DESIGN OF A COUNTERFORT RETAINING WALL ALONG RED CEDAR RIVER. EAST LANSING, MICH.

THESIS FOR THE DEGREE OF B. S.

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1930

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Design of a Counterfort Retaining Wall along Red Cedar River, East Lansing, Michigan.

A Thesis Submitted to

The Faculty of

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of

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By

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Candidate for the Degree of

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Philip H. Anderson.

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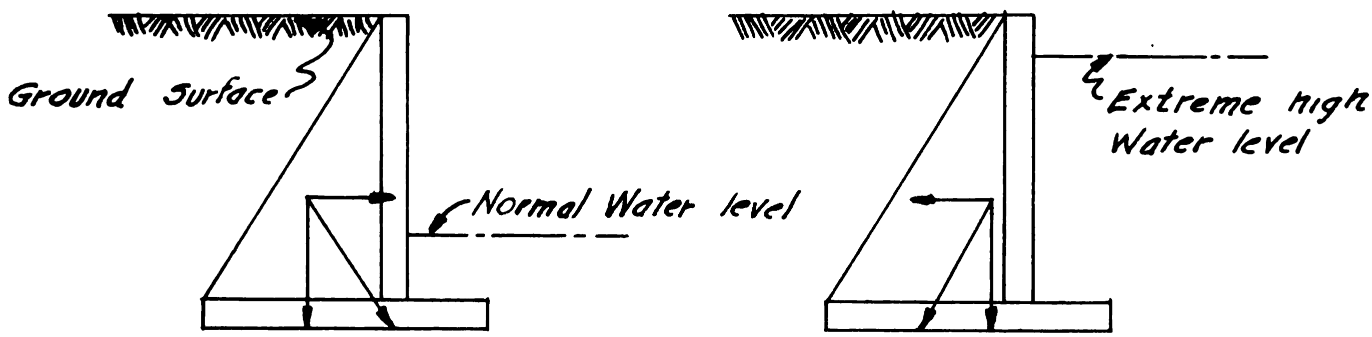
The protection of property from damage by floods has always been one of primary importance.

The site chosen for this design is located on the outskirts of East Lansing at the intersection of the Red Cedar River and Harrison Road.

In the mid summer this land is comparitively dry, but in the early spring the Red Cedar rises above its banks and floods the area. The difference in the extreme High Water level and the normal water level is approximately 10 feet. This difference provides an excellent opportunity for study of the variations of the resultant pressures and the subsequent reversal of stresses.

In this particular case the following sketch shows the variation in pressures.



This design was made adequate to provide safety in both cases and is found necessary to deviate from the minimum allowable dimensions in several cases to produce a satisfactory design.

The site was surveyed and countours run. A log of Borings was obtained from the State Highway Department and are shown together with a Topographical map on Sheet No. 1

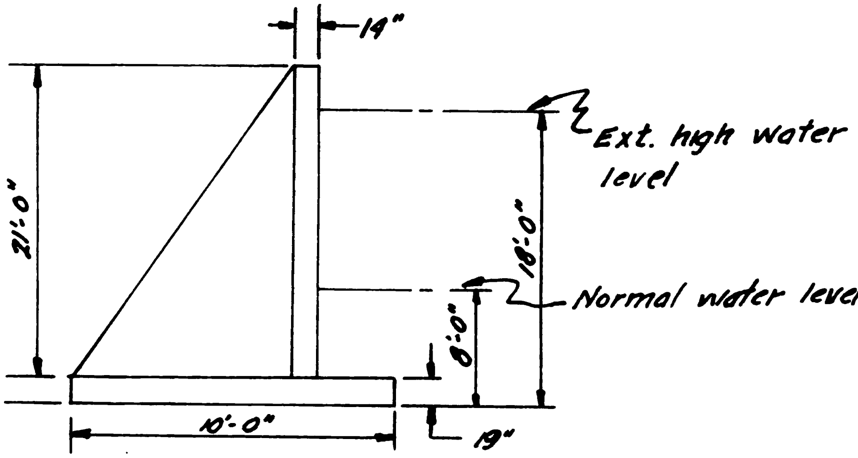
in the back folder of this book.

Profiles were taken at intervals of important changes in contour. From this data a height of 21 feet was considered necessary as determined on the profile map marked Sheet No. 2.

The counterforted type of wall was chosen, since the height exceeded 20 feet and results show that this type is more economical when the height is greater than 20 feet.

A value of $\frac{t}{h}$ equals .42 was selected with an assumed weight of 25 and a design was worked out. The Resultant pressure failed to pass within the middle third and these values were discarded. After several trials value of t equals 10' h equals 21' were found to satisfy the condition and were used.

A value of 30" was assumed for the thickness of the footing, which was later found to be high and a correction was made in the next trial.



Verticle Wall

W due to earth equals 25#

W due to earth & water equals (62.4 - 25) equals 37.4#

Verticle Wall

The pressure at a depth of 18.5' is wh. equals 37.4 X 18.5

wh equals 730#

The counterforts are spread 8' apart c - c with a thickness of 16". Clear Span equals 8-1.33 equals 6.67'

M equals 1/10 wl^2 equals 730/10 X $(6.67)^2$ equals 3242# per ft. of width

d equals $\sqrt{M/bk}$ equals $\sqrt{3242/107.7}$ equals 5.71

For Shear----

V equals 730 (4 - .67) equals 2430

d equals V/vbj equals 2430/(40)(.874).(12) equals 5.78 or 6"

The minimum allowable d to allow for placing of the steel is 12". It was found advisable to use 14" here.

Assume 1/2" round bars spaced 4" on centers.

A equals p d b

A, equals (.0077) (12) (5.78) equals .535

u equals V/eojd equals 2430/12/4 X (1.571) X (.874) (5.78) equals 102#

Since a bond stress of 102# is too high the spacing was decreased to 3"

$$u \text{ equals } \frac{2430}{(12/3)\ (1.57)\ X\ (.874)\ (5.78)} \text{ equals } 76\#$$

$$v \text{ equals } \frac{V}{bjd} \text{ equals } \frac{2430}{12(.874(5.78)} \text{ equals } 40\#$$

<u>For Outer Steel:</u>

wh equals 25 X 18.5 equals 487#

$$M \text{ equals } \frac{1\ X\ 487\ X\ (6.07)^2}{10} \text{ equals } 2132\#$$

$$d \text{ equals } \sqrt{\frac{2132}{107.7}} \text{ equals } 4.45$$

A, equals p d b equals (.0077) 12 (4.45) equals .41

Use 1/2" round bars spaced 5 1/2" c - c

Spacing of Steel:

Inner Wall,

at Quarter Point equals 4 X 4/3 equals 5.33"

at one-half point equals 4 X 4/2 equals 8."

Outer Wall

at Quarter Pt. equals 5 1/2 X 4/3 equals 7.33"

at One-half Pt. equals 5 1/2 X 2 equals 11"

Design of Footing: (High Water)

To determine total pressure on Base.

wt. of Earth	equals	(18.5 X 5.09 X 100)	equals	9425
" " Stem	"	(1.165 X 18.5 X 150)	"	3230
" " Footing	"	(10 X 2.50 X 150)	"	3750
" " Water	"	(62.4 X 15.5 X 2.75)	"	2660
				18075

$$r \text{ equals } \frac{(9425 \times 2.54) \text{ plus } (3230 \times 6.67) \text{ plus } (3750 \times 5) \text{ plus } (2660 \times 8.63)}{18075}$$

$$r \text{ equals } \frac{85250}{18075} \text{ equals } 4.72$$

To Find where Resultant Pressure Acts:

P (earth) equals 1/2 wh^2 equals $1/2 . 25 . (21)^2$ equals 5520

P (water) equals 1/2 wh^2 equals 1/2 62.4 X 58^2 equals 10100#

P_r equals 10100 equals 5520 equals 4580#

$$X_r \text{ equals } \frac{5520 \times 7 - 10100 \times 6}{4500} \text{ equals } 5.66$$

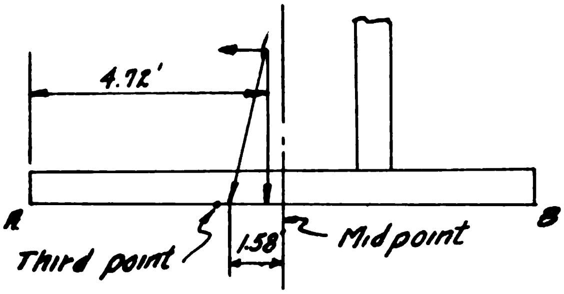
$$\frac{x}{5.22} \text{ equals } \frac{4580}{18075} \text{ equals } 1.3$$

X_o equals (5.00 - 4.72) plus 1.3 equals 1.58

$$P_a \text{ equals } \frac{18075}{10} \left(1 \text{ plus } \frac{(6)\,(1.58)}{10}\right)$$

equals 1807 plus 1720 equals 3527#

P_b equals 1807 - 1720 equals 87#



Safety Factors:

$$\text{Sliding equals } \frac{18075 \times .5}{4580} \text{ equals } 1.9$$

$$\text{Overturning equals } \frac{4.72}{4.72-3.42} \text{ equals } 2.5$$

Pressures for Normal Water level:

Wt. of Earth	equals	(18.5 X 5.09 X 100)	equals 9425
" " Stem	"	(1.165 X 18.5 X 150)	" 3230
" " Footing	"	(10 X 2.50 X 150)	" 3750
" " Water	"	(2.75 X 62.4 X 5.5)	" 945
			17350

$$r \text{ equals } \frac{(9425 \times 2.54) \text{ plus } (3230 \times 6.67) \text{ plus } (3750 \times 5) \text{ plus } (945 \times 8.63)}{17350}$$

$$r \text{ equals } \frac{70500}{17350} \text{ equals } 4.05$$

To Find where Resultant Pressure Acts:

$$P \text{ (earth) equals } \tfrac{1}{2} \,.\, 25 \times (21)^2 \text{ equals } 5520$$

$$P \text{ (water) equals } \tfrac{1}{2} \,.\, 62.4 \times 8^2 \text{ equals } 2000$$

$$R \text{ equals } 5520 - 2000 \text{ equals } 3520$$

$$X_r \text{ equals } \frac{5520 \times 7 - 2000 \times 2.66}{3520} \text{ equals } 9.45$$

$$\frac{x}{9.45} \text{ equals } \frac{3520}{17350}$$

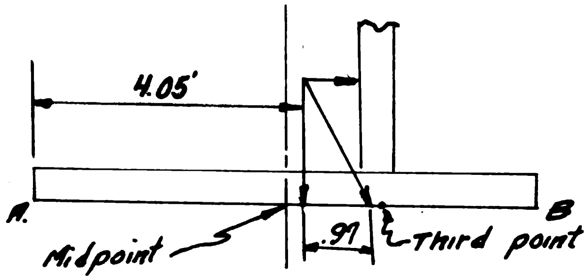
$$x \text{ equals } 1.92$$

$$X_o \text{ equals } (4.05 \text{ plus } 1.92) - 5.00 \text{ equals } .97$$

$$P_a \text{ equals } \frac{17350}{10} \left(1 \text{ plus } \frac{.97 \times 6}{10} \right)$$

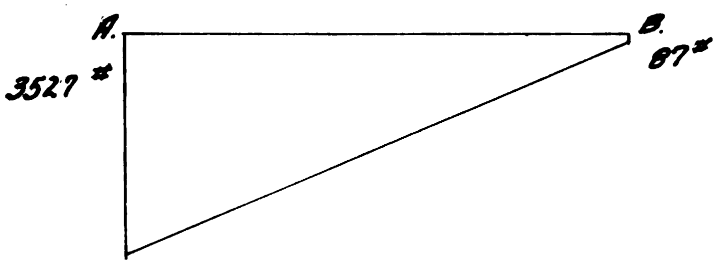
equals 1735 - 1010 equals 725#

P_b equals 1735 plus 1010 equals 2745#

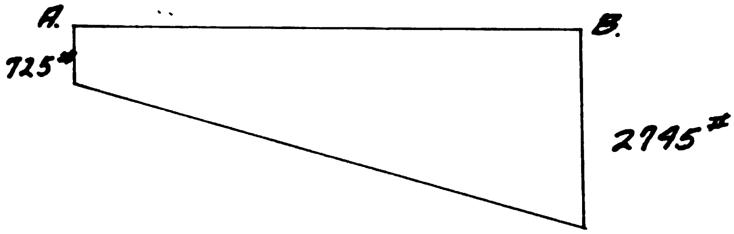


Pressures on Base in both Cases.

High Water.



Normal Water.



<u>Inner</u> <u>Floor</u> <u>Slab.</u>

The decrease in load per foot is

$$\frac{725 \text{ plus } 931}{2} \text{ equals } 828\#$$

Uniform load on end Step equals 1850 plus 375 - 828#

equals 1397#

Max. Bending Moment equals $\frac{(1397) \times (6.67)^2}{10}$ equals 6220#

d equals $\sqrt{\frac{6220}{107.7}}$ equals 5.8"

For Shear.

V equals 1397 (4.00 - 67) equals 4700#

d equals $\frac{4700\#}{(12).(87).(30)}$ equals 15" plus or 16"

Total depth equals 16 plus 3 equals 19"

K equals $\frac{17}{bd^2}$ equals $\frac{6220}{15}$ equals 27.6

P equals $\frac{27.6}{(16000)X(.87)}$ equals .00194

A_s equals (.00194)(12)(15) equals .342 sq. in.

Use $\frac{3}{4}$ in. round bars spaced 12" center to center

Spacing over Supports equals $\frac{(80)(12)(2.36)(.87)(15)}{4700}$

s equals 6.3 or 6.5

decrease in load per foot equals $\frac{2745 - 725}{10}$ equals 202#

At 2 feet from End:

Top Spacing equals $\frac{6 \ X \ 1397}{1349}$ equals 6.3 or 6.5"

Bottom Spacing equals 2 X 6.5 equals 13"

At 4 feet from end:

Top Spacing equals $\frac{6 \ X \ 1397}{698}$ equals 12.2 or 12.5"

Bottom Spacing equals 12.5 X 2 equals 25" - 18" equal Max.

P equals $\frac{.44}{6 \ X \ 15}$ equals .0049, j equals .894

f_s equals $\frac{(6220)(12)}{(.0049)(.894)(12)(225)}$ equals 74600

$\frac{74600}{1182}$ equals 6320#

$\frac{fi}{4u}$ equals $\frac{6320 \ X \ .75}{4 \ X \ 80}$ equals 14.8 or 15"

length of Embedment equals 15"

v equals $\frac{4700}{(12)(.894)(15)}$ equals $\frac{4700}{161}$ equals

29.2#

Outer Cantilever:

Wt. of Wall	equals 2.75 X 150 X 2.5 equals	1030#
" " Water "		945#
	Total	1975#

distance to c. g. equals $\frac{2.75}{3}$ $\frac{(2.(2189) \text{ plus } 2745)}{4934}$ equals 1.43

M equals $(2.467)(2.75)(1.43) - [(2.75)(2.5)(150) \text{ plus } 945]\, 1.375$

d equals $\sqrt{\frac{7100}{107.7}}$ equals 8" plus

Shear equals (2075)(2.75)-(2.75 X 2.5) X 150

5700 - 568 equals 5132

d equals $\frac{5132}{(12)(30)(.87)}$ equals 16"

Total equals 16 plus 3 equals 19"

Use $\frac{3}{4}$" round bars spaced 12" center to center.

P equals $\frac{.44}{6 \times 15}$ equals .0040 $\quad$ j equals .899

u equals $\frac{5132}{\frac{12}{6}(2.36)(.899)(16)}$ equals 76#

F_s equals $\frac{7100 \times 12}{(1004)(.899)(.256)12}$ equals 7700#

Length of embedment of Steel:

$\frac{Fi}{4u}$ equals $\frac{7700 \;.\; .75}{4.80}$ equals 18"

Design of Counterfort.

Horizontal force transmitted equals $\frac{1}{2}(25)(18.5)^2.8$ equals 34200#

M equals $34{,}200 \left(\frac{18.5}{3}\right) 12$ equals 2,540,000"#

K equals $\frac{2{,}540{,}000}{16(5.65)^2.(12)^2}$ equals 34.6

P equals .00247

A_s equals (5.65)(12)(16)(.00247) equals 2.68

Use 4- 1 inch buss spaced $3\frac{1}{2}$ c - c

Moment at 14' below top

$\frac{1}{2}(25)(14)^2$ X 8 equals 19600

M equals 19600 (14/3) X 8 equals 1,090,000 in lbs.

Moment at 7' below top

$\frac{1}{2}(25)(49)(8)$ equals 4900

M equals 4900 (8/3) 12 equals 15700 in lbs.

At 14' below top

$$K \text{ equals } \frac{1,090,000}{16(4.18)^2(12)^2} \text{ equals } 25.8$$

Rigid P equals .0018

At 7' below top

$$K \text{ equals } \frac{15700}{16(3.13)^2(12)} \text{ equals } 6.90$$

Rigid P equals .0005

2 rods carried above 14' point

2 rods carried above 7' point

$$P_1 \text{ equals } \frac{(.785)\ .2}{16(4.28)(12} \text{ equals } .0020$$

$$P_2 \text{ equals } \frac{(.785)\ .2}{16(3.13)(12)} \text{ equals } .0026$$

These rods may be stopped as planned.

Horizontal Steel:

Shear on 1 ft. in height.

V equals 25 X (18.5)(6.67) equals 3080

assume 1/2" round bars.

$$\text{No. per one ft. ht. equals } \frac{3080}{16000 \times .196} \text{ equals } .97 \text{ or } 1$$

$$\text{Spacing at Footing equals } \frac{(12)(2)}{1} \text{ equals } 24"$$

Spacing at 10' point

V equals (25)(10)(6.67) equals 1670

$$\text{No. per one ft. ht. equals } \frac{1670}{16000 \times .196} \text{ equals } .55$$

$$\text{Spacing equals } \frac{12 \times 2}{.55} \text{ equals } 43"$$

Max. spacing is 24"

Verticle Steel:

V equals (1397)(6.67) equals 9320#

Use 5/8" round bars

$$\text{No. per ft. ht. equals } \frac{9320}{16000\ .\ .306} \text{ equals } 1.9 \text{ or } 2$$

$$\text{Spacing equals } \frac{12 \times 2}{2} \text{ equals } 12"$$

3rd Strip

V equals 9320 - (3 X 828) equals 6836

No. per ft. ht. equals $\frac{6836}{16000 \cdot 306}$ equals 1.3

Spacing equals $\frac{12.2}{1.3}$ equals 18"

4th Strip

V equals 9320 - (4 X 828) equals 6000

No. equals $\frac{6008}{16000 \times 306}$ equals 1.2

Spacing equals $\frac{24}{1.2}$ equals 20"

5th Strip

V equals 9320 - (5 X 828) equals 5180

No. equals $\frac{5180}{16000 \times 306}$ equals 1.05

spacing - $\frac{24}{1.05}$ = 22.4"

Amount of steel for one Bay & Counterfort.

Footing.

16 - $\frac{3}{4}$" round bars - 8' - 128 lin. ft.

16 - $\frac{3}{4}$" " " -3'10"- 62 lin. ft,
190 X 1.5 = 285#

Wall - Horizontal

74 - $\frac{1}{2}$" round bars - 8'0" -592 lin. ft.X.67= 396#

Verticle

3 - $\frac{1}{2}$" round bars -20'$\frac{1}{2}$" - 62 lin. ft.X.67= 42#

2 - $\frac{3}{4}$" " " - " " " " - 41 " " X1.5= 62#

Counterfort

2 - 1" round bars -25' - 50 lin. ft.

2 - 1" " " -20' - 40 " "
90 X 2.67 = 240#

Verticle

2 - $\frac{5}{3}$" round bars -5' - 10 lin. ft.

2 - " " " " -3'6" - 17 " "

2 - " " " " -13'6" - 27 " "

2 - " " " " -18' - 36 " "
90 X 1.04 = 94#

Horizontal

2 - $\frac{1}{2}$" round bars -6'2" lin. ft. - 13

2 - " " " " -5'3" " " - 11

2 - " " " " -5'0" " " - 10

Horizontal con't.

2	- $\frac{1}{2}$"	round	bars	-4'8"	lin.	ft.	- 9
2	- ""	"	"	-4'2"	"	"	- 9
2	- ""	"	"	-3'6"	"	"	- 7
2	- ""	"	"	-2'8"	"	"	- 5
2	- ""	"	"	-2'3"	"	"	- 5
2	- ""	"	"	-1'6"	"	"	- 3
2	- ""	"	"	-1'0"	"	"	- 2

74 X .67 = 50#

Total = 1169#

Sheet No.III shows a detailed drawing of one bay and counterfort. This drawing shows the spacing and arrangement of the steel reinforcement.

The specifications used in design were 2000# concrete, $n = 15$, $f = 16000$, $f = 650$, $k = 107.7$, $j = .874$, and $p = .0077$.

In assuming $\frac{t}{h} = .42$ a reference was made to Trantwine's tables which was the basis of this assumption, however several trials showed that this ratio would not hold in this case due to the effect of the water pressure on the outside of the wall. The method of finding the correct ratio that would make the resultant pressures pass thru the third point was therefore one of trial and error and considerable time was spent in this manner.