DESIGN OF A SMALL, SUBMERGED DAM FOR THE IMPROVEMENT OF POTTER PARK

THESIS FOR THE DEGREE OF B. S.

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Design of a Small, Submerged Dam for the Improvement of Potter Park

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INTRODUCTION

The site of the proposed dam is located not in Potter Park proper, but in a small addition to Potter Park, known as Trager Park.

For many years a canoe and boating livery has operated in Trager Park at a point just below, and west of the Pennsylvania Avenue Highway Bridge, making canoeing and boating accessible to all those who enjoy the sport.

In midsummer, however, a condition of low flow takes place rendering the river unsightly and evil smelling, and it is for this reason that the building of the proposed dam is being investigated.

We, the authors of this thesis, wish at this point to acknowledge the valuable aid and assistance given us by several of the city of Lansing's technical staff, especially Mr. Bancroft, the city forester, and chief of the park department.

In the past three years a number of channels have been dredged out in the east end of Potter Park and last year a number of rustic wooden bridged varying from about 18-25 feet in length were built across the channel. We have shown the majority of these bridges and channels on our topographic map, and also the topography of the park adjacent to the river. A complete map of the park was not needed for the purpose of this thesis, and so to save time, we took only the data that was necessary, and omitted many details of the park layout which were interesting, but which were not required.

In view of the original cost of this park (which is a large park for a city the size of Lansing) and the cost of maintenance we shall take the liberty to criticize the park in a friendly manner, and also to suggest improvements in the park.

We must confess that at the start of this thesis, we were somewhat sceptical as to the practicibility of a dam, but now we are thoroughly convinced that it is practical, and also necessary if full benefit is to be realized from the expenditures made in Potter Park.

PROCEDURE

The first and one of the most important details of our thesis was a comprehensive topographic map of the park, showing the differences in elevations of the ground and showing the lower regions of the park that would be inundated by the water backed up by the proposed dam.

We were held back considerably on our survey by one of the latest springs for the past several years, and if we had waited for reasonable weather, we would have lost about four weeks time.

During adverse weather we confined our efforts to what information we could find at the City Engineer's and the City Forester's offices.

As soon as the flood waters had abated to somewhat near normal proportions we began our many and frequent trips to the park, putting in our travels with the many checks that go along with it, and then with that completed the almost endless task of "shooting" in the topography.

With the instrument at Station B we oriented ourselves by sighting at the N.E. abutment of the Pennsylvania Avenue Highway Bridge, distance 180', and azimuth 82 04', and also by sighting at the S.E. abutment of the Grand Trunk Railroad viaduct, distance 325', azimuth 145 00'. At this station we took a magnetic bearing, using that as our south point from which our aximuths were computed. We ran a check on Pennsylvania Avenue to compare its direction with our azimuth, and found it checked within reasonable limit. We then located our initial traverse point A in Trager Park, immediately to the west of Potter Park, distance 397', azimuth 110 10'. Also from Station B we located the third point on our traverse, Station C, distance 708', azimuth 292 29'. Thence to Station E, distance 778', azimuth 305 43'. Up to and including Station E our traverse ran practically parallel to the river, but at Station E we began to broaden it out to include the channels which began in that section. The next "shot" was to Station F, distance 395', azimuth 208 32'. Stations H, J, and K were the other stations in our traverse polygon. We then checked the traverse thus completed to Stations E and D. The polygon came 2' from closing.

With our control survey completed, we took topography that we thought would be of value to us, putting in prominent roads, etc., and also "shooting" in detail, the channel territory.

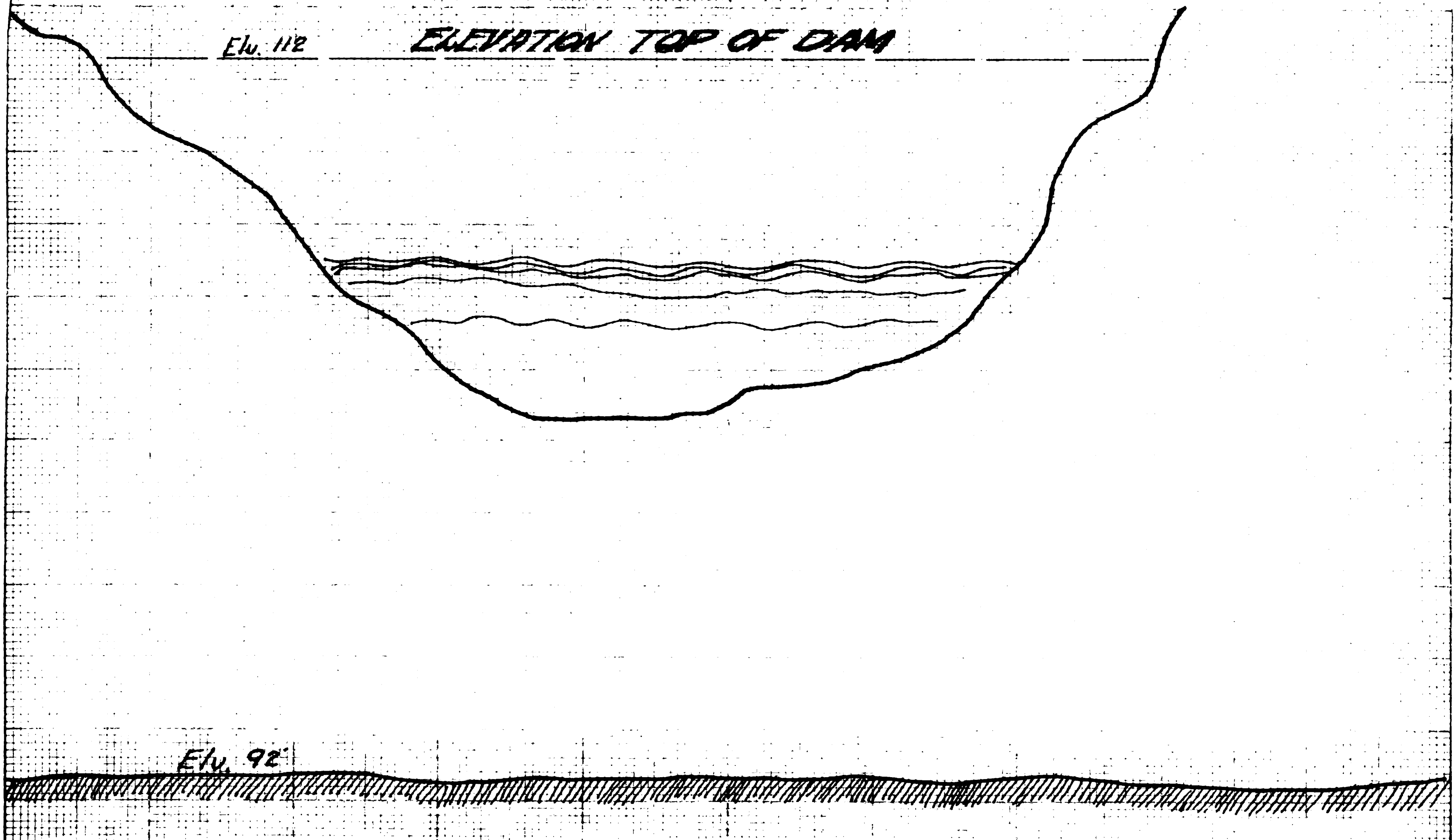
Our next problem was to obtain some sort of information as to the cross section of the river at the dam location, and to ascertain as close as possible the depth of existing rock layers at that point. The cross section of the river bottom was found by setting the transit at a point on the shore at the dam location, and using a stadia rod as the means to determine the different levels. We were somewhat handicapped by the fact that a canoe was our only means of navigating the river, and at its best this means of determining a cross section was faulty. To find rock we proceeded to drive a long pipe at intervals across the stream, but the results were discouraging. Not having the necessary equipment and not being able to locate any, we consulted Mr. Smith of the State Geology Department.

By the use of his records on certain wells in the vicinity of Potter Park, and from his maps, we estimated a good sandstone to be about 20' down from normal river level which is an elevation of 818' from the United States Coast and Geodetic Survey map. The strata at this point is approximately horizontal. Our maximum flood flow at this point was calculated from the records of the United States Gaging station at East Lansing. The additional flow from the East Lansing station to this point was in direct proportion to the respective drainage areas.

Stadia Survey of Portion of Potter Park Adjoining the Red Cedar River

Sta.	Dist.	Azimuth	Rod Rdg.	Vert ∠	Elev.	Remarks
⊼ at B	H.I. = 4.60				118.39	
Penn St. Br.	180'	82° 4'				N.E. Abut.
G.T.R.R. Br.	325'	145° 0'				S.E. "
B.M	263'			+1° 40'	126.04	S.E. end Penn Bridge
A	397'	110° 10'	6.66		116.33	
⊼ at A	H.I. = 4.55					
	300	339° 28'	8.65		112.23	
	294	345° 12		+1° 5'	117.78	
	265	343° 50'	8.78		112.13	
	238	355° 22'	8.7		112.18	Outfall
	250	358° 57'	0.26		120.36	
	190	9° 38'	8.52		112.53	
	175	26° 16'	8.78		112.10	
	190	"	1.00		119.88	
	180	52° 59'	0.40		120.48	
	170	"	8.75		112.13	
	124	330° 32'	8.35		112.53	
	55	344° 08'	8.76		112.11	
	45	91° 04	8.80		112.08	
⊼ at A	H.I. = 4.5				116.33	
	150	304° 31'		1° 47'	121.00	Road
	144	243° 20'	4.52		116.31	"
	133	292° 22'	3.32		117.51	Walk
	119	216° 47	3.96		116.87	"
	77	216° 53	3.72		117.11	
	57	165° 36'	4.09		116.74	
	120	161° 13'	4.10		116.73	
	93	126° 45'	5.74		115.09	
	22	76° 06'	5.75		115.08	
	70	334° 22'	6.60		114.23	
	110	327° 06'	7.35		113.48	Boathouse 35' long
	102	316° 9'	4.19		116.64	Boathouse
	84	292° 27	1.77		119.06	
	130	306° 07'	2.70		118.13	
	143	305° 56'		2° 2'	121.33	
	200	67° 19'	0.00		120.83	River
	180	68° 11'	8.55		112.28	
	220	88° 22	0.60		120.23	
	210	88° 56'	8.45		112.38	
	250	101° 55'		1° 18'	122.03	
	240	103° 48'	8.70		112.13	

Sta	Dist.	Azimuth	Vert. L	Rod Rdg	Elev.	Remarks
	330	116°16'		7.00	113.83	R.R. Bridge
	200	127° 0'		8.50	112.33	"
	156	133°10'		"	112.33	River
⊼ at B	H.I. = 4.60				118.40	
	108	292°59'		4.45	118.65	Line
	110	263°27'		5.60	117.40	Road ℄
	130	243°47'		6.28	116.90	"
	295	267°19'		6.20	116.80	"
	313	279°37'		5.95	117.05	
	330	307°40'		10.82	112.18	River
	200	320°15'		10.90	112.10	"
	190	115°25'		3.10	119.90	℄ Road on E. Barn
	205	123°12'		3.88	119.12	
B-C	708	292°29'	H.I. = 4.78	4.55	116.50	
C-D	698	286°56'	H.I. = 4.70	6.49	116.50	
D-E	778	305°43'	H.I. = 4.90	6.90	114.30	
E-F	395	208°32'	H.I. = 4.75	2.25	116.95	
F-H	450	306°10'	H.I. = 4.70	6.35	115.35	
H-J	512	287°20'	H.I. = 4.70	6.23	113.82	
J-K	885	57°51'	H.I. = 4.70	5.10	113.42	
K-E	614	151°13'				
E-D	780	125°40'				



GRAPH SHOWING RIVER CROSSECTION, ELEVATION OF DAM, AND BEDROCK

VERTICAL SCALE 4'=1" HORIZONTAL SCALE 20'=1"

Calculations

The principal volumes, which we used for reference purposes, are listed as follows:

Earth Dam Projects - - - Justin

Hydraulics - - - Schroeder and Dawson

Hydraulics - - - Russell

The Design and Construction of Dams - - - Wegmann

Water Power Engineering - - - Barrows

The notes shown in this thesis are only a small portion of the total notes taken, however, they are sufficient to indicate the type of survey that we made.

Because of the original cost of construction, and knowing that the park department would not be able to provide for the cost of an expensive structure, we investigated at length the many varieties of dams that seemed to be practical for the project.

We first considered the possibilities of a wooden dam, knowing that the original cost would be low because, of the fact, that the cost material would be low. Wood is the most durable of all structural materials, if it can be kept permanently submerged under water, this was one of the chief reasons for not building a dam of timber, because of low flow in the summer, which is characteristic of the Red Cedar River, a large portion of the structure would be exposed to the elements and would deteriorate rapidly.

We next considered the earth dam with a concrete spillway and its possibilities, but upon investigating we found that it was impractical due to heavy flood conditions, and would necessitate building such a large spillway that the dam, in order to avoid overtopping which is disastrous in the case of an earth dam, would be largely concrete instead of earth. To prevent erosion at the apron of the dam it would be necessary to construct a concrete retaining wall to guide the water from the spillway to the tail race.

After carefully considering the amount of concrete necessary for this type of dam we decided that it would be nearly as economical, and require only a small, additional amount of concrete to construct a spillway completely of concrete, and thus acquire a uniform structure of better appearance, and of a more durable nature.

The dam which we decided upon was of the gravity concrete spillway type. The first problem was to estimate the approximate dimensions, and after several trials the correct dimensions were obtained.

The formula used for determining the base was 0.7(H +h) which in our case was 16.8 or 17', however, we found that the length of base needed was 19.66'. The length 140', perpendicular to the direction of the stream, was determined by the topography of the banks. We next divided the structure into longitudinal sections, 4' in height, and found that the resultant of all the forces fell within the middle third of the section in each case. We also checked for shear, and for suitable values of pressure at the heel and toe. The forces which we considered were, 1st the water pressure acting at the center of pressure, 2nd, uplift, and 3rd, the weight of the dam itself. These are the major forces which we used in our computations. Ice, wind, and other minor forces were not considered in our design.

The elevation of the top of the spillway should be at 112', city datum, or 818' U. S. Coast and Geodetic Survey datum, the elevation would be to an elevation of 92', city datum.

To compute the number of cubic yards of concrete necessary we used the formula, $C = \frac{h^2 + 2Hh}{66} \times L$

$$\frac{20^2 + 2 \times 4 \times 20}{66} \times 140 = 1189 \text{ cubic yds.}$$

Which result will be found to accord fairly well with the actual dam section of these heights.

The spillway section of our thesis was designed to carry over it safely a sheet of water equivalent to that for the maximum flood discharge. The length of the spillway was fixed so as to limit the maximum head possible on its crest to about 4'

Another important consideration not occurring with an abutment section must be kept in mind in designing the upper part of the spillway section, that is, to so proportion the curve of the upper part of the spillway that the overfalling sheet of water will not leave it, but rather be guided steadily to the lower level and by a reverse curve be started horizontally downstream again without undue shock or wearing on the toe of the dam or its foundations.

The theoretical path of particles of water going over the dam will evidently vary with their initial velocity, which, however, will be greatest for the maximum head onthe crest.

The theoretical or base section for the spillway will be a trapezoid, which is the portion of a triangle of height (h+H), and base about 0.7(h+H).

It will be found that this section will satisfy the rules relating to position of resultant inside the middle third and that for sliding.

The crest of the trapezoid must be rounded somewhat in order to eliminate contraction of the flowing water, and allow floating material, such as ice, logs, etc., to pass the crest without injuring it. There should be a small, horizontal section to give room for placing and removing flashboards and also enough width to allow walking along the crest.

The curve just below the crest where the water starts falling approximates in form the parabola, the equation of which is $y=\frac{1}{2}\times g\times\frac{x^2}{v}$. The head H on the spillway enables the discharge per linear foot Q to be computed based on a suitable value of C in the formula $Q=CLH^{\frac{3}{2}}$. With the water area passing over the crest known the mean velocity may be computed. Then if x and y are coordinates of the parabola at any point:

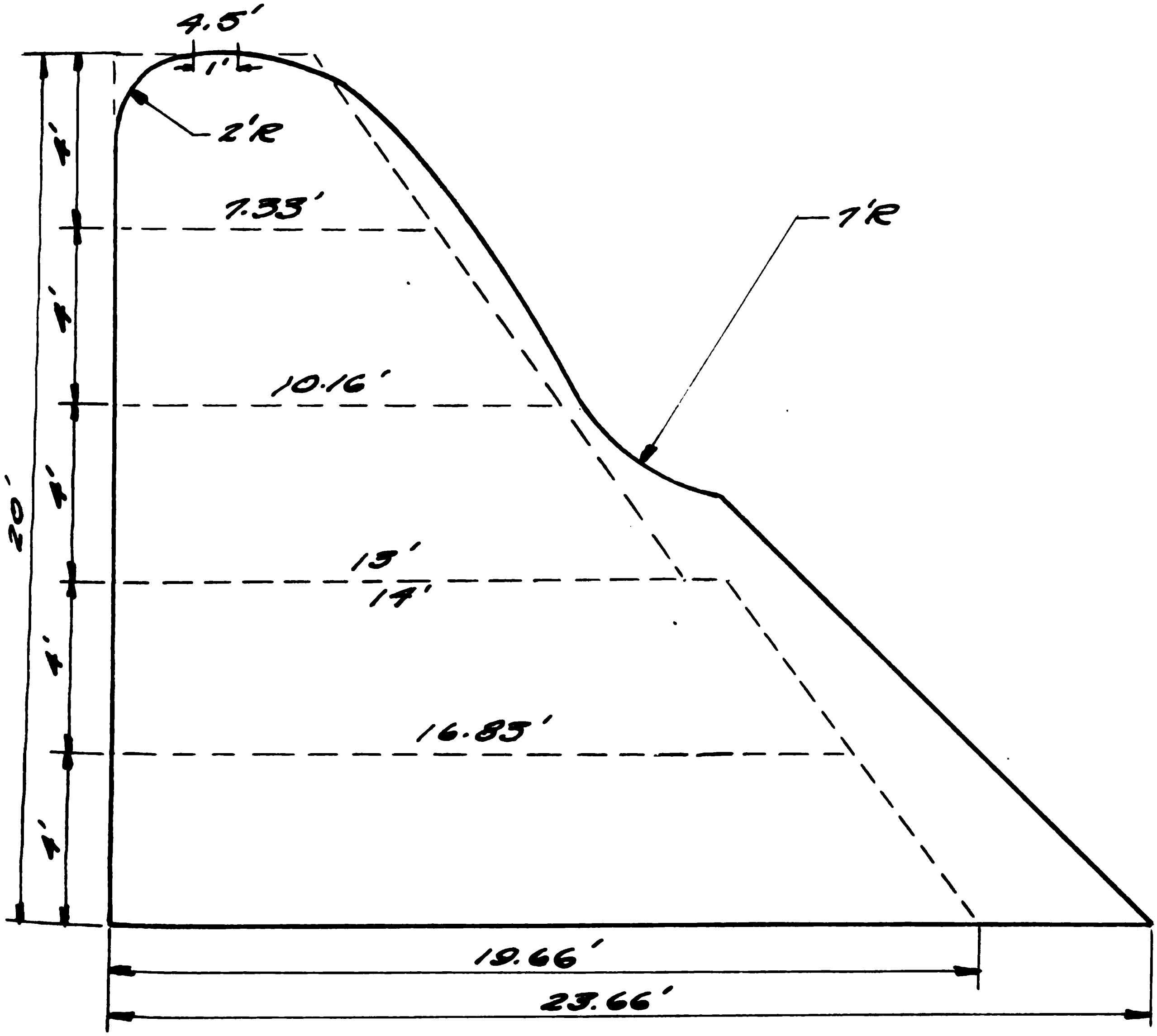
$$x=vt \qquad \text{and} \qquad y=\frac{1}{2}\times g\times t^2$$

With the values found for these formulas points on the parabola may be plotted, then a length of constant slope continues to the point or elevation where the reverse curve begins to straighten the water out in a horizontal direction again. This curve may be of a radius of $\frac{h}{3}$ or $\frac{h}{4}$. If the last point terminates above the foundation level, the latter may be reached by a 1 to 1 slope.

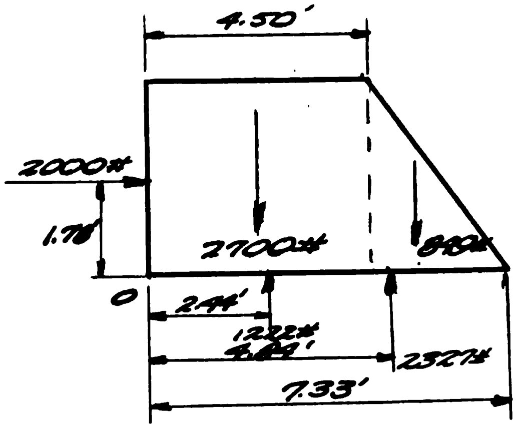
In constructing the parabola used as a basis for the spillway face, a discharge somewhat less than the maximum expected may be used, as the former is usually a very rare occurrance and would prevail for only a short time. It should be remembered however, that backwater on the toe of the spillway at time of maximum flood, would usually help considerably to lessen the shock of the falling sheet of water.

More experimental data are needed on the form of curve of the overfalling sheet of water for spillway and the amount of drop in this surface curve at the downstream limit of the flat portion of the crest.

A masonry dam of gravity section, whether of spillway or abutment type, must be able to withstand with suitable factor of safety; (1) overturning, a dendency to overturn about the downstream edge of the dam, at any assumed joint level in the dam, including the base of the dam and its foundation; (2) sliding, a tendency to slide on any assumed horizontal joint in the dam or its foundation; (3) stresses, occasioned in the masonry of the dam by its loading; (4) other possible stresses or conditions requiring special design. These calculations are shown in detail in this thesis.



4.5'
1'
2'R
7.33'
1'R
10.16'
13'
14'
16.83'
20'
4'
4'
4'
4'
4'
19.66'
23.66'



Weight $= 4.5 \times 4 \times 150 + \frac{2.83}{2} \times 4 \times 150 = 2700 + 849$
$= 3549\#$

water pressure $= \frac{wh^2}{2} = \frac{62.5 \times 8^2}{2} = 2000\#$

h.s. $= \frac{62.5 \times 8 \times \frac{2}{3}}{2} \times 7.33 = 1222\#$

center of pressure $= \frac{d^2}{12 x_0} + x_0 = \frac{4^2}{12 \times 6} = 6.22'$

$\Sigma M_0 = 0$

$2700 \times 2.25 + 849 \times 5.44 + 2000 \times 1.78 - 1222 \times 2.44$
$- (3549 - 1222) x = 0$

$6000 + 4620 + 3560 - 2980 - 2327 x = 0$

$x = \frac{11{,}275}{2327} = 4.84'$

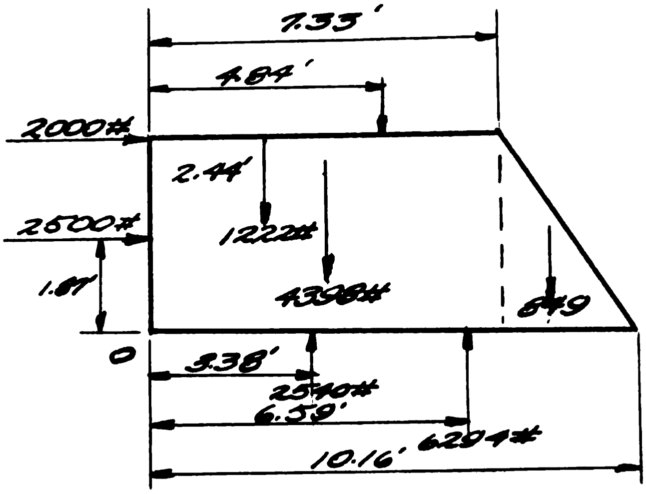
shearing force

$\frac{2000}{7.33} = 272\#/\square'$

accentricity

$4.84 - 3.66 = 1.18'$

$P = \frac{2327}{7.33}\left(1 \pm \frac{6 \times 1.18}{7.33}\right) = 625\#/\square' \text{ or } 12\#/\square'$



weight = 7.33 × 4 × 150 + $\frac{2.83}{2}$ × 4 × 150 = 4398 + 849 = 5247#

water pressure = $\frac{wh^2}{2} = \frac{62.5 \times 12^2}{2}$ = 4500#

4500 − 2000 = 2500#

h.s. = $\frac{62.5 \times 12 \times \frac{2}{3}}{2}$ × 10.16 = 2540#

center of pressure = $\frac{16}{12 \times 10}$ + 10 = 10.13'

$\Sigma M_o = 0$

23,118 + 4675 − 2540 × 3.38 + 2327 × 4.84

+ 2000 × 4 + 1222 × 2.44

= (5247 − 2500 + 2325 + 1222) x

x = $\frac{41,452}{6294}$ = 6.59'

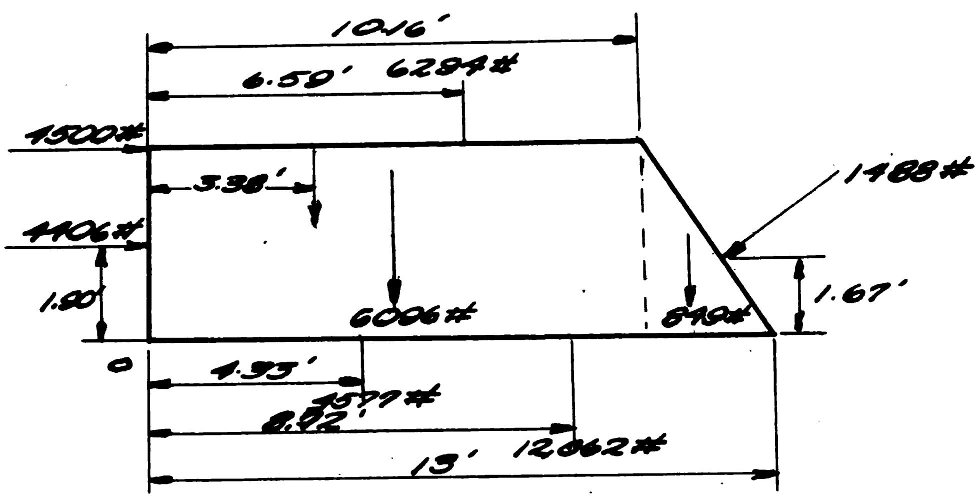
shearing force

$\frac{4500}{10.16}$ = 442 #/□'

eccentricity

6.59 − 5.08 = 1.51'

p = $\frac{6294}{10.16}\left(1 \pm \frac{6 \times 1.51}{10.16}\right)$ = 1171 #/□' or 68 #/□'



weight = 10.16 x 4 x 150 + $\frac{2.83}{2}$ x 4 x 150 = 6096 + 849
= 6945#

upstream –

$w.p. = \frac{wh^2}{2} = \frac{62.5 \times (14 + \frac{90}{62.5} \times 2)^2}{2} = 8906\#$

8906 − 4500 = 4406#

$h.s. = \frac{62.5 \times 16.9 \times \frac{2}{3}}{2} \times 13 = 4577\#$

center of pressure = $\frac{16}{12 \times 14} + 14 = 14.1'$

downstream –

$w.p. = \frac{wh^2}{2} = \frac{62.5 \times (4 + \frac{90}{62.5} \times 2)^2}{2} = 1488\#$

center of pressure = $\frac{16}{12 \times 4} + 4 = 4.33'$

$\Sigma M_o = 0$

4406 x 1.9 + 4 x 4500 + 3.38 x 2540 + 6284 x 6.59
− 4577 x 4.33 + 860 x 11.82 − 1216 x 1.67
+ 6096 x 5.08 + 849 x 11.10
= (6945 + 6284 + 2540 − 4577 + 860) x

$x = \frac{105,143}{12,062} = 8.52'$

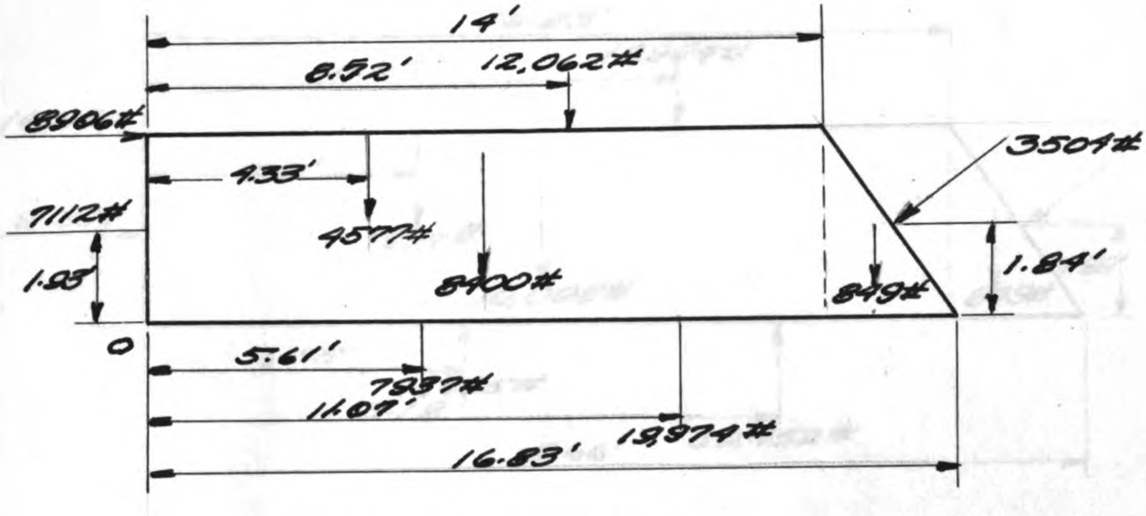
shearing force

$\frac{8906}{13} = 685 \#/\square'$

eccentricity

8.52 − 6.50 = 2.02'

$P = \frac{12,062}{13}\left(1 \pm \frac{6 \times 2.02}{13}\right) = 1792 \#/\square'$ or $65 \#/\square'$



$$\text{weight} = 14 \times 4 \times 150 + \frac{2.83}{2} \times 4 \times 150 = 8400 + 849$$
$$= 9249\ \#$$

upstream -

$$w.p. = \frac{wh^2}{2} = \frac{62.5 \times \left(14 + \frac{90}{62.5} \times 6\right)^2}{2} = 16{,}018\ \#$$

$$16{,}018 - 8906 = 7112\#$$

$$h.s. = \frac{62.5 \times 22.64}{2} \times \frac{2}{3} \times 16.83 = 7937\#$$

$$\text{center of pressure} = \frac{16}{12 \times 18} + 18 = 18.07'$$

downstream -

$$w.p. = \frac{wh^2}{2} = \frac{62.5 \times \left(4 + 6 \times \frac{90}{62.5}\right)^2}{2} = 4992\ \#$$

$$4992 - 1488 = 3504\#$$

center of pressure

$$= \frac{16}{12 \times 8} + 8 = 8.16'$$

$$\Sigma M_0 = 0$$

$$7112 \times 1.93 + 8906 \times 4 + 4577 \times 4.33 + 12{,}062 \times 8.72 + 8400 \times 7 + 849 \times 7.94 - 2860 \times 1.84 + 2023 \times 15.53 - 7937 \times 5.61 = (12{,}062 + 4577 + 9249 + 2023 - 7937)x$$

$$x = \frac{221{,}118}{19{,}974} = 11.07'$$

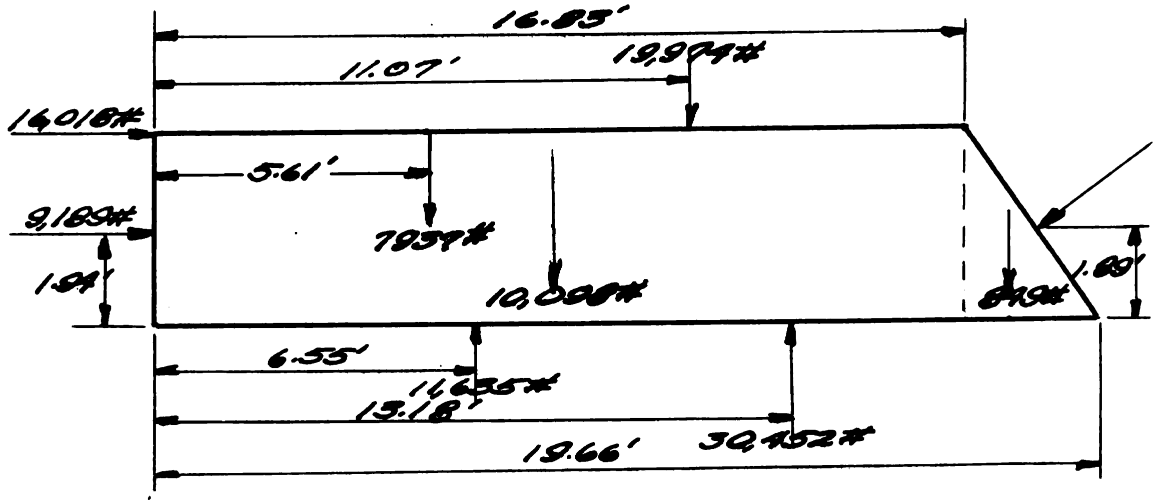
shearing force

$$\frac{16{,}018}{16.83} = 952\ \#/\square'$$

eccentricity

$$11.07 - 8.43 = 2.64'$$

$$P = \frac{19{,}074}{16.83}\left(1 \pm \frac{6 \times 2.64}{16.83}\right) = 2303\ \#/\square' \text{ or } 71\ \#/\square'$$



$$\text{weight} = 16.83 \times 4 \times 150 + \frac{2.83}{2} \times 4 \times 150$$
$$= 10,098 + 849 = 10,947\#$$

upstream —

$$w.p. = \frac{wh^2}{2} = \frac{62.5 \times (14 + \frac{90}{62.5} \times 10)^2}{2} = 25,205$$
$$= 25,205 - 16,018 = 9,187\#$$
$$h.s. = \frac{62.5 \times 28.4 \times \frac{2}{3}}{2} \times 19.66 = 11,635\#$$
$$c.p. = \frac{16}{12 \times 22} + 22 = 22.06'$$

downstream -

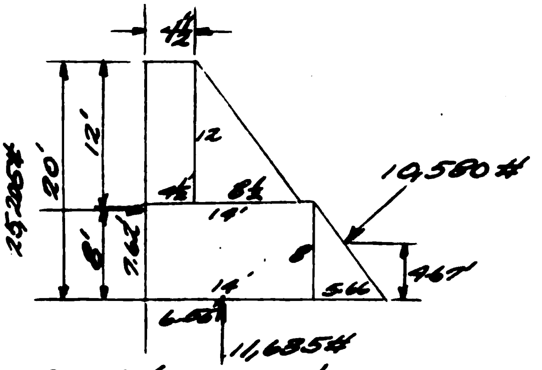
$$w.p. = \frac{wh^2}{2} = \frac{62.5 \times (4 + 10 \times \frac{90}{62.5})^2}{2} = 10,580$$
$$10,580 - 4902 = 5,688\#$$
$$c.p. = \frac{16}{12 \times 12} + 12 = 12.11'$$

$$\Sigma M_0 = 0$$
$$9189 \times 1.94 + 16,018 \times 4 + 19,974 \times 11.12 + 7937 \times 5.61$$
$$+ 3229 \times 18.32 + 10,098 \times 8.42 + 849 \times 17.77$$
$$- 4564 \times 1.89 - 11,635 \times 6.55$$
$$= (7937 + 19,974 + 10,947 + 3229 - 11,635)x$$
$$x = \frac{401,966}{30,452} = 13.18'$$

Shearing force

$$\frac{25,209}{19.66} = 1282\#/\square'$$

For the arrangement above, the resultant falls outside the middle third by .08. The actual design of the dam adds 4' to this base, giving section a large factor of safety in all respects.



Weight = $12 \times 4\frac{1}{2} \times 150 + \frac{12}{2} \times 8\frac{1}{2} \times 150 + 14 \times 8 \times 150 + \frac{8}{2} \times 5.66 \times 150$

$= 8100 + 7650 + 16{,}800 + 3396 = 35\,946\,\#$

Upstream

W.P. $= \dfrac{62.5\left(14 + \frac{90}{62.5} \times 10\right)}{2} = 25{,}200\,\#$

h.s. $= \dfrac{62.5 \times 28.4 \times \frac{2}{3}}{2} \times 19.66 = 11{,}635\,\#$

c.p. $= \dfrac{20^2}{12 \times 14} + 14 = 16.38'$

downstream

W.P. $= \dfrac{62.5\left(4 + \frac{90}{62.5} \times 10\right)^2}{2} = 10{,}580\,\#$

c.p. $= \dfrac{14^2}{12 \times 7} + 7 = 9.33'$

$\Sigma M_0 = 0$

$25{,}205 \times 7.62 - 11{,}635 \times 6.55 - 5940 \times 4.67 + 8750 \times 16.36$
$+ 8100 \times 2.25 + 7650 \times 7.33 + 16{,}800 \times 7 + 3396 \times 15.87$
$= (8100 + 7650 + 16{,}800 + 3396 + 8750 - 11{,}635)\,x$

$x = \dfrac{477{,}058}{33{,}061} = 14.43'$

This resultant will fall outside the middle third. Due to the fact that the actual design of the dam will add four feet to the base we will reconsider dam using this base.

h.s. $= \dfrac{62.5 \times 28.4 \times \frac{2}{3}}{2} \times 23.66' = 13{,}997\,\#$ acting 7.89' from toe.

Using this value in place of previous one, x will then be $\dfrac{481{,}814}{30{,}700} = 15.62'$

Shear $= \dfrac{25{,}205}{23.66} = 1065\,\#/\square'$

eccentricity $= 15.62 - 11.83 = 3.79'$

$p = \dfrac{30{,}700}{23.66}\left(1 \pm \dfrac{6 \times 3.79}{23.66}\right) = 2542$ or $52\,\#/\square'$

Conclusion

We are of the opinion and we suggest, after a thorough investigation, that certain channels which we have noted on the map, need further dredging, in order that a certain constant depth may be maintained throughout the channel system, and so that the maximum benefit may be derived from the heighth of the dam which we decided upon.

We accorded upon a height of 112' for the top of the dam after a study of the fluctuations of the Red Cedar River, and its neighbor the Sycamore Creek. A height greater than 112' would unnecessarily flood low portions of Potter Park, and low portions of the Sycamore Golf Course. We also concluded after consultation with government maps and local authorities, that the normal height to be maintained in the vicinity of Potter Park is 112' city datum.

We have shown to the best of our knowledge that the concrete spillway type of dam is the best and the most practical for the purpose of improving Potter Park.

Potter Park, which already possesses much natural beauty, would be greatly benefited by this proposed improvement. We also suggest that careful attention be given to seeding the banks and islands adjacent to the channels, with a grade of grass especially suited to that type of soil and shade, which would prevent or lessen erosion of the soil by rain or wind.