A DESIGN OF A REVETMENT WALL FOR EROSION CONTROL ON RED CEDAR RIVER

Thesis for the Degree of B. S.

MICHIGAN STATE COLLEGE

J. Holgate

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A Design of a Revetment Wall for Erosion Control on Red Cedar River

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by

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I Introduction

This thesis is concerned with the protection of an embankment against erosion by current. A problem frequently met in engineering, bank erosion often has destructive effects on abuting land and structures.

A case, in point, is that treated in this paper. In 1934, a highway bridge was built over the Red Cedar River on Kalamazoo Road between Lansing and East Lansing. The outline of the banks of the river, adjacent to the bridge, was as shown in the situation plan at the end of this report. During the ensuing fourteen years to 1948, the northwest bank has been subjected to erosive action by the current. This so-called "scouring" has changed the location of that bank, as noted in the map.

The significance of this condition has been recognized by local authorities. Further scouring of the bank can result in subsequent exposure of the foundation piles supporting abutment "A". This exposure is most likely to occur when the summer low water level is less than Elev. 819.0 and the soil has been washed away under the abutment. Timber piles are most subject to decay at the water line where they become alternately wet and dry, while the portion of a pile, which remains continuously immersed in water, does not decay and lasts practically forever.

This situation warrants the designing and building of a structure to resist further erosive action. A retaining wall has been selected as the design problem herein.

Enclosed are photographs from various angles showing the present appearance of the site for the proposed retaining wall.

Photo No. 1 - Scour begins at this part of bank

Photo No. 2 - Erosion occuring on west bank

Photo No. 3 - Additional view showing scouring action

Photo No. 4 - Bridge adjacent to site of retaining wall

No. 2

No. 2

No. 3

No. 4

II Design of Cantilever Retaining Wall

A. Data and Assumptions for Design

. <u>Data:</u>

Cantilever Retaining Wall

Surcharge: none

Impact (Vibration): none

Earth: W_e = 100 pcf

$\theta = 0^\circ$

$\phi = 33^\circ\ 40'$ = angle of internal friction

Foundation pressure = 3000 psf (assumed maximum)

<u>Specifications:</u> (assumed)

wt. of Conc. = 150 pcf

$f'c$ = 2000 psi n = 15

fc = 800 psi

v = 40 psi

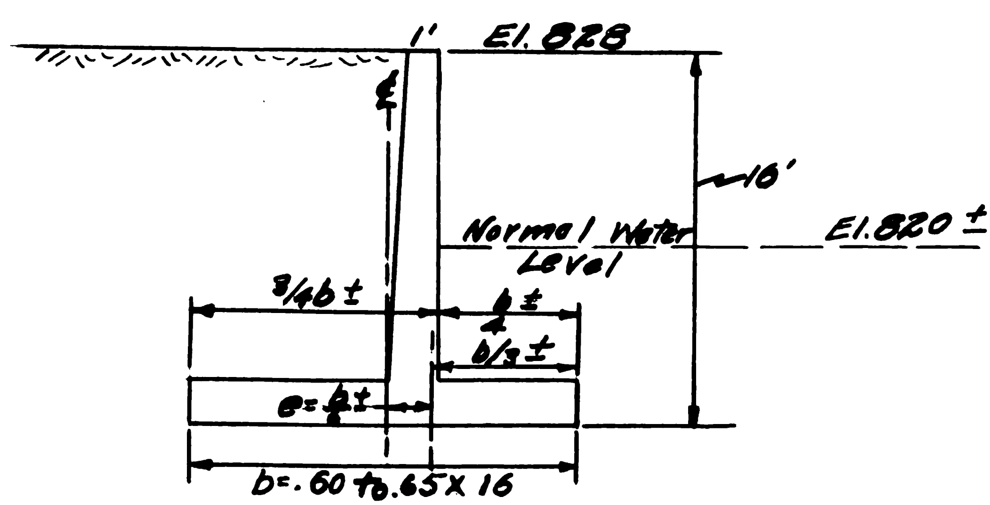
u = 100 psi

fs = 18,000 psi

<u>Design Constants:</u> $R = \frac{M}{bd^2} = 139$

$j = 7/8$

Coef. of friction between base & earth = .40



B. Determination of Economical Dimensions

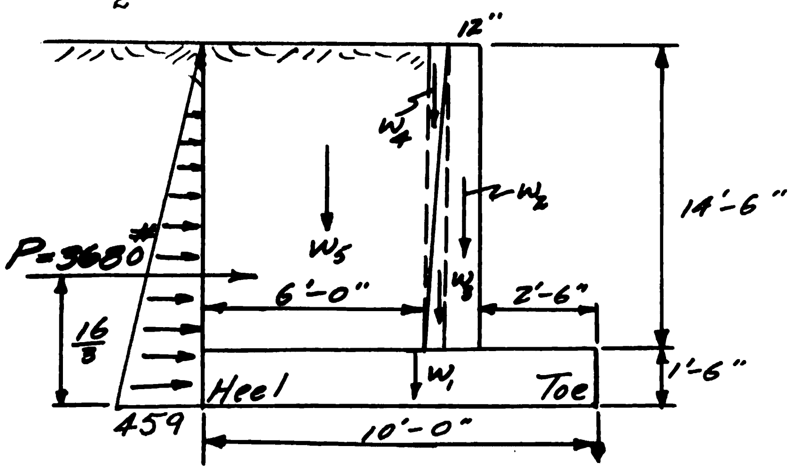
Pressure on base

$$C = \cos\theta \frac{(\cos\theta - \cos^2\theta - \cos^2\phi)}{(\cos\theta + \cos^2\theta - \cos^2\phi)}$$

$$= \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-.554}{1+.554} = .287$$

$$p = Cwh = .287X100X16 = 459 \text{ psf}$$

$$= \frac{459 \times 16}{2} = 3680 \text{ lb.}$$



Check for trial width:

$$M_{\text{third pt.}} = 3680 \times 5.33 = 3/4b \times 16 \times 100 \times (2/3b - 3/8b)$$

$$= 19640 = 1200b\ (2/3b - 3/8b\ )$$

$$19640 = 800b^2 - 450b^2 = 350b^2$$

$b^2 = 56.1$ $\quad$ $b = 7.5$ $\quad$ let $b = 10'$

Base pressures: Moments about toe:

W_1 =	1.5x10x1x150 =	2250 lb.	x 5.0 =	11,250 lb. ft.
W_2 =	1x14.5x1x150 =	2170 "	x 3.0 =	6,520 " "
W_3 =	½x½x14.5x1x150=	543 "	x 3.67=	1,994 " "
W_4 =	½x½x14.5x1x100=	362 "	x 3.83=	1,386 " "
W_5 =	6x1x14.5x1x100=	8700 "	x 7.00=	60,900 " "
	W_{tot} =	14,025 lb.		82,050 lb. ft.

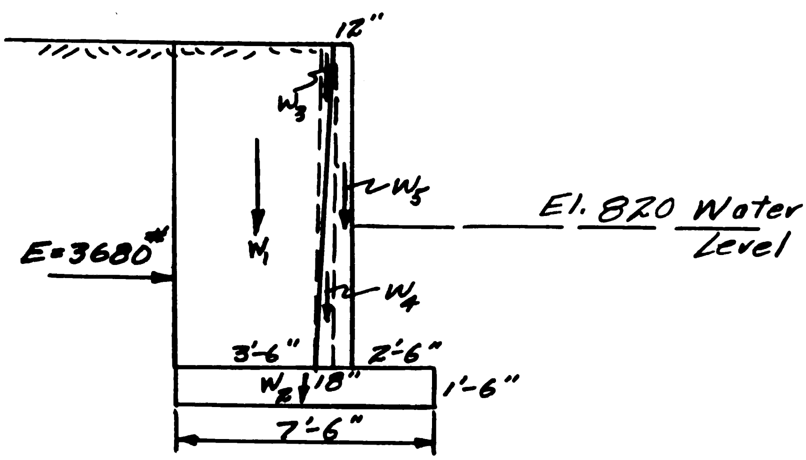
Dist. from toe to W_{tot} = $\frac{82050}{14025}$ = 5.86 ft.

$\frac{x}{5.33} = \frac{3680}{14025}$ x = 1.40 1.40 - .86 = .74
5.86 - 5.00 = .86

Eccentricity = .74 ft. (Allowable = 1/3 base x .50 = 1.67)

Since this design with base width equal to 10 ft. shows a distance of .93 ft (1.67 - .74) between the extremity of the middle third and the point where the resultant load cuts the base, it was decided to take a smaller value for 'b' in order to obtain a more economical design. It is generally agreed that the optimum situation for economical design occurs when the resultant cuts the base of the wall at the extremity of the middle third.

Let b = 7.50 ft.



Base Pressures: Moments about toe:

W_1 =	3.5x14.5x100 =	5075 lb x 5.75 =	29200	lb.ft.	
W_2 =	7.5x 1.5x150 =	1690 '' x 3.75 =	6340	"	"
W_3 =	1/2x1/2x14.5x100 =	362 x 3.83 =	1386	"	"
W_4 =	1/2x1/2x14.5x150 =	544 x 3.67 =	1997	"	"
W_5 =	1x14.5x150 =	2170x 3.00 =	6500	"	"
	W_{tot}=	9841 lb.	45423	lb ft	

$$\text{Dist. from toe to } W_{tot} = \frac{45423}{9841} = 4.62 \text{ ft.}$$

$$\frac{x}{5.33} = \frac{3680}{9841} \qquad x = 2.00 \text{ ft.} \qquad 4.62 - 3.75 = .87\text{ft.}$$

$$\text{Eccentricity} = 2.00 - .87 = \underline{1.13 \text{ ft.}}$$

(Allowable = 1.25)

$$\text{Base Pressure} = f = \frac{P}{A} \pm \frac{Mc}{I} = \frac{9841}{7.5} = \frac{9841 x 1.13 x 3.75 x 12}{1 x 7.5^3}$$

$$f = 1310 \pm 1185 = \underline{2495} \text{ psf at toe}$$
$$\underline{125} \text{ psf at heel}$$

$$\text{Factor of safety for overturning} = \frac{W_{tot} \text{ x mom. arm}}{E \text{ x } 5.33}$$

$$\text{S.F.} = \frac{9841 x 4.62}{3680 x 5.33} = \frac{45423}{19600} = 2.32 \text{ (Allowable} = 2.00)$$

$$\text{Factor of Safety for Sliding} = \frac{W \text{ x Coef. of Friction}}{E}$$

$$\text{S.F.} = \frac{9841 x .40}{3680} = 1.07$$ (Anchorage not required since the soil is low in bearing capacity and piles will be driven)

Sometime during the spring, the Red Cedar River can be counted on to reach flood levels and overflow its banks. Because of this, the forces acting will be analysed herein.

As shown in the following sketch, the earth pressure of water pressure tend to cancel each other and consequently the resultant force cuts the base closer to the center than at low water. Therefore, the base pressure is less at the toe than before.

The picture is also improved for shear along face a-b. The bending moment on the stem could possibly be changed an appreciable amount, however.

C. Investigation of Forces during High Water

Moments about face a-b = 3680 x 5.33 - 2000 (9.17)

= 540 ft lb = 6500 in lb.

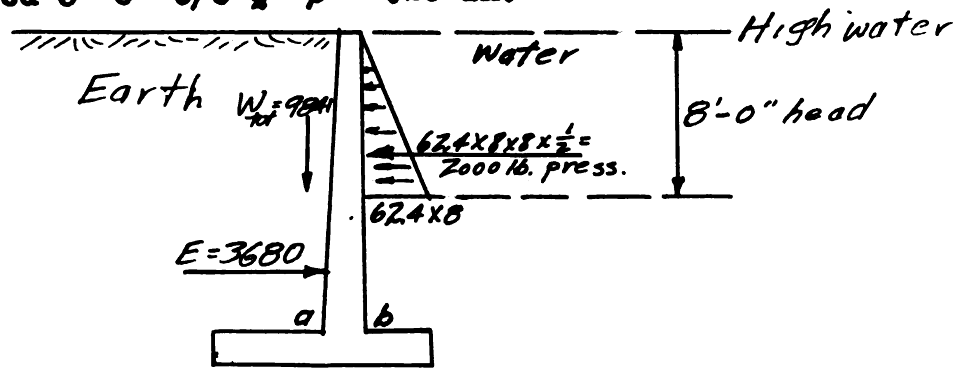
$d = \frac{V}{bjv} = \frac{1680}{12x7/8x40} = 4.00$ in.

assume d = 12" at this point

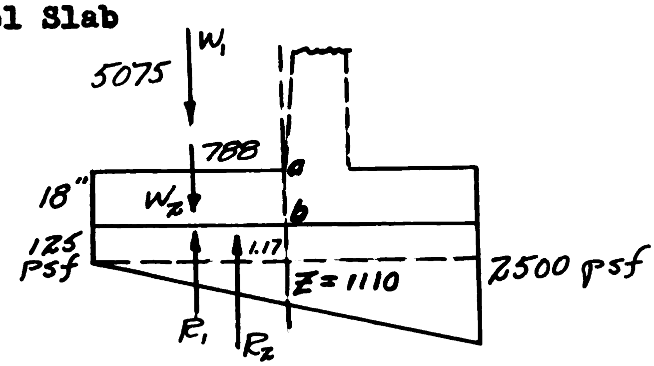
$d = \frac{M}{Rb} = \frac{540}{139} = 1.98$ in

$As = \frac{M}{fsjd} = \frac{6500}{1800x7/8x12} = .034$ in.^{2}

This area of steel will be taken care of by temp. steel spaced 3'-0" c/c ½" ∅ = .20 in.^{2}



D. Design of Heel Slab



W_2 = 1.5 x 3.5 x 150 = 787.5 = 788

R_1 = 125 x 3.5 = 437.5 = 438

R_2 = 1110 x ½ x 3.5 = 1940

Moments about a-b:

+5075 (1.75) + 788 (1.75) - 438 (1.75) - 1940 (1.17)=0

10250 - 767 - 2270 = 7,213 = M a-b.

Bending causes tension in top fibers of heel slab.

$V = 5075 + 788 - 438 - 1940 = 3485$ lb.

$d = \frac{V}{bjv} = \frac{3485}{12x7/8x60} = \underline{5.53 \text{ in.}}$

$d = \frac{M}{Kb} = \frac{7213}{139} = 51.9$

$\frac{Z}{2375} = \frac{3.5}{7.5}$

$Z = 1110$ psf

$d = \underline{7.20 \text{ in.}} =$ minimum "d"

In this case assume d = 15 in. with 3 in. cover.

Check for allowable shear:

$v = \frac{V}{bjd} = \frac{3485}{12x7/8x15} = \underline{22.1 \text{ psi}}$

Steel Design for Heel Slab:

$A_s = \frac{M}{fsjd} = \frac{7213 \text{ x } 12}{18{,}000x7/8x15} = .366 \text{ in.}^2$ reqd. per 12 in.

Use 2 - ½" ∅ bars = .40 in.^{2} Top

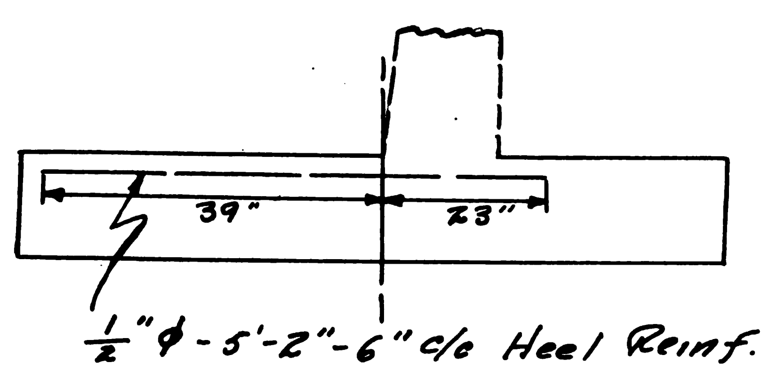
$\frac{12}{2} = 6"$ spacing c/c

Check for Bond Stress: $\Sigma o = 3.14$ in.

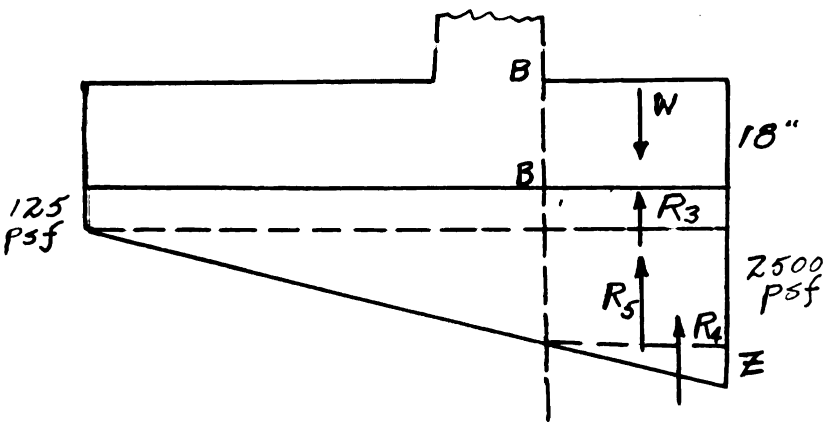
$M = \frac{V}{\Sigma ojd} = \frac{3485}{3.14x7/8x15} = \underline{84.5 \text{ psi}} < 100$ O.K.

Therefore, special anchorage not required.

$L = \frac{fs\ D}{4u} = \frac{18000x.5}{4 \text{ x } 100} = \underline{22.5}$ inches.



E. Design of Toe Slab



$$\frac{Z}{2375} = \frac{2.5}{7.5}$$

Z = 793 psf

W = 1.5 x 150 x 3.5 = 788 lb. R_3 = 125 x 2.5 = 313 lb.

R_4 = 793 x ½ x 2.5 = 990 lb. R_5 = 1582 x 2.5 = 3950 lb.

Moments about face B-B:

-788 x 1.25 + 313 x 1.25 + 3950 x 1.25 + 990 x 1.67 = 6000 ft.l

4350 + 1650

Shear = V = 4465 lb. Assume toe 18" thick & d = 15"

$$v = \frac{V}{bjd} = \frac{4465}{12x7/8x15} = 28.3 \text{ psi}$$

$$R = \frac{M}{bd_2} = \frac{6000}{225} = 26.7$$

$$As = \frac{M}{fsjd} = \frac{6000 \times 12}{18,000x7/8x15} = .305 \text{ in.}^2 \text{ req'd. per foot.}$$

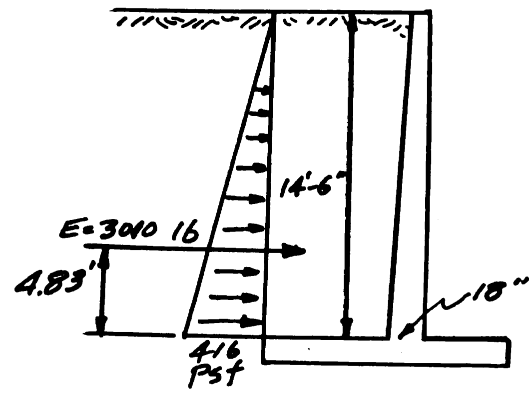
Use 2-½" ø bars = .40 in.^{2} Bottom
at 6" spacing c/c

Check for Bond Stress:

$$u = \frac{V}{\Sigma ojd} = \frac{4465}{3.14x7/8x15} = 108 \text{ psi}$$

$$L = \frac{fsD}{4u} = \frac{18000 \times \frac{1}{2}}{4 \times 100} = 22.5 \text{ inches.}$$

F. Design of Stem



$p = Cwh = .287 \times 100 \times 14.5 = 416$

$E = \frac{416 \times 14.5}{2} = 3010$ lb.

Shear = <u>3010 lb.</u>

Moment = 3010 x 4.83 x 12 = <u>174,500 in. lb.</u>

$d = \frac{V}{bjv} = \frac{3010}{12x7/8x40} = \underline{7.17}$ inches

$d = \sqrt{\frac{M}{Rb}} = \sqrt{\frac{14540}{139}} = \sqrt{104.5} = \underline{10.2}$ inches

Let d = 15 in.

Make stem 12 in. at top & 18 in. at bottom

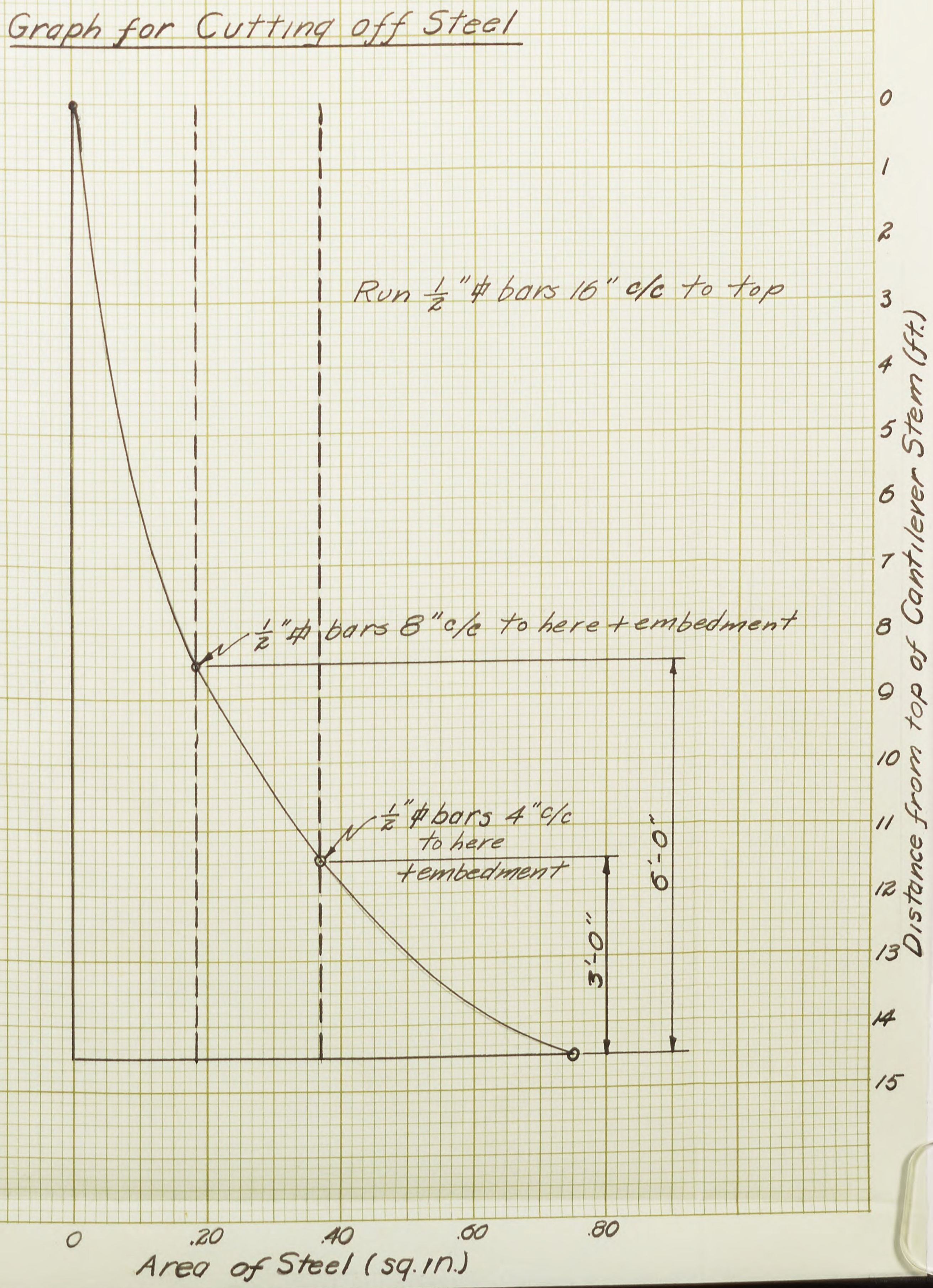
$V_x = \frac{28.7h^2}{2}$ $\quad M_x = \frac{28.7h^2}{2}\left(\frac{h}{3}\right)$

$V_x = \underline{14.35}\ h^2$ $\quad M_x = \frac{28.7h^3}{6} = \underline{4.78h^3}$

Steel required at junction of stem & base:

$As = \frac{M}{fsjd} = \frac{174,500}{18000x7/8x15} = .738$ in.^{2}

Use <u>3-½" ϕ bars</u> gives .75 in.^{2} per 12 inches



Graph for Cutting off Steel
Run 1/2" ϕ bars 16" c/c to top
1/2" ϕ bars 8" c/c to here + embedment
1/2" ϕ bars 4" c/c to here + embedment
6'-0"
3'-0"
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Distance from top of Cantilever Stem (ft.)
0
.20
.40
.60
.80
Area of Steel (sq. in.)

$\frac{12}{3}$ = <u>4 inch</u> spacing

$L = \frac{f_sD}{4u} = \frac{18000 x .5}{4 x 100} = 22.5$ inches embedment

Investigation of shear & moment at third points:

$V_x = 14.35\ h^2 \qquad M_x = 4.78\ h^3$

Where V_x & M_x = shear & moment at any section "h" dist. from top of wall

$\frac{2x14.5}{3}$ = <u>9.67 ft. = h</u> $\qquad V_x = 14.35 \times 9.67^2 = 1340$ lb.

$M_x = 4.78\ h^3 = 4.78 \times 9.67^3 = 4320$ ft.lb.

$d = \frac{V}{vjb} = \frac{1340}{40x7/8x12} = 3.19$ in.

$d = \sqrt{\frac{M}{K}} = \sqrt{\frac{4320}{139}} = \sqrt{31.1} = 5.58$ in. O.K. actual "d" = 13"

$As = \frac{M}{f_sjd} = \frac{4320x12}{18000x7/8x13} = .253\ in.^2$

$h = \frac{14.5}{3} = 4.83$ ft. $\qquad V_x = 14.35 \times 4.83^2 = 335$ lb.

$M_x = 4.78 \times 4.83^3 = 545$ ft.lb.

$d = \frac{V}{vjb} = \frac{335}{40x7/8x12} = .798$ in.

$d = \sqrt{\frac{M}{K}} = \sqrt{\frac{545}{139}} = \sqrt{3.92} = 1.98$ or 2 inches

$As = \frac{545x12}{18000x7/8x11} = .0377\ in.^2$

G. Temperature Steel:

.0025 (ave.) x concrete x-section area

$.0025 \times 12 \times 15 = .450\ in.^2$

Use ½ ∅ @ 9" c/c Front + ⅜" ∅ @ 12" c/c Back = .46 in.²

To support horiz. steel in front of stem: Use ½" ∅ bars @ 3'-0"

Longitudnal bars in base: Use ½" ∅ bars - 18" c/c

H. Design of Piles

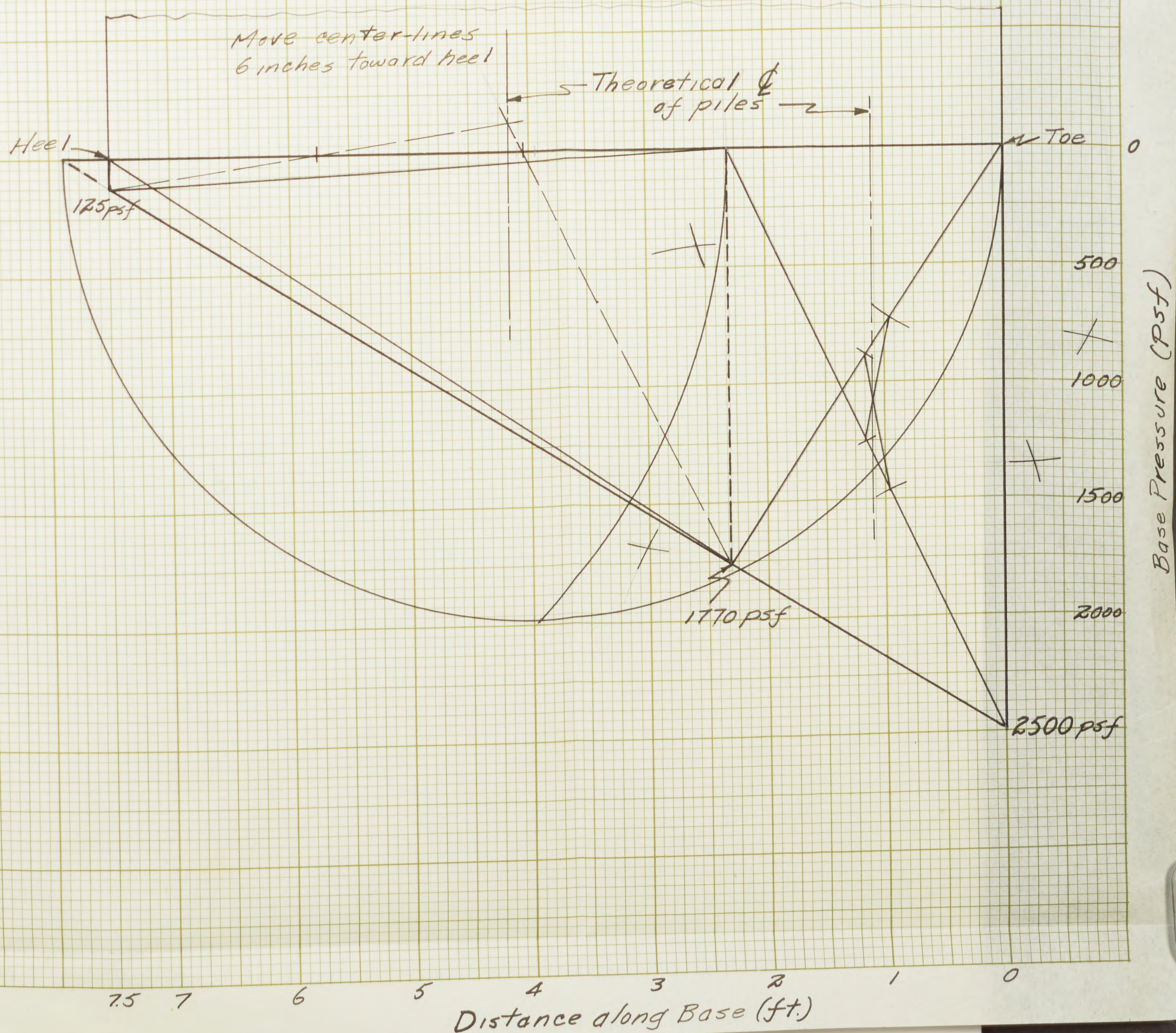
Although data concerning soundings was not available for this design, helpful information was contributed by Mr. W. C. Gunn, Civil Engineer. Mr. Gunn was the construction engineer for the bridge job and consequently is familiar with the supporting characteristics of the soil. Considering the soil pressure developed at the toe, of the wall in this design, he advised the addition of timber piling to assure ample support.

The problem of spacing and size of piles was taken up with Prof. C. A. Miller, Dept. of Civil Engineering. His reference to a graphical method of determining this spacing was greatly appreciated along with his other helpful assistance on the design of the wall.

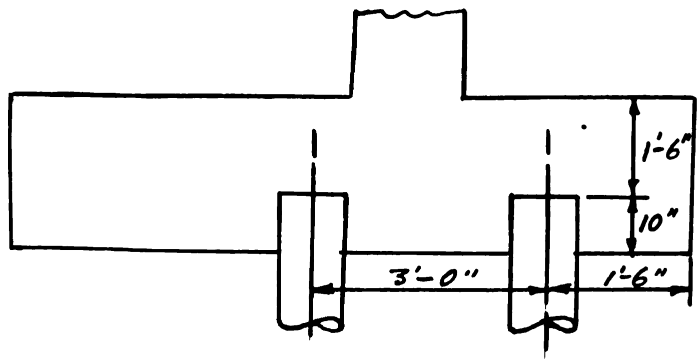
Use 15 feet long piles, measuring 12 inches at butt and tapering down to 9 inches at the tip. These piles can be rated at 15 tons in this soil accurding to Mr. Gunn.

The graphical method for determining spacing is shown on the following page. Since the theoretical center-line of the piles on the toe side is only 1 foot from the toe, the piles will be moved in another 6 inches. This will fulfill the required minimum distance of 18 inches from pile center-line to edge of concrete. The second line of piles at 4 feet from the toe will be moved a corresponding distance.

Graphical Method of Determining Spacing of Piles



Calculation of load transfered to each pile:



Load per pile with $4\frac{1}{2}$ ft. longitudnal spacing. $= \dfrac{2500\text{psf} + 1770\text{psf}}{2} \times 2.3 \times 4.5 = 22{,}100$ lb.

Load per pile equals approx. 11 tons.
Allowable pile capacity = 15 tons.

I. Drainage Weepholes

The drainage problem for this retaining wall is somewhat different from the ordinary. Since the usual location of weepholes near the bottom of the stem is, in this case, below the river bed, the outlet will be placed at a higher elevation (820 ft.). Above this point bankrun gravel is to be filled in as a filtering medium for catching silt and other foreign matter which would tend to clog the drains.

The weepholes are to be constructed by building 6" x 6" boxes integrally with the stem forms. This technique is desirable because scrap lumber can be used for the boxes and the work need not be complicated by a possible difference in tile lengths and wall thickness.

III Construction Estimate

A. Current Unit Prices

In the construction field, unit prices fluctuate due to many varying conditions. Therefore, it is often difficult to predict at a glance how much a certain structure will cost to build.

For this problem, the writer consulted with an engineer connected with a local contracting firm to get a typical picture of the current prices in this area. The co-operation of Mr. Dave Cole of the Reniger Construction Company was greatly appreciated in connection with this matter.

The following unit prices will be used herewith:

<u>Excavation</u>

Power excavate - 80¢/yd.

Backfill - 25¢/yd.

<u>Concrete</u>

Materials: 2500lb. - 5 sack concrete - $8.70/yd. delivered (ready mix)

Labor: Footing concrete - $2.00/yd.

Wall concrete - $3.50/yd.

Forms: Footings - Material - 15¢/sq.ft.

Labor - 25¢/sq.ft.

Walls - Material - 38¢/sq.ft.

Labor - 50¢/sq.ft.

Const. joint - 50¢/lin.ft.

Reinforcing Steel

Material: Deformed, intermediate grade, billet steel will be used.

Material Fabricated - \$125/ton (this figure includes accessories such as tie wire, beam chairs & spacers.)

Placing Steel - \$50.00/ton

Carborundum Rub (surface finish)

Material - ½¢/sq.ft.

Labor - 30¢/sq.ft.

Overhead - 10%

Includes: supervision, timekeeping, layout, expediting, sheds, workmen's compensation, social security.

Bonds - ½%

Profit - 10% for a job of this type and size.

B. Quantitie of Materials Estimate

Concrete : Footing - Vol. $= \frac{28}{12} \times 7.5 \times 370.7 \times 1/27 = 240$ cu.yds.

Deduct cylinders for pile heads:

Vol. of one cyl. $= \frac{\pi d^2 h}{4} = .785 \times 1 \times \frac{10}{12} = .655$ cu.ft.

.655 cu.ft./cyl.x166 cyl. = 108.5 cu.ft.

$\frac{108.5}{27} = 4.0$ cu.yds.

240 - 4 = 236 cu.yds. = conc.vol.in footing

Stem - Vol. $= \frac{1 + 1.5}{2} \times 14.5 \times 370.7 \times 1/27 =$ 249 cu.yds.

Total Concrete Yardage = 236 + 249 = 485 cu.yds.

Steel : Footing steel top - ½" ø bars 5'-2" rods @ 6" c/c

2 x 370 = 740 rods 740 x 5.17 = 3820 lin.ft.

Footing steel bottom - ½" ø bars 4'-2" rods @ 6" c/c

2 x 370 x 417= 3080 lin.ft.

Footing steel longitudnal - 7½" ∅ rods, entire length of wall

7 x 370 = 2590 lin.ft.

Dowel steel - ½" ⦶/ bars - 4'-0" - 4" c/c

3 x 370 x 4 = 4440 lin.ft.

Stem steel - ½" ⦶/ bars - 7'-0" - 8" c/c

1.5 x 370 x 7 = 3880 lin.ft.

Temp. steel horiz. - ½" ∅ bars

15 x 370 + 19 x 370 = 12,580 lin.ft.

Temp. steel vert. - ½" ∅ bars - 14'-6" - 3'-0" c/c

14.5 x 123 rods = 1780 lin.ft.

Totals: 8320 lin.ft. of ½" ⦶/ bars

23850 lin.ft. of ½" ∅ bars

½" ⦶/ bars weigh .850 lb/lin.ft.

½" ∅ " " .668 lb/lin.ft.

Total wt. = 8320 x .850 + 23,850 x .668 = 23,020 lb.

= 11.50 tons

Excavation: Slope trench 60° with horizontal

Volume of excavation = $\frac{178 \times 370}{27}$ = 2440 cu.yd.

C. Cost Estimate

Power Excavate - 2440 cu. yds. x .80¢/cu.yd.	= $ 1950.00
Backfill - 1450 cu.yds. x .25¢/cu.yd.	= 362.00
Forms:Footing:	
Materials - 15¢/sq.ft. x 370 ft. x $\frac{28}{12}$ x 2	= 259.00
Labor - 25¢/sq.ft. x 370 x $\frac{28}{12}$ x 2	= 432.00
Forms:Stem:	
Materials - 38¢/sq.ft. x 14.5 x 370 x 2	= 4080.00
Labor - 50¢/sq.ft. x 14.5 x 370 x 2	= 5370.00
Footing Concrete:	
Materials - 236 cu.yd. x 8.70/cu.yd. delivered	= 2050.00
Labor - 236 cu.yd. x 2.00/cu.yd.	= 472.00
Stem Concrete:	
Materials - 249 cu.yd. x 8.70/cu.yd delivered	= 2170.00
Labor - 236 cu.yd. x 3.50/cu.yd.	= 872.00
Construction joints:	
One joint every 40 ft. = 92 joints	
22 lin.ft./joint x 92 joints x 50¢/lin.ft.	= 1010.00
Reinforcing Steel:	
Materials - 11.5 tons x $125/ton	= 1440.00
Labor (placing) - 11.5 tons x $50/ton	= 575.00
Carborundum Rub: upper 8ft. of front surface of stem will be rubbed for appearance.	
Materials: - 8 x 370 x ½¢/sq.ft.	= 14.80
Labor - 8 x 370 x 30¢/sq.ft.	= 888.00
Piling: 166 piles x $60/pile (driving + materials)	= 9950.00
Tot.	= 31894.80
Contractor's overhead = 10%	= 3189.48
	35084.28
Contractor's profit = 8%	2810.00
	=$ 37894.28

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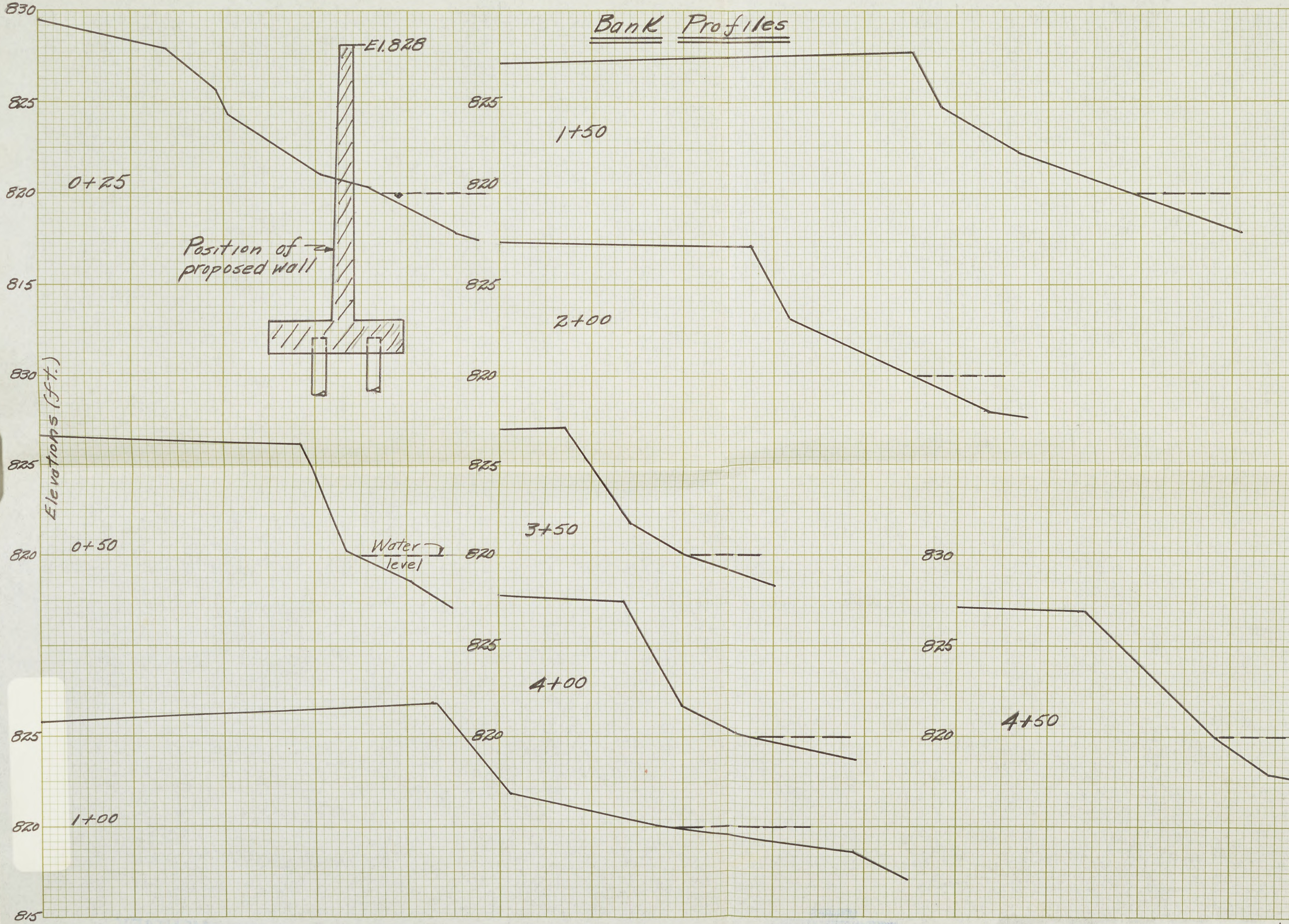
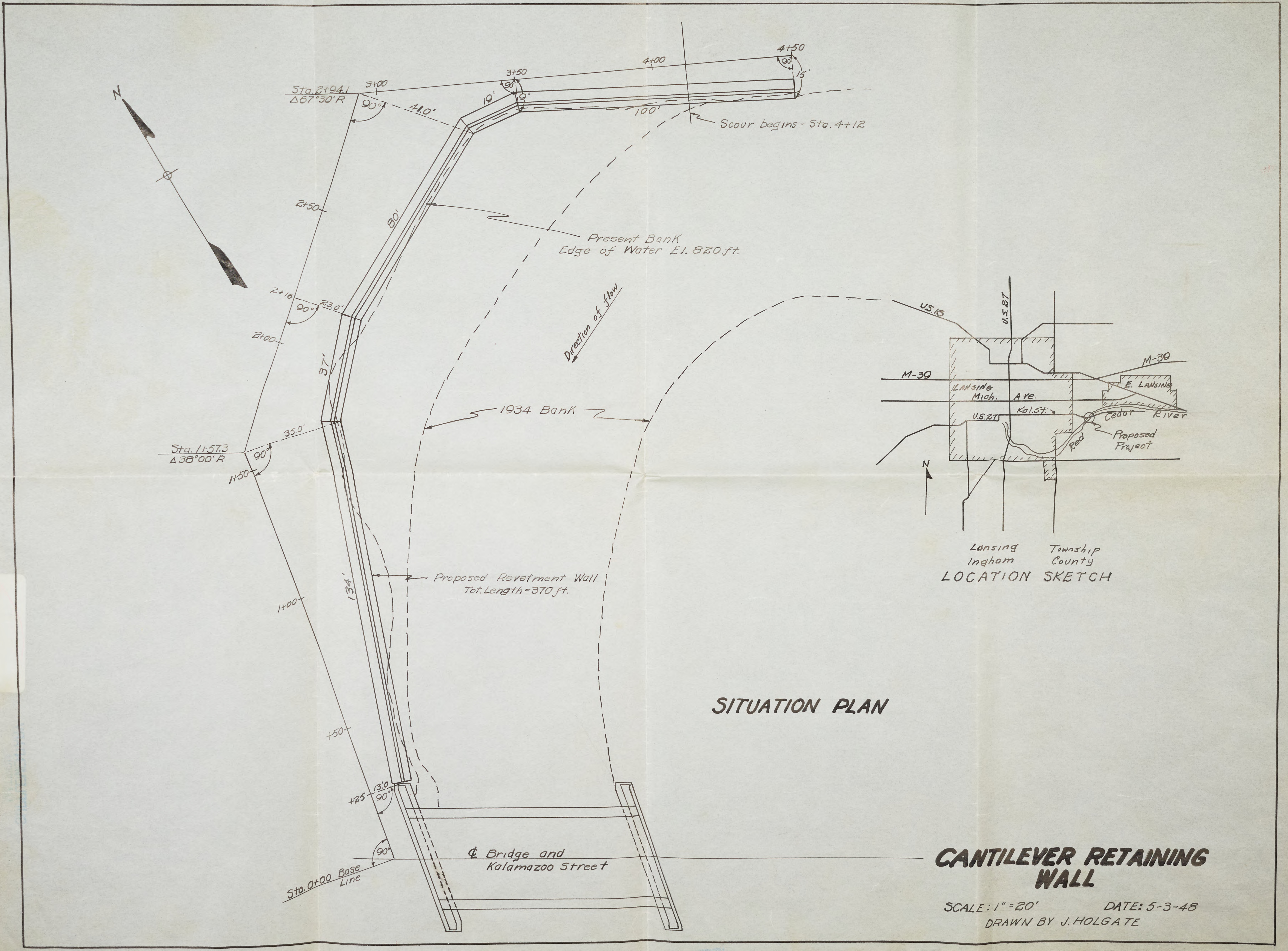

Bank Profiles
Elevations (ft.)
El. 828
Position of proposed wall
Water level
0+25
0+50
1+00
1+50
2+00
3+50
4+00
4+50
830
825
820
815

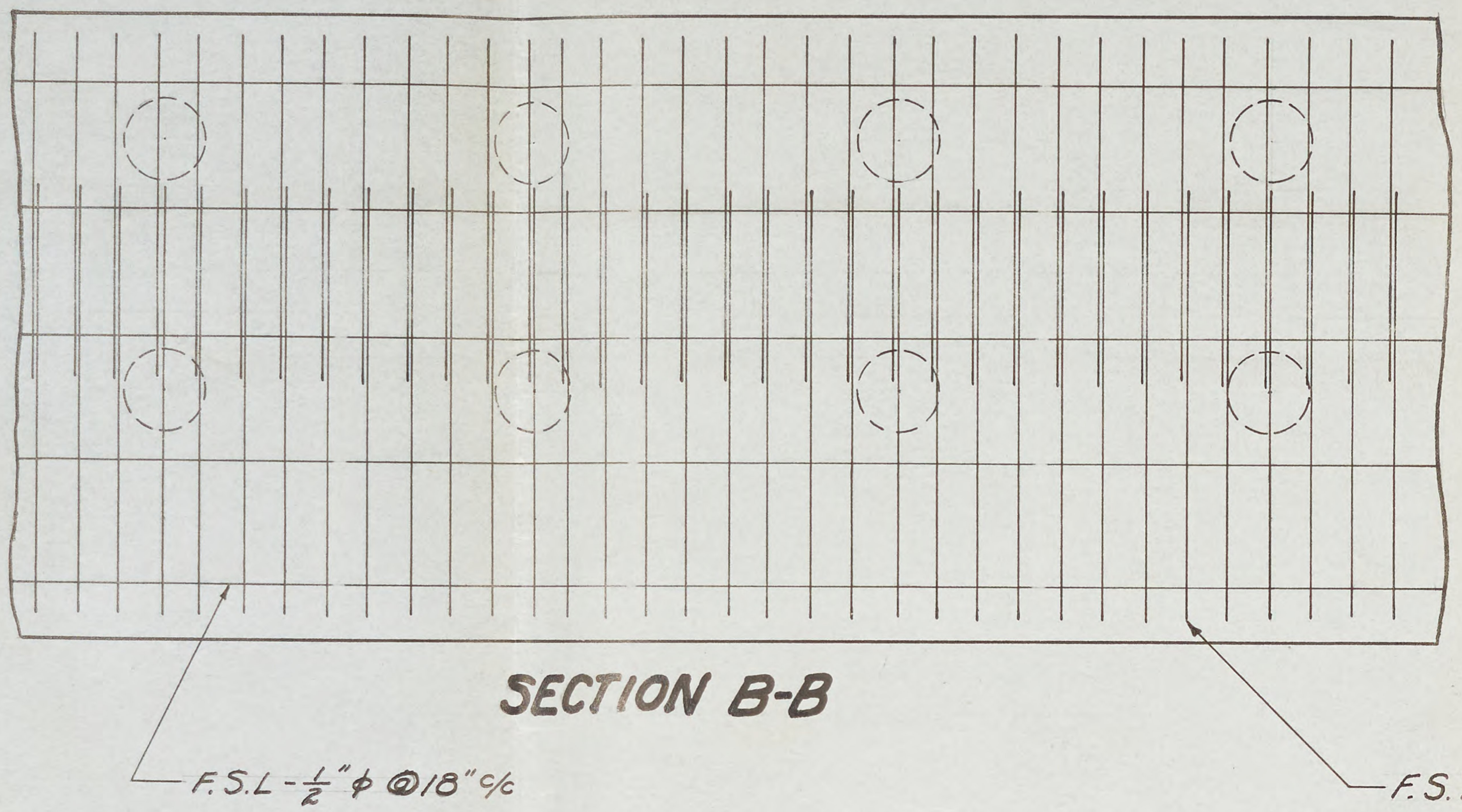
J. Holgate



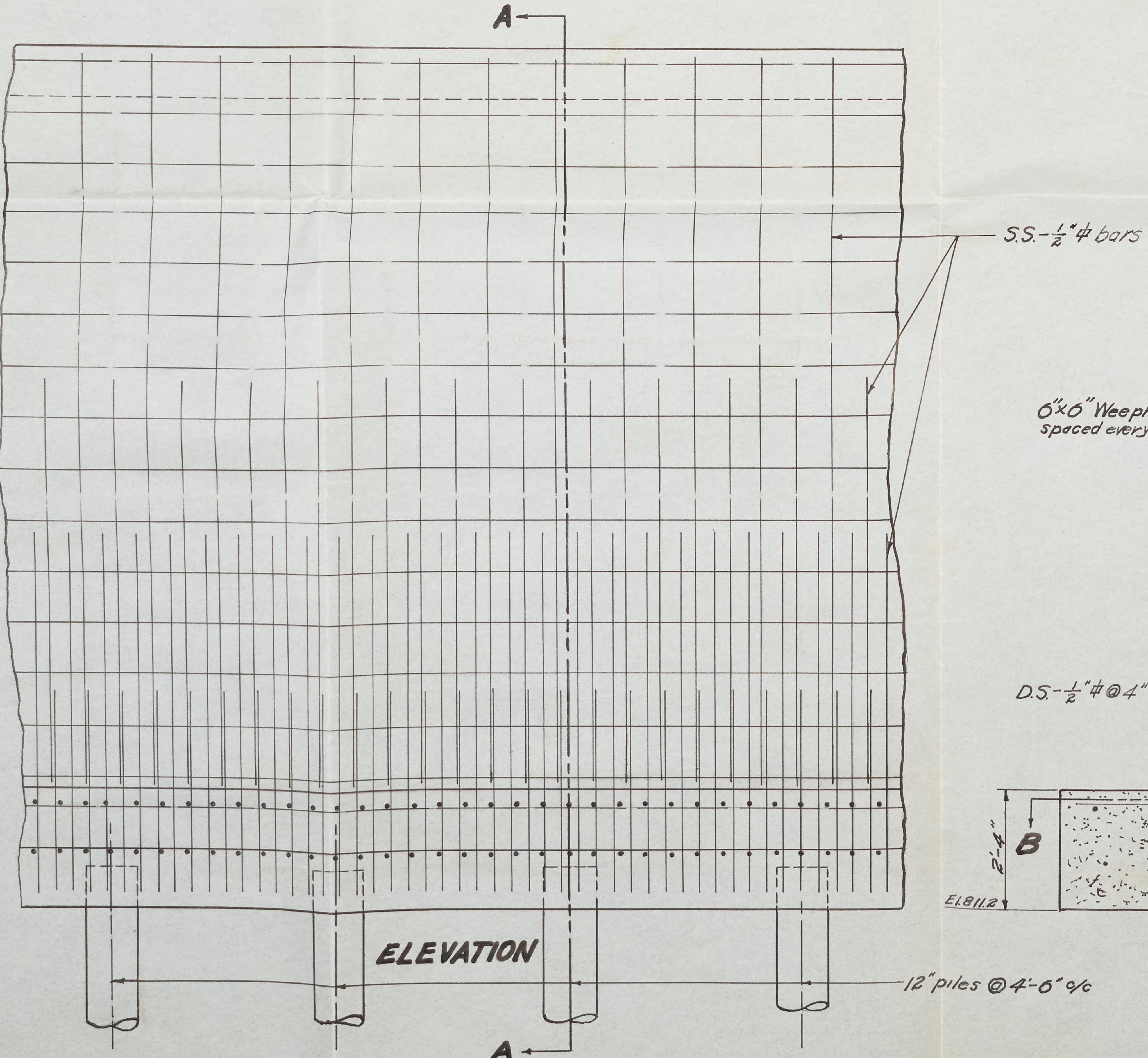
N
Sta. 2+94.1
Δ67°30' R
3+00
90°
41.0'
3+50
90°
19'
9'
4+00
4+50
90°
15'
100'
Scour begins - Sta. 4+12
2+50
80'
Present Bank
Edge of Water El. 820 ft.
2+16
90°
23.0'
2+00
Direction of flow
37'
1934 Bank
Sta. 1+57.3
Δ38°00' R
90°
35.0'
1+50
1+00
134'
Proposed Revetment Wall
Tot. Length = 370 ft.
+50
+25
13.0
90°
90°
℄ Bridge and
Kalamazoo Street
Sta. 0+00 Base
Line
SITUATION PLAN
US 16
U.S. 27
M-39
M-39
Lansing
Mich.
Ave.
E. Lansing
U.S. 27
Kal. St.
Cedar River
Red
Proposed
Project
N
Lansing
Ingham
Township
County
LOCATION SKETCH
CANTILEVER RETAINING
WALL
SCALE: 1" = 20'
DATE: 5-3-48
DRAWN BY J. HOLGATE

BILL OF MATERIALS

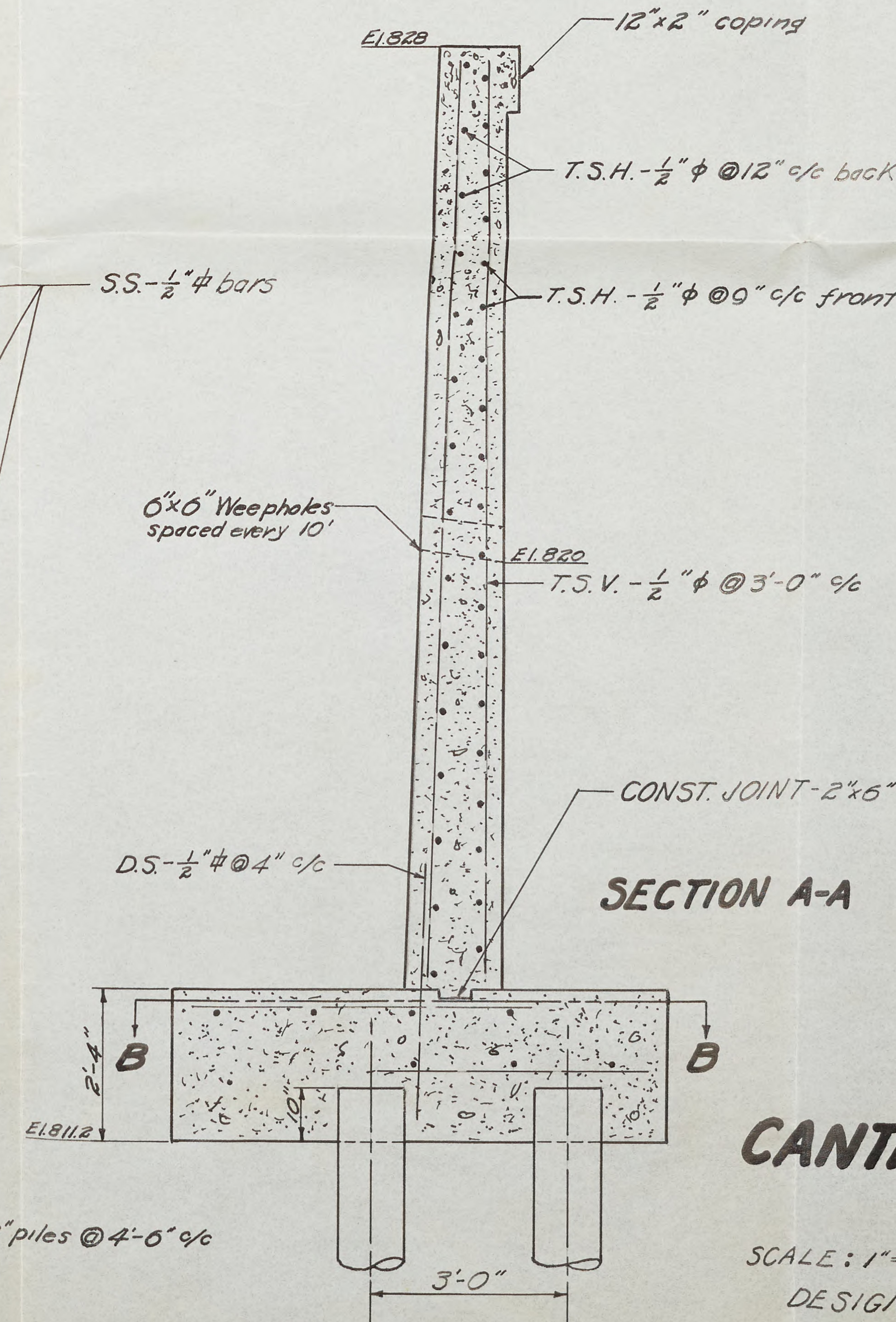
ITEM	Notation	Cu. Yds. Concrete	Reinf. Steel lin. feet	Reinf. Steel lbs.	Timber piles	Cu. Yds. Excavation	Sheet Piling
Footing		236			166		375 lin. feet
Foot. Steel Top	F.S.T		3820	2550			
" " Bott.	F.S.B.		3080	2060			
" " Long.	F.S.L.		2590	1730			
Stem		249					
Stem Steel	S.S.		3880	3300			
Dowel Steel	D.S.		4440	3780			
Temp. Stl. Hor.	T.S.H.		12,580	8410			
Temp. Stl. Vert.	T.S.V.		1780	1190			
Tot. Excav.						3020	
Totals		485	32,170	23,020	166	3020	375



SECTION B-B



ELEVATION



SECTION A-A

CANTILEVER RETAINING WALL

SCALE: 1"=2' DATE: 5-3-48

DESIGNED BY J. HOLGATE