DESIGN OF A SMALL CONCRETE DAM

THESIS FOR THE DEGREE OF B. S.

Clyde H. Coster

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DESIGN OF A SMALL CONCRETE DAM

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By

Clyde H. Coster

Candidate for the Degree of

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DESIGN OF A SMALL CONCRETE DAM
(GRAVITY TYPE)

Object:

The object of this thesis is to locate and design a small dam. In order to properly proceed with this work the following field operations were carried out and a copy of the field notes taken is submitted as a portion of this thesis.

Notes were taken for the topography of the reservoir and dam site, and levels were run for the profile of the stream.

The following are a few of the factors which make the project desirable and worthwhile.

There are, all over the country, countless small streams which are unsuited for even small water power development. If they cannot be considered from a utilitarian standpoint perhaps they can be developed from some other angle. Consider this one case in particular. About two miles north of Montague, Michigan, on the property of Charles Larson there is a small spring fed stream. It originates near one edge of the property and flows across the farm for about one-eighth of a mile. There is only a negible amount of water flowing near the source but the flow is increased by the contributions of numerous other springs downstream. The stream flows along the bottom of a gully considerably below the level of the surrounding land. Near the source, the gully is quite wide making an ideal site for a pond.

In its present state, the stream instead of adding to the attractiveness of the property, detracts from it for the following reasons:

The sides of the gully are made up of clean sand which is very unstable, and although the stream naturally serves only as a drainage for the springs, its flow is increased in the spring when melting ice and snow from the lands above find their way to it. This large proportional increase in flow washes the loose sand from the side of the gully and carries it downstream. The sand has practically no binder and is absolutely unstable. It is estimated that in the last five years hundreds of tons of sand have been washed downstream, filling up the stream bed and making the site near the head of the stream very unsightly.

Two ways of preventing this disfiguration of the land present themselves. The first is by protecting the sides of the gully by planting or rip-rap; the second is by regulating the stream flow. Planting, however, is extremely difficult on account of the nature of the soil and rip-rap complete enough to offer protection would be very expensive and of questionable value. The most satisfactory method would be to regulate the stream flow by means of a small dam.

A concrete dam was designed because of the accessibility of a good grade of coarse aggregate about 600 feet from the dam site, and because of the permanence and unquestioned stability of a correctly designed concrete dam. An earthen dam with a concrete spillway would be an alternative choice for this type of dam. The only reason it was not used here was because of the factors mentioned above.

The spillway section does not extend across the entire length of the dam. It is 8 feet long and is placed at the center line of the stream. In times of high water the velocity of the stream will be greatest in the center and practically neglible along the sides of the reservoir thus preventing scouring and erosion of the reservoir. If at any time the flow should be so great that the spillway section could not handle it, the water could overflow the crest of the dam without any permanent harm.

The dam site was selected where the sides of the gully are close together at a point about 300 feet from the source. The left bank has a slope of about 3 on 5 and the right bank about 2 on 7. Both banks are quite solid at this point. The right bank is more stable here than at most other places. It is well sodded and has several good-sized trees in it.

The top of the dam will be at an elevation of 505.0 feet, and the top of the spillway at an elevation of 503.5 feet. This will give about 7 feet of water back of the dam and about 5 feet of water at the source when the reservoir is full. At this stage the reservoir will have a capacity of 26 acre feet. No provision has been made for flashboards but if it is so desired the dam may be equipped with them to raise the level of the pond and increase its capacity. Due to the natural topography of the land, none of the adjoining property will be flooded.

Estimate of Cost:

Land:	
Acquisition of property	$ 0.00
Damages to property	0.00
Dam and Cement Work:	
Concrete, 37 cu.yds. at $1.80	99.90
Excavating, 206 cu.yds. at .40	82.40
Piling, 28 - 10 ft. piles at 15¢ ft.	4.20
Total	$186.50

This estimate has been based on the following:

Six sacks of cement per cu. yd. of concrete cement at

$0.45 per sack.

Aggregates to be secured from gravel pit 600 feet away at no cost.

This assumes that all labor will be done by the owner, as is his intention.

In case the job should be let by contract (a more general case) the cost estimate would be revised as follows:

Concrete, 37 cu.yds at $6.00	$222.00
Excavating, 206 cu.yds. at .40	82.40
Piling, 28 - 10 ft. piles at .15	4.20
Total	$308.60

DESIGN OF DAM

(FROM CREAGER & JUSTIN)

For economy, a trapezoidal dam with vertical face upstream was chosen. The top width which may be assumed was taken as six inches and the base figured as follows:

$$b = \sqrt{\frac{H^2}{S} - \frac{5}{4} a^2} - \frac{a}{2}$$

b = base

H = Height

a = top width

S = specific gravity of masonry

$$b = \sqrt{\frac{64}{2.4} - \frac{5}{4} \times \frac{1}{4}} - \frac{1}{4} = \quad 26.7 - .31 - .25$$

$$= \quad 5.1 \quad - \quad .25 \quad = \quad 4.85 \qquad \text{Use } 5'$$

This formula gives a base of sufficient width so that the resultant of the forces acting on the dam falls within the middle one-third of the base. This is absolutely essential for a correctly designed dam.

The common methods of failure of a gravity dam are three; 1st, by sliding along a horizontal joint, 2nd, by overturning about the toe, 3rd, by crushing. In investigating these methods of failure we need only consider the first two as the dam is of insufficient height to cause failure by crushing.

Computations for factor of safety in sliding:

$$\frac{P'}{P} = \frac{W'f}{\frac{1}{2} Wh^2} = S$$

P' = Resisting force

W' = Effective wt. of section of dam 1 ft. long

f = Friction factor (gravel foundation with piles) = .6

P = Pressure in lbs. of water against section of dam 1 ft. wide and h ft. high

W = Unit weight of water

S = Factor of safety

The effective weight of the dam is obtained by subtracting from the weight of the masonry in a section

1 ft. long, the upward pressure on this section. The upward pressure is due to the weight of a column of water h ft. high times 62.5 lbs. This pressure varies from the toe to the heel of the dam. The average upward pressure is taken and multiplied by the width of the base giving the total upward pressure.

The effective weight of the dam when multiplied by its friction factor and divided by the water pressure gives the factor of safety.

Downward pressure	= 6000.0#
Upward pressure	= 2187.5#
W_1 = Effective wt.	= 3812.5#

Effective head = 7'

$$\frac{W_1 f}{\frac{1}{2} wh^2} = S$$

$$\frac{3812.5 \times .5}{\frac{1}{2}\, 62.4 \times 49} = \frac{1956.25}{1460} = 1.35$$

This factor of safety is not very large but it may be considered sufficient when it is realized that this is an extreme case. It is figured in the above computations that the reservoir is full and that there is no tail water, which would be an unusual case. If there is any tail water at all, it of course will decrease the effective head and thus give a larger factor of safety. For instance, with 2 ft. of tail water the effective head is only 5 ft. and the factor of safety is:

$$\frac{3812.5 \times .5}{\frac{1}{2} \times 62.4 \times 25} = \frac{1956.25}{780} = 2.5$$

Computations of factor of safety to resist overturning.

Take moments about the toe.

There are three forces which tend to overturn the dam. They are:

1. Ice pressure which may be disregarded in this case due to the very short length of the dam, the gentle slopes, and soft soil of the sides of the gully.
2. Pressure of the impounded water in a horizontal direction, and,
3. Pressure of the underground water in a vertical upward direction.

These may be computed as follows:

2. $P = \frac{wh^2}{2} \times \frac{h}{3}$

w = unit weight of water

h = head of water

$P = \frac{62.4 \times 64}{2} \times \frac{8}{3} =$ 5,330#

3. $P_1 = \frac{whb}{2} \times \frac{b}{3}$

b = base of dam

$P_1 = \frac{62.4 \times 8 \times 5}{2} \times \frac{10}{3} =$ 4,160#

Total overturning force = 9,490#

The force resisting these overturning forces is the weight of the dam acting thru the center of gravity of the dam.

Solving for the center of gravity of the dam.

$$d = \frac{.5 \times 8 \times 2 + 4 \times 4.5 \times (.5 \times .33 \times 5.5)}{8 \times .5 + 4 \times 4.5} =$$

1.11 ft. from upstream edge.

$P_R = W \times 3.89$

W = wt. of 1 ft. section of dam

$P_R = 4500 \times 3.89 = 17{,}505\#$

The resisting moment divided by the overturning moment given the factor of safety against overturning.

$$\frac{P_R}{P} = \frac{17{,}505}{9{,}490} = 1.85$$

In designing a dam which impounds a large body of water above a village or city, a factor of safety of 1.85 would be too small. However, in this case where economy is a major factor and no harm would be done in case the dam failed, a factor of safety approaching 2 may be considered sufficient.

The dam as designed provides for double sheet piling near the upstream edge of the dam. This is primarily to shut off the flow of underground water which appears to be quite large. The sheet piling acts also as support for the dam. As an alternative, corrugated sheet metal may be driven or jetted to hard pan and used as a cut-off wall. In this case, it would be well to re-space the piles or use an additional row in order to distribute the weight of the dam evenly.

The base of the dam proper is 5 feet as calculated from the design formula. The base at the spillway section has been extended an additional five feet making a total of ten feet. The top of the section has been rounded off and the lower third is concavely curved in order that the water leaving the apron has only a horizontal force. In this way the impact of the falling water has been practically done away with. At the outside edge of the apron there is a cut-off wall extending downward two feet. This will prevent the spillway flow from eroding or washing away the earth from beneath the apron.

In case it is desired to construct a walk across the top of the dam 2 inch pipe may be imbedded in the top of the dam at five foot intervals. These should be threaded on the top and a "tee" screwed on. One foot sections of pipe may be threaded into each side of the "tee" perpendiculary to the dam. A 2 ft. plank walk may be laid on these as supports.

Large field stones may be imbedded in the dam during construction for the sake of economy. They should be surrounded by at least six inches of mortar. This is known as "cyclopean" concrete and may be used without harmful results. A desirable effect may be secured on the spillway by placing small stones of not more than 4 inches diameter in the surface of the concrete.

It is recommended that a four inch steel pipe be put thru the spillway section about 1 foot above stream bed. This will provide for draining the reservoir in case it should ever be desirable or necessary. A hand operated valve on the upstream end of the pipe will serve as a gate. This pipe could be used as a regulator on the height of the water in the pond.

No loss of water need be expected thru saturation as the water table is very close to the surface of the ground at all points. The only loss will be thru underground flow. It is therefore important that the sheet piling in the cut-off wall be driven as deep as possible and fitted together carefully in order to prevent this loss.

There is no provision made for retaining walls along the sides of the reservoir. The banks near the ends of the dam should be carefully filled in and protected so as to prevent washing out around the ends of the dam in case of exceptional high water. They should be well sodded and planted with shrubbery or trees.

SUMMARY

As shown by the cost estimate, the dam can be constructed for approximately $175.00. The owner will then have a fresh spring water reservoir of 26 acre-feet capacity. The water will have an average depth of 6 feet.

The usefulness of the dam will be confined mainly to improvement of the surrounding land, although the reservoir may be planted with trout with very successful results as demonstrated by a property owner about one mile downstream.

Another phase which might be developed in the near future is the possibility of using the reservoir for irrigation purposes. During the winter ice may be removed from the pond and stored for summer utilization. Thus the dam will have an economic value in addition to the intangible values for which it is designed.

[redacted] [redacted]

Field Notes

Taken in connection with

Design of a Small
Concrete Dam

June, 1931

Clyde H. Caster

Profile

Sta	+S	H.I.	−S	Elev.	
BM,	3.00	503.00		500.00	
#1			5.01	497.99	
#2			7.40	495.60	
BM,			4.39	499.99	ok.
BM,	3.06	503.06		500.00	
#3			5.65	497.41	
#4			7.49	495.57	
BM,			4.44	500.01	ck.

Note:

BM. N.W. corner old concrete abutment.
Elev. 500.00

Elev.

500.00

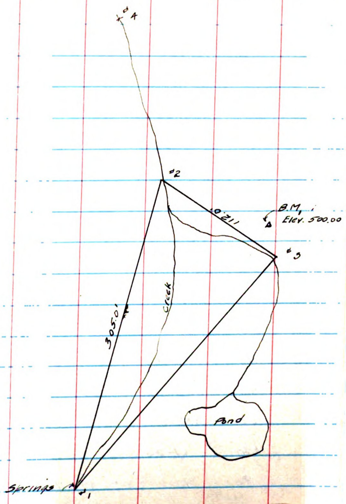
97.99

5.60

99 ok

00

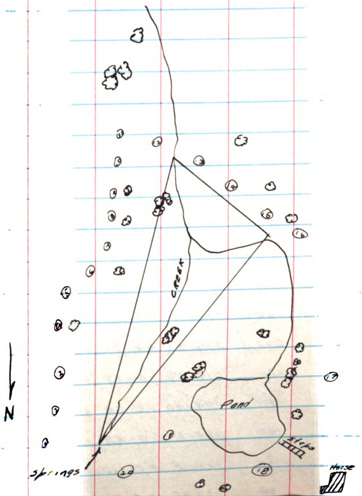
ck



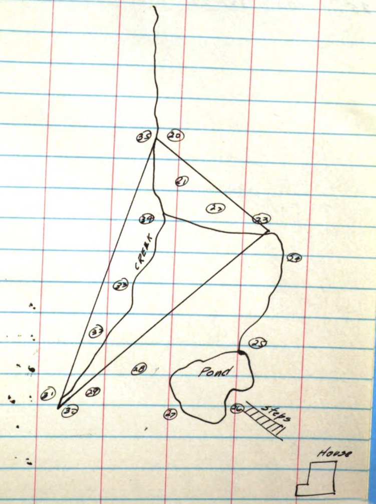
Topography

Sta.	Dist.	Az. ∠	Vert. ∠	Diff. El.	Elev.
⊼ at 3					
Pt. 2		326°	Bearing	S - 34° E	
⊼ at 3	BM.	Rod	reading	1.9	501.9
				H. I. = 4.6	
#1	290	233-30	+2-55	+14.7	516.6
2	260	237-5	+3-5	+13.9	515.8
3	210	244-25	+4-40	+11.6	513.5
4	180	247-52	+5-40	+14.6	516.5
5	175	250-19	+7-8	+17.2	519.1
6	150	255-32	+8-7	+16.8	518.7
7	120	265-11	+9-0	+16.8	518.7
8	110	269-50	+9-23	+17.0	518.9
9	110	273-9	+7-30	+17.7	519.6
10	140	308-40	+0-20	+18.1	520.0
11	100	333-57	+11-6	+0.6	502.5
12	100	61-26	+12-10	+18.9	520.8
13	90	97-11	+7-37	+18.5	520.4
14	140	141-25	+6-32	+18.4	520.3
15	180	156-37	+5-[illegible]	[illegible]	

N


CREEK
Pond
steps
springs
House
N

Sta.	Dist.	Az ∠	Vert ∠	Diff. El	Elev.
16	200	168-27	+5-32	+ 19.2	521.1
17	200	179-12	+5-0	+ 17.4	519.3
18	180	208-52	+4-20	+12.6	515.5
19	220	211-55	+5-0	+19.1	521.0
20	240	217-12	+3-25	+14.3	516.2
⊼ at 3	BM. Rod read. 2.10			H.I. = 4.8	502.1
21	120	322-39	-0-41	-1.4	500.7
22	80	296-7	-0-19	-0.4	501.7
23	80	260-47	-0-5	-0.1	502.0
24	120	243-56	-0-7	-0.2	501.9
25	180	234-18	+0-5	+0.3	502.4
26	200	223-2	+0-56	+3.3	505.4
27	220	220-18	+0-33	+2.1	504.2
28	260	226-23	+0-35	+2.6	504.7
29	120	219-47	+0-59	+2.1	504.2
30	120	194-40	+0-58	+2.0	504.1
31	130	184-31	+0-13	+1.6	502.7
32	80	162.15	+0-10	+0.2	502.3
33	40	133.37	+0-[illegible]		



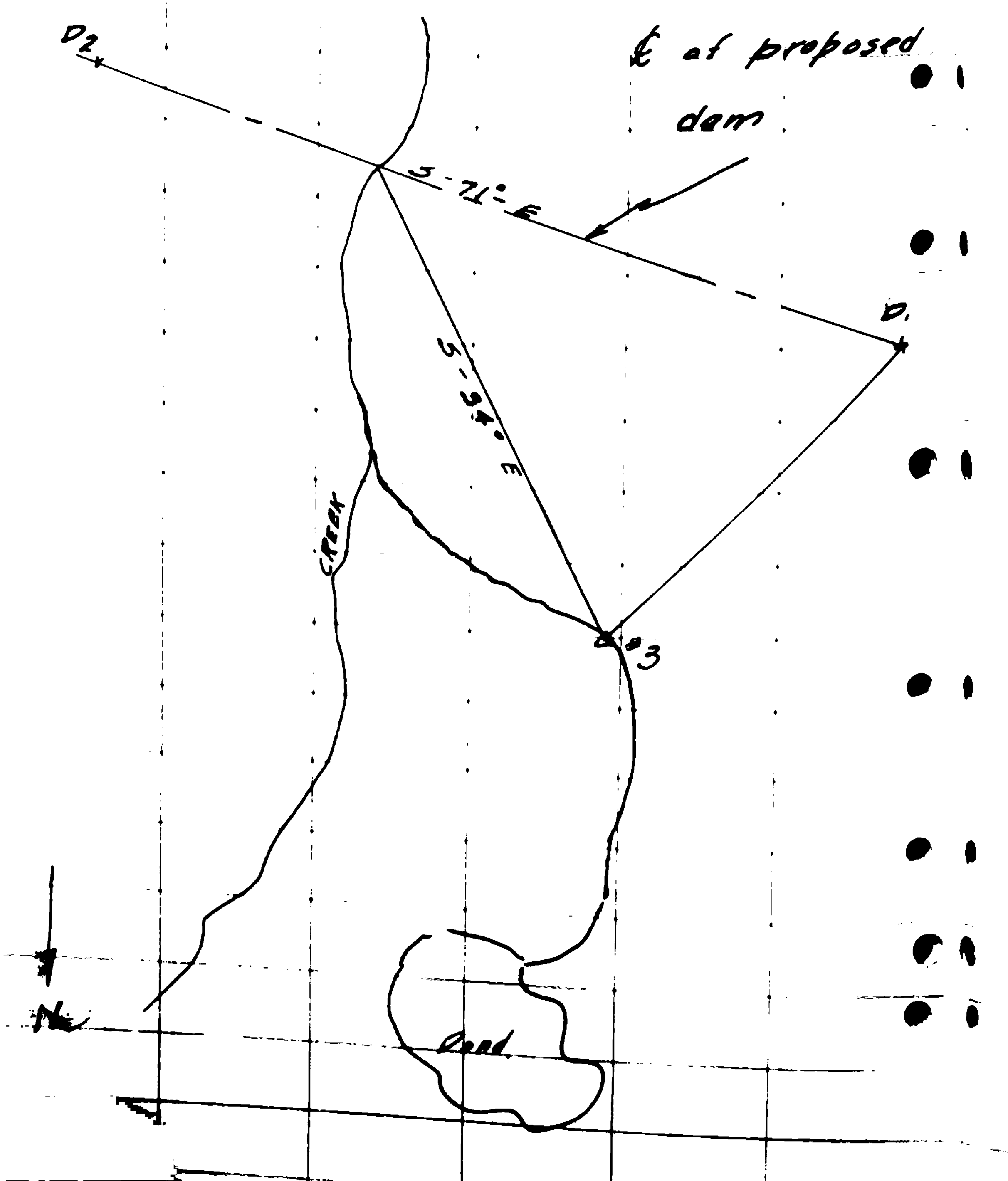
35
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
CREEK
Pond
Steps
House

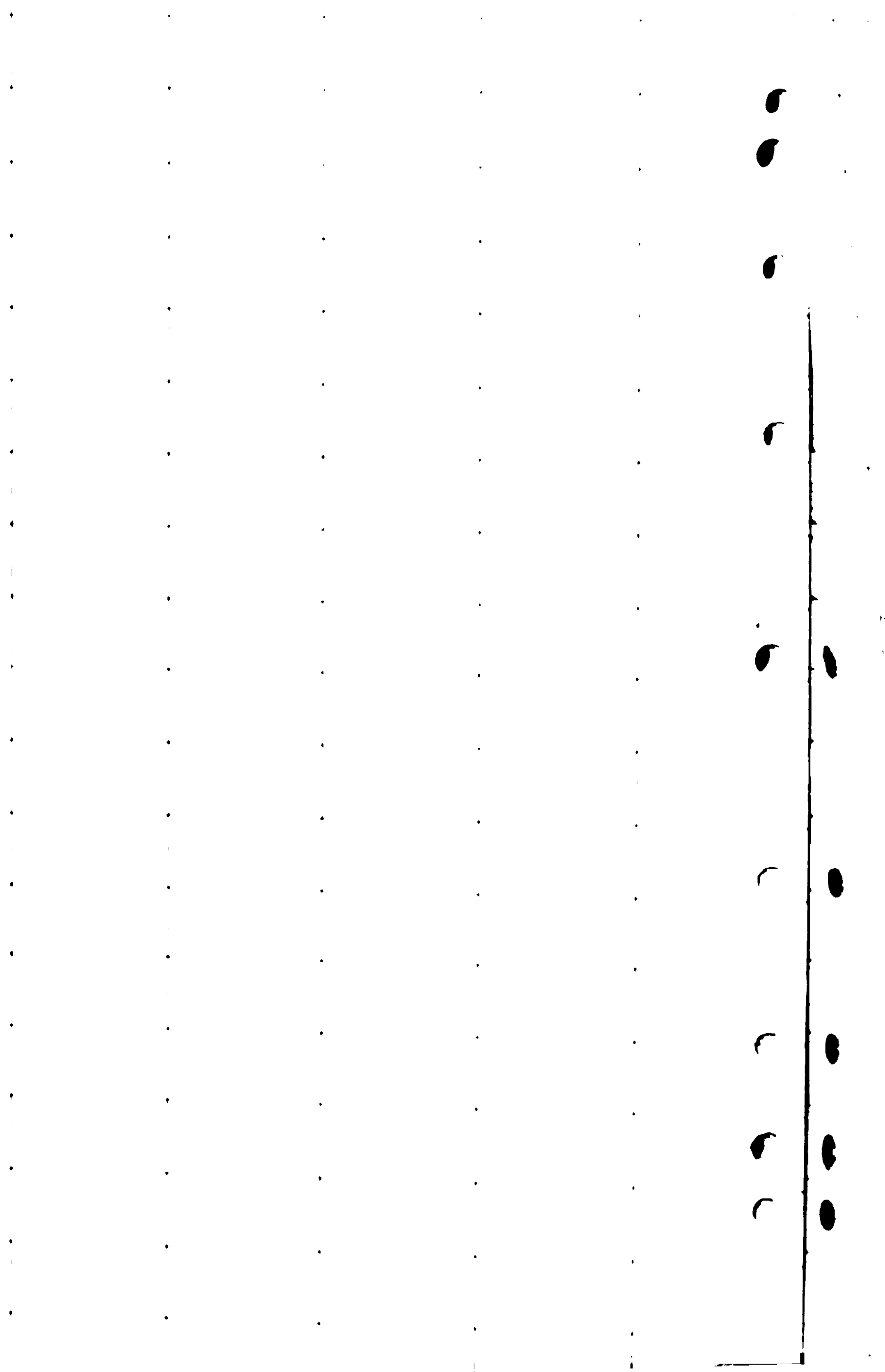
Sta	Dist	Az. ∠	Vert. ∠	Diff. El.	Elev.
34	50	311-0	-0-55	-0.8	501.3
35	100	327-22	-1-0	-1.79	500.1

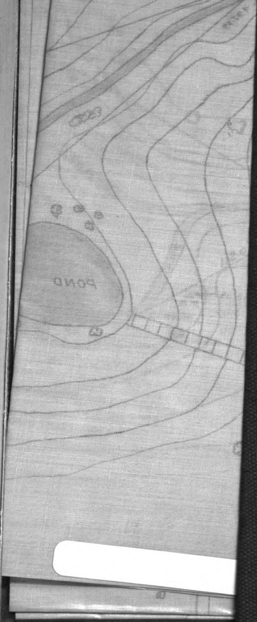
Sketch

Same as preceding page.

Location of Dam Site






POND