained draw linear arch and thru springing points of intrados draw true abutment lines radial to linear arch. Now start at left abutment and divide linear arch into 20 equal parts. Find centers of each of these parts numbering them 1-3-5-···39. and the boundaries of each section 0-2-4-·····40

4. Scale and tabulate the values of Δx & Δy for each center. Also ϕ. Calculate the values of Δx & Δy from the formulae:- $\Delta x_n = 2(x_n - x_{n-1}) - \Delta x_{(n-1)}$; $\Delta y = 2(y_n - y_{n-1}) - \Delta y_{(n-1)}$. Being careful to use the proper sign. Then $\Delta s^2 = \Delta x^2 + \Delta y^2$.

5. For each of the above center points scale the depths of the radial joints (h) and locate the steel. Compute areas & moments of inertia of the transformed sections.

6. Calculate and tabulate for center points values of $\frac{\Delta s}{I}$, $x\frac{\Delta s}{I}$, $y\frac{\Delta s}{I}$, $xy\frac{\Delta s}{I}$, $x^2\frac{\Delta s}{I}$, $y^2\frac{\Delta s}{I}$, $\frac{\Delta s}{A}$, $x\frac{\Delta s}{A}\cos\phi$, $y\frac{\Delta s}{A}\cos\phi$, $x\frac{\Delta s}{A}\sin\phi$, $y\frac{\Delta s}{A}\sin\phi$

7. For a 30000# load at points; 1-5-9-13-17-21-25-29-33-37, calculate & tabulate values of $(x-a)\frac{\Delta s}{I}$, $(x-a)x\frac{\Delta s}{I}$, $(x-a)y\frac{\Delta s}{I}$.

8. Sum up the above tabulations and make a table of arch constants, $a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3, A_1, A_2, B_1, B_2$

9. Sum up and tabulate for each of the loads the values of the constants $d_1, d_2, d_3, C_1, C_2, D_1, E_1$.

10. Make a tabulated solution for M_L, V_L, H_L, M_R. where $M_R = M_L + V_L m - H_L n - W_n(m-a)$

11. Construct on the linear arch the true equilibrium polygon for each load. Resolve each reaction into its thrust & shear components at points 1-5-9-13-17-21-25-29-33-37

12. Plat influence curves for moments, thrusts, & shears tabulating values scaled from same.

13. Find & tabulate values of actual dead loads, uniform live load & equivalent concentrated wheel loads.

14 Make a table of dead load moments thrusts & shears at points 1-5-9-·····37.

15. Make a table of live load moments thrusts & shears for d.-Thrusts Max. & Positive. Moments Max.-c.-Neg. Moments Max.-d.-Shears Max. Positive or Negative, Stating loading & position of same.

16 Calculate Max. f_c & f_s for the following combinations of loading 3. Max Resultant Thrust, & Max Resultant Moment Pos. & Max Resultant Moment Neg. C

17. Tabulate Max. Average shear on concete- Test for Stirrups.

18 Tabulate Temperature stresses for a rise or fall of 40°F. Also Max Resultant stresses when combined with those of (16)

COMPLETED STRUCTURE

SIDE ELEVATION
2-SPANS, 80' CLEAR

SIDE ELEVATION

COMPLETED STRUCTURE

SHOWING ROADWAY
18' IN THE CLEAR

CENTER PIER

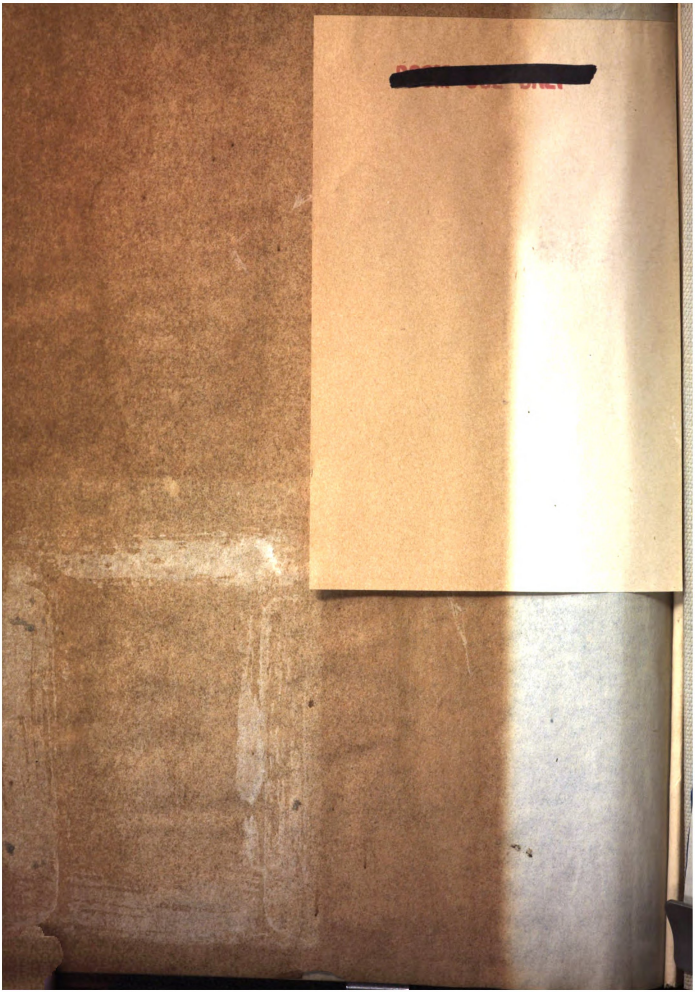
SIDE ELEVATION OF FORMS

SIDE ELEVATION OF FORMS

FALSE WORK

CONCRETEING PLANT.

THE ARCH UNDER CONSTRUCTION



Pocket
has: 1 Plan

12
76
TH
Pla

SUPPLEMENTARY
MATERIAL