AN ANALYSIS OF THE PILE FOUNDATIONS
UNDER THE MICHIGAN STATE
COLLEGE AUDITORIUM

Thesis for the Degree of B. S.
MICHIGAN STATE COLLEGE

Stephan John Patoprsty

1949

An analysis of the pile foundations under the Michigan State College Auditorium

A thesis submitted to the faculty of Michigan State College of Agriculture and Applied Science by Stephan John Patoprsty, a candidate for the Degree of Bachelor of Science, 1949

Introduction

This thesis covers the analysis of the design of the pile foundations of the College Auditorium. The original plans for the foundations were found and the data was obtained from them. This data was then used with the text books on reinforced concrete that we have used in our studies.

At this time I want to thank Dr. Pian, Professor Miller, Mr. Mundson the Architect of the Auditorium, Mr. Reniger the builder of the building, both of whom gave me much information which was never put on file, and Mr. Dave Lassiter who is a construction engineer.

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Part of the Specifications for pilings

by Boyd Munson Co.

4) Cast in place piles shall be cast in steel shell which shall remain permanently in the ground and which shall be driven with a mandrel unless the wall thickness of the shell is at least 3/16 in. The shell shall be of sufficient strength to prevent its distortion by the ground pressure developed by the driving of adjacent piles. After piles are cast in place the original resistance to which the shell is driven must be maintained. The use of piles in which a fresh or unset concrete is placed against the soil will not be permitted. The mirded minimum diameter of the straight cast in place piles shall be 15 inches. The minimum diameter of tapered cast in place piles shall be 8 inches at the point. The taper shall be four-tenths of an inch in the diameter for each linear foot of length of the pile. The minimum diameter of the cap shall be 15 inches. When the length of the pile does not develope the required diameter the top then must have a minimum diameter of 10.8 inches.

(cont.

cont. Specifications for Piling

5) The concrete for all piles shall be 1-2-4 mix of Portland cement, clean, coarse sa nd and 3/4" gravel or broken stone.

6) All piles shall be driven by means of a single acting stea m hammer having a falling part weighing not less than 5,000 # to a sufficient depth to carry a safe load of 20 Tons / pile. The capacity shall be determined by the following formula,

$$P = \frac{2\ WH}{S + 1}$$

Where p = safe bearing capacity in #.

W = wt. in # of striking parts of hammer

H = height of falling in feet

S = Average penetration of blow in inches per blow for the last 3 blows, for gravity hammers and the last 20 blows for steam hammers.

Constants and Abbreviations used

A(s)	Area of Steel	
b	Width	
d	Effective depth	
fc'	Ultimate compressive strength of concrete	2500psi:
fc	Compressive stress in extreme fiber .45 fc'	1125psi.
fs	Stress in reinforcing steel	20,000 psi.
j	Ratio of distance between resultants of stresses to effective depth.	.866
k	Ratio of distance between extreme fiber and neutral axis to effective depth	106
L	Lever arm	
M	Moment of Bending	
n	Ratio of modulus of elasticity (Es) to that of concrete (Ec)	12
P	Pressure or Load of Pile	
u	Bond stress	.05 fc' - 125psi.
V	Total Shear	
v	Shearing Stress	.03 fc'- 75psi.

FORMULAS

For the depth of the cap

$$M = kbd^2$$

$$d = \sqrt{\frac{M}{kb}}$$

However for a two way reinforcing use the factor 85%

Therefore

$$d = \sqrt{\frac{.85M}{kb}}$$

However the depth in this case is determined by the shear since the moment arm is so short.

$$A(s) = \frac{M}{f(s)jd}$$

$$d = \frac{f(s)\ jd\ A(s)}{M}$$

However for two way reinforcing use 85%

There fore

$$d = \frac{.85\ f(S)jdA(s)}{M}$$

Shear is checked at d/2 from the edge of the column or the edge of the footing cap, unless the center to center distance from the two outer most piles whose shearing forces are being checked is greater than the d at d/2 from the edge, then the center to center distance is used .

cont.

For checking shear to calculate d

$$\Sigma o = \frac{V}{ujd}$$

$$d = \frac{V}{ouj}$$

However for two way steel use 85%

$$d = \frac{.85\ V}{\Sigma ouj}$$

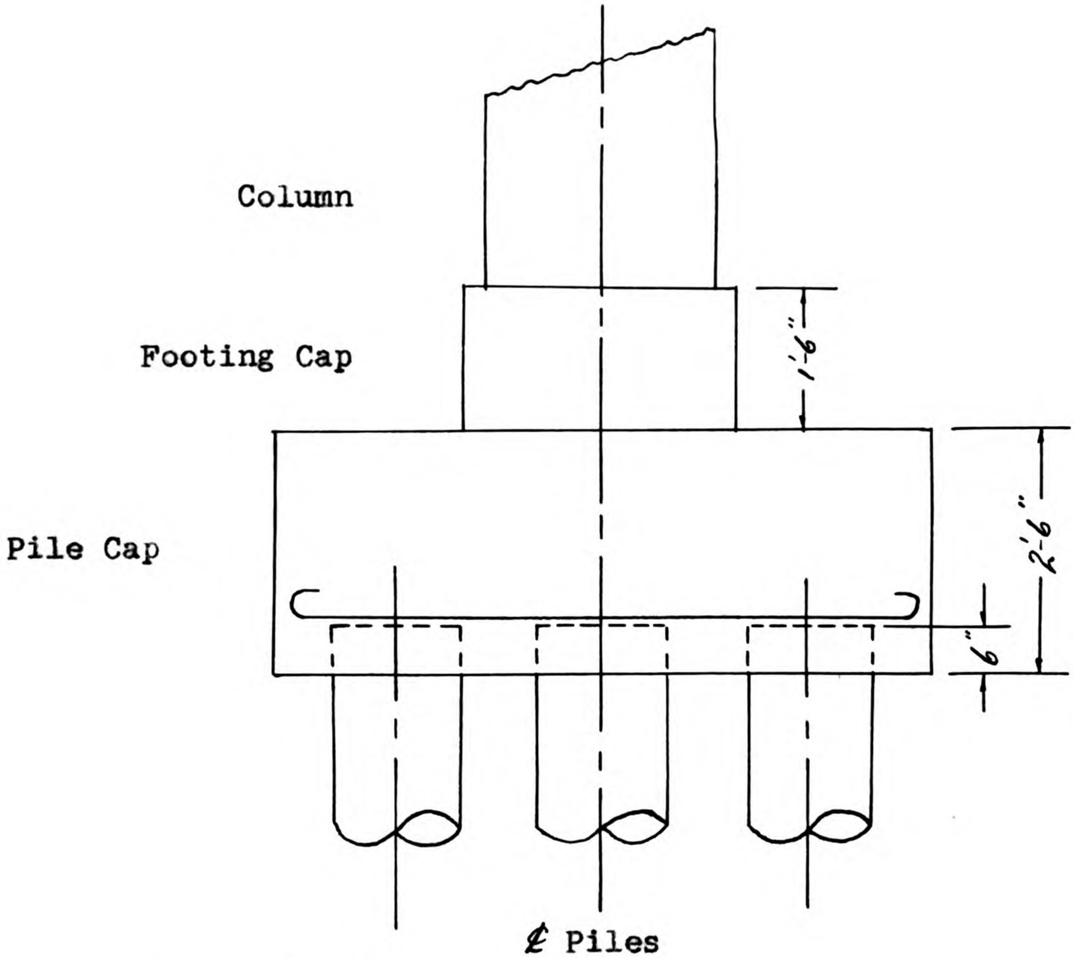
d also checked by

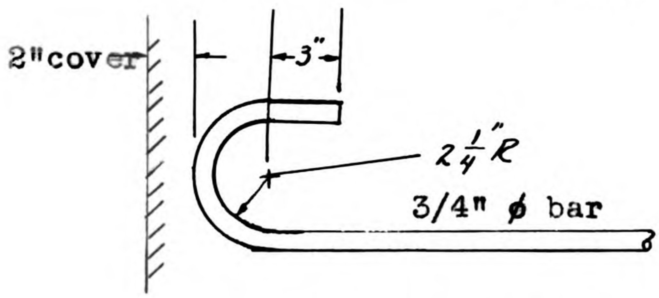
$$v = \frac{V}{bjd}$$

$$d = \frac{V}{bjv}$$

However in most cases and especially in the case of a completed building the depth d is known so the formulas were used to claculate the maximum allowable load that the pile footings will withstand.

GENERAL FOOTING ELEVATIONS





HOOK CONSTRUCTION

All cap bars are to be bent as shown

Explanation of computation sheets

The number and size of reinforcing bars, area, and perimeters

The maximum moment

$M = f(s)\ j\ d\ A(s)$

The maximum shear

$V = u\ b\ j\ d$

The maximum shear

$V = \Sigma o\ u\ j\ d$

Check moment

Allowable load per pile

Total Load

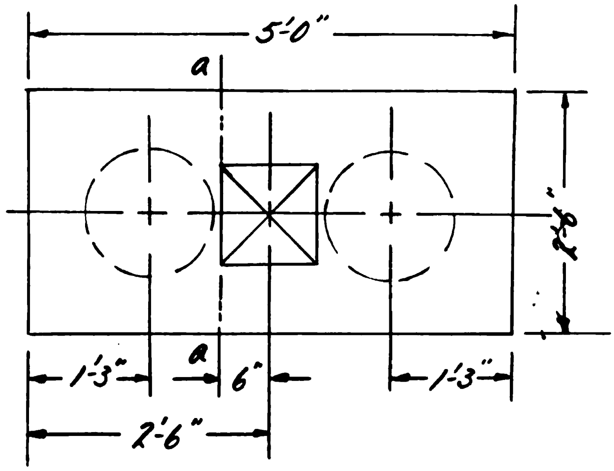
Total Load -
Wt. of Footing = Net Load

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
The number and kind of reinforcing bars in caps.	$m = f(s) j d A(s)$	$V = ubjd$	$V = \Sigma o u j d$		P x L
	The maximum moment that the cap will stand as determined by the area of steel.	The maximum shear that the cap will stand as determined by the unit shear of the concrete.	The maximum shear that the cap will stand as determined by unit bond stress and the perimeters of the bar steel.	The maximum shear that may be used to check the foundations and footings (the smaller of the pervious two columns).	The check of the moment using the loading as determined. Must be less than column 2.
	Allowable Load per pile	Total Load	Wt. of Footing	Net Load	
	The max. design shear divided by the number of piles at that section. Must be less than 30 tons per pile.	The Allowable load per pile multiplied by the number of piles in the footing.	The weight of the footing	The total load minus the weight of the footing. This column is then changed to tons and put on the layout drawing.	

THE EXPLANATION OF THE TABLE

DESIGN A

2 Piles



Column size 12"x 12"

Wt. of cap.

150 x 5'-0" x 2'-6" x 2'-6"

4,690#

Use this design for footings no.

23A, 32A, 83, 84, 85, 86,

94,97, 105, 106

20 Piles ----- 10 Footings

6-3/4" ∅

A(s)	2.64 in.^{2}
Σ(o)	14.14 in.^{2}

M = 20,000 x 1.02 x 1.75 x 2.64

92,500 #'

V = 125 x 1.02x21 x 14.14

37,200 #

V = 75 x .866 x 24 x 30

46,800 #

37,200 x .75 = 27,900 #' ck.

37,200/1 = 37,200 #/pile

37,200 2 = 74,400 #

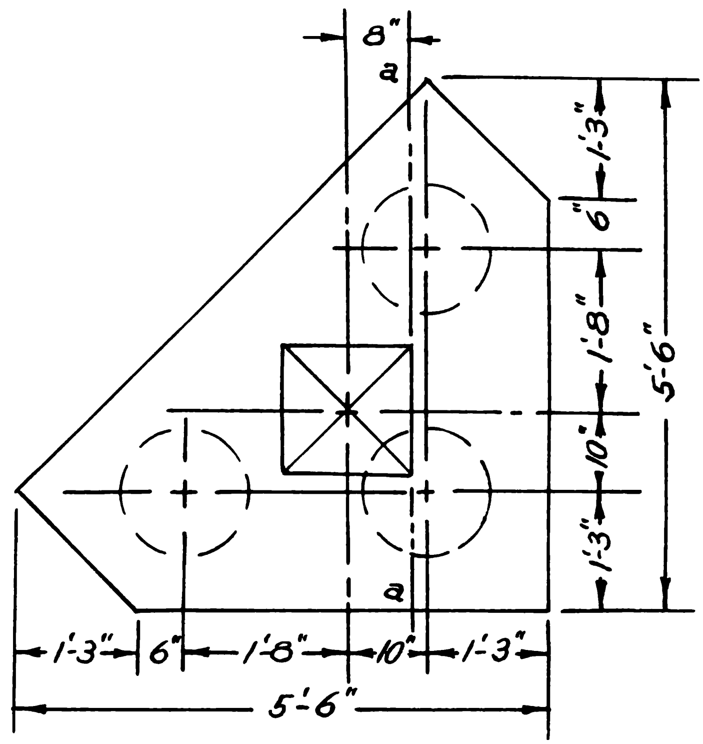
74,400 - 4,700 # = 69,700 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma oujd$		P x L
6- 3/4" ϕ @ 4½" cc.	m= 92,500 #'	V= 37,200 #	V= 46,800	37,200	27,900 #' ok.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
37,200 #	74,400 #	4,690 #	69,700 #

DESIGN B

3 Piles



Column size 16" x 16"

Wt. of cap

150 x 2.5 x 19.6

7,350 #

Use this design for footings no.

36, 37, 38, 39, 46, 47, 48, 49,

56, 57, 58, 59, 66, 67, 68, 69,

76, 77, 78, 79, 99.

Total

21 Footings--- 63 Piles

11-3/4" ø

A(s)	4.84 in.^{2}
Σ(o)	25.96 in.^{2}

M = 20,000 x 1.02 x 1.75 x 4.84

170,000 #'

V = 125 x 1.02 x 21 x 25.96

68,200 #

V = 75 x .866 x 24 x 30

46,800 #

46,800 x .19 = 8,900 #' ck.

46,800/2 = 23,400 #/pile

46,800 x 3 = 70,200 #

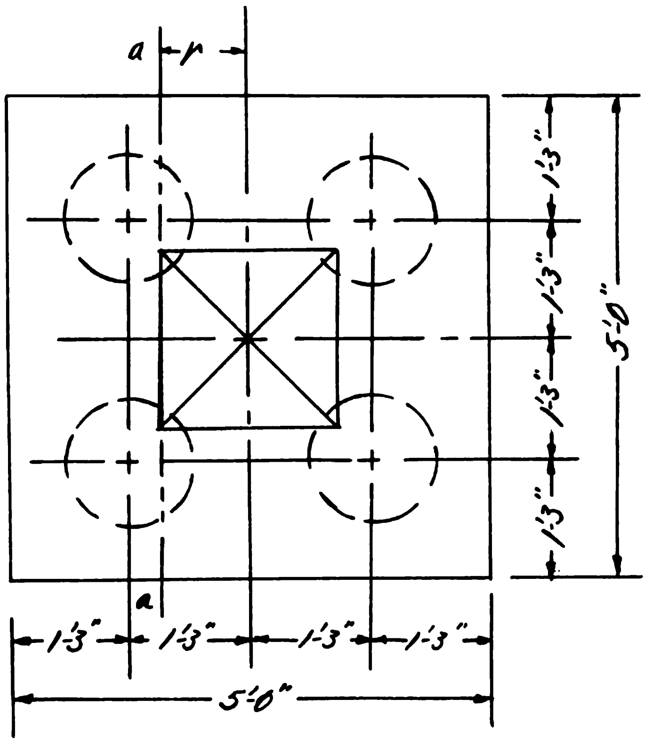
70,200 - 7,300 = 62,900 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma oujd$		$P \times L$
11- $\frac{3}{4}$" ∅ @ $4\frac{1}{2}$" cc.	170,000 #'	68,200 #	46,800 #	46,800 #	8,900 ck.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
23,400 #	70,200 #	7,350 #	62,900 #

DESIGN C

4 Piles



Column size   22" x 22",   24" x 24"

Wt. of cap

150 x 5 x 5 x 2.5

9,380

Use this design for footings no.

93, 95, 96, 98, 104

Total

5 Footings --- 20 Piles

13-3/4" ø

A (S) 5.72 in.^{2}

Σ (O) 30.6 in.^{2}

M = 20,000 x 1.02 x 1.75 x 5.72

200,000 #'

V = 125 x 1.02 x 21 x 30.6

80,000 #

V = 75 x .866 x 24 x 30

46,800 #

46,800 x .33 = **15,400** #' ck.

46,800 x .25 = **11,700** #' ck.

46,800/2 = 23,400 #/pile

23,400 x 4 = 93,600 #

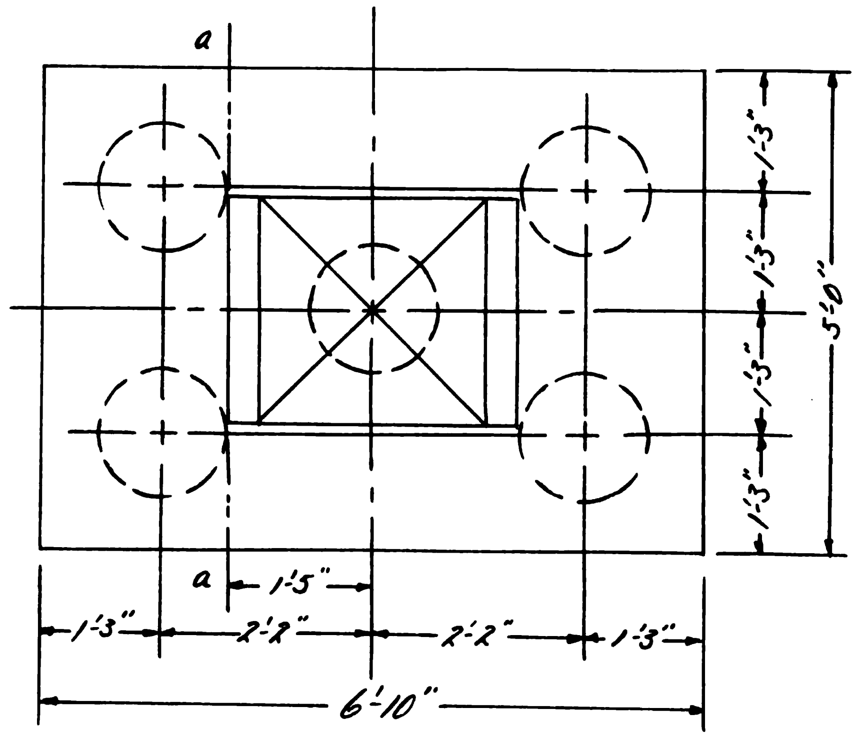
93,600 - 9,400 = 84,900 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma oujd$		P x L
13- $\frac{3}{4}$" ø @ $4\frac{1}{2}$" cc.	200,000 #'	80,000 #	46,800 #	46,800 #	15,400 #' ok. 11,700 #' ok.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
23,400 #	93,600 #	9,400 #	84,900 #

DESIGN D

5 Piles



Column size 28" x 28"

Wt. of cap footing

150 x 1.5 x 3 x 2.33 = 1,570

Pile Foot. 150 x 2.5 x 6.8 = 12,700

14,300 #

Use this design for footings no.

9, 16, 27, 28, 87, 92.

Total

6 Footings --- 30 Piles

13-3/4" ø

A(s) 5.72 in.^{2}

Σ(o) 30.6 in.^{2}

M = 20,000 x 1.02 x 1.75 x 5.72

200,000 #'

V = 125 x 1.02 x 21 x 30.6

80,000 #

V = 75 x .866 x 24 x 46 =

72,000 #

72,000 x .75 = 54,000 #' ck.

72,000 x ½ = 36,000 #/pile

36,000 x 5 = 180,000 #

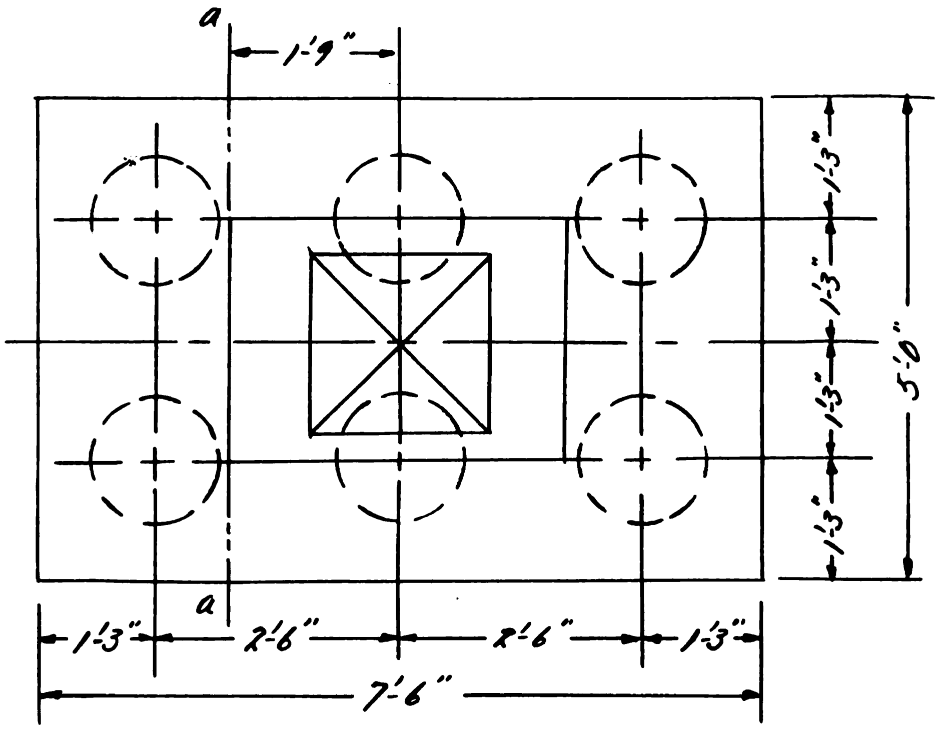
180,000 - 14,400 = 165,600 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma oujd$		P x L
13- $\frac{3}{4}$" ∅ @ $4\frac{1}{2}$"	200,000 #'	80,000 #	72,000 #	72,000#	54,000 #' ck.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
36,000 #	180,000 #	14,400 #	165,600 #

DESIGN E

6 Piles



Column size 26" x 28", 26" x 30",
22" x 22", 28" x 28".

Wt.

Footing cap	150 x 1.5 x 2.5 x 3.5	=	1,960
Pile cap	150 x 2.5 x 5.0 x 7.5	=	14,100
	16,000 #		

Use this design for footings no.

1, 3, 4, 6, 12, 13,
25, 26, 29, 30, 88,
100, 103.

Total

13 Footings --- 98 Piles

13-3/4" ∅

A(s) 5.72 in.^{2}

Σ(o) 30.6 in.^{2}

M = 20,000 x 1.02 x 1.75 x 5.72

200,000 #'

V = 125 x 1.02 x 21 x 30.6

80,000 #

V = 75 x .866 x 24 x 40

62,400 #

62,400 x .75 47,000 #' ok.

62,400/2 = 31,200 #/pile

31,200 x 6 = 187,200 #

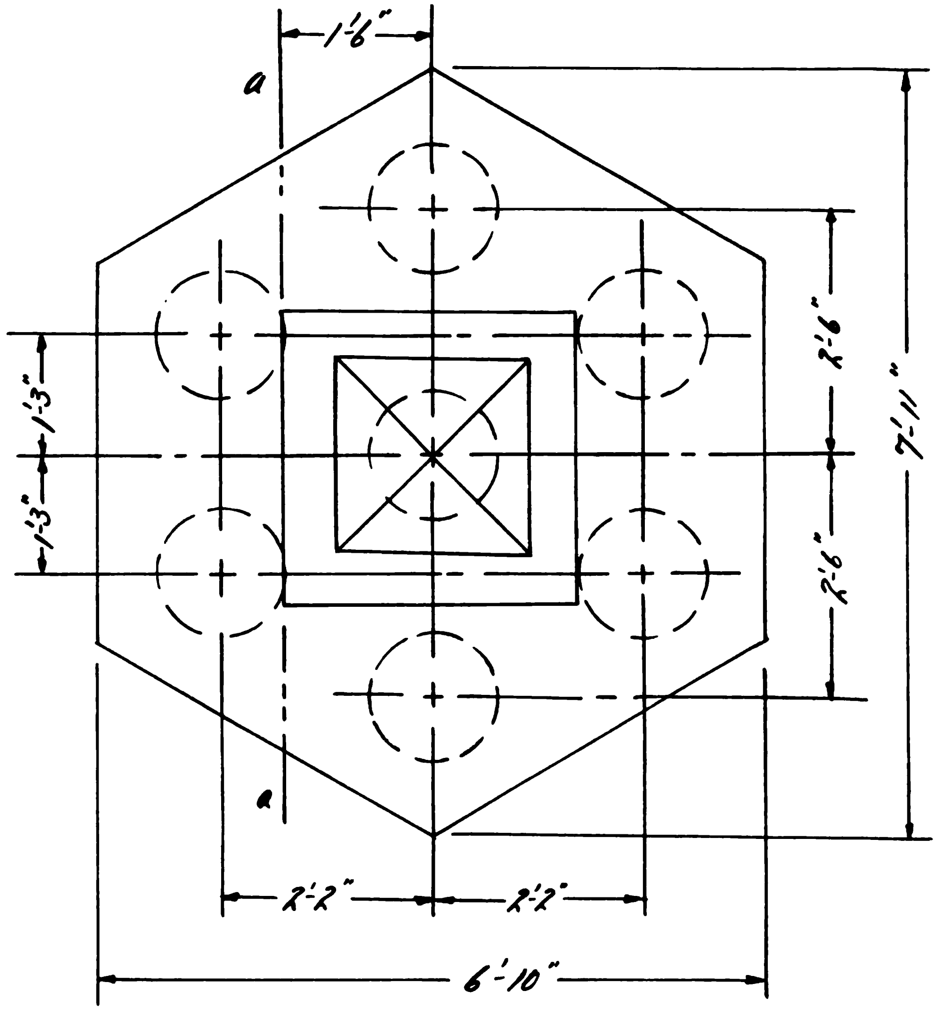
187,200 - 16,000 = 171,200 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma o u j d$		P x L
13-3/4" ∅ @ $4\frac{1}{2}$"	200,000 #'	80,000#	62,400#	62,400#	47,000 #' ck.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
31,200 #	187,200 #	16,000 #	171,200#

DESIGN F

7 Piles



Column size 24" x 24", 30" x 30"

Wt.

Footing cap 150 x 1.5 x 3 x 3 = 2,020

Pile cap 150 x 2.5 x 6.5 x 6.8 = 16,600

18,600 #

Use this design for footings no.

11, 14, 35, 40, 91.

Total

5 Footings --- 35 Piles

12-3/4" Ø

A(s)	5.28 in.^{2}
Σ(o)	28.3 in.^{2}

M= 20,000 x 1.02 x 1.75 x 5.28

185,000 #'

V = 1.25 x 1.02 x 21 x 28.3

74,500 #

V = 75 x .866 x 24 x 40

62,400 #

62,400 x .67 = 41,800 #' ck.

62,400 x ½ = 31,200 #/pile

31,200 x 7 = 218,400 #

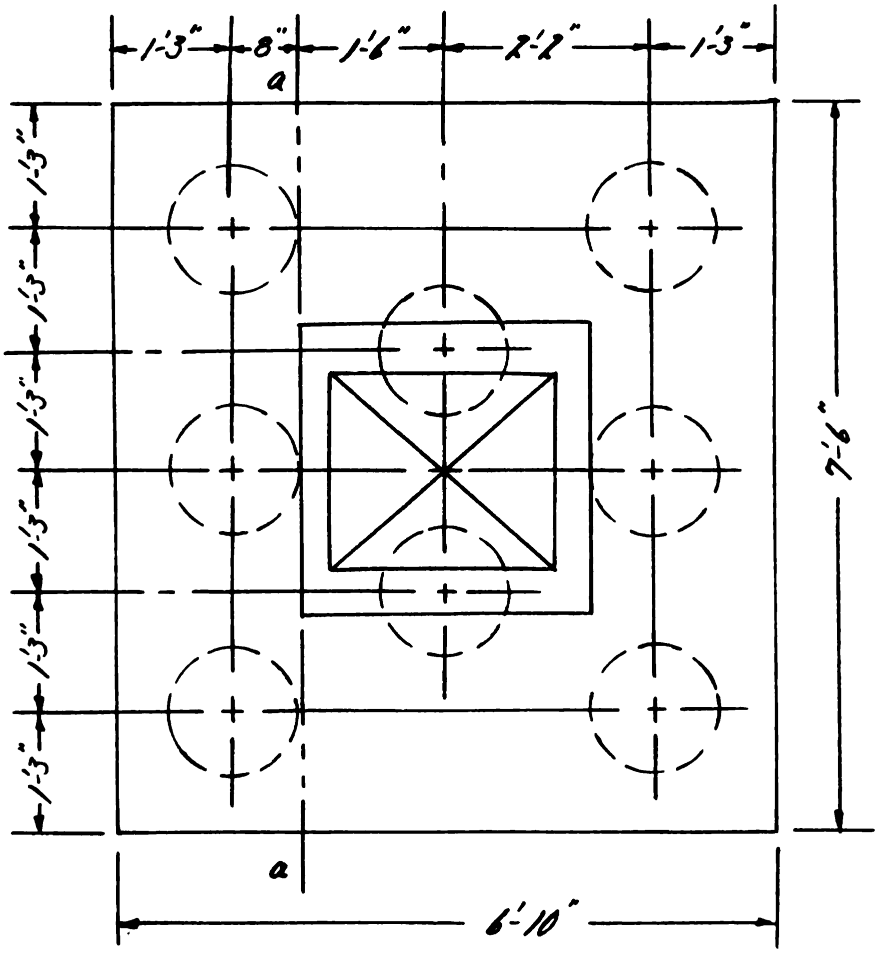
218,400 - 18,700 = 199,700 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V=ubjd$	$V=\Sigma oujd$		$P \times L$
12- $\frac{3}{4}$" ∅ @ $4\frac{1}{2}$" cc.	185,000 #'	74,500 #	62,400 #	62,400 #	41,800 #' ok.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
31,200 #	218,400 #	18,700 #	199,700 #

DESIGN G

8 Piles



Column size 24" x 28", 26" x 28"

Wt.

Footing cap 150 x 1.5 x 3 x 3 = 2,020

Pile cap 150 x 2.5 x 7.5 x 6.8 =19,400

21,200 #

Use this design for footings nos.

2, 5, 10, 15.

Total

4 Footings --- 32 Piles

20-3/4" ø

A(s) 8.0in^2

Σ(o) 47.2in^2

M = 20,000 x 1.02 x 1.75 x 8.0

280,000 #'

V = 125 x 1.02 x 21 x 47.2

124,000 #

V = 75 x (.866) x 24 x 60

93,600 #

93,600 x .75 = 70,000 #' ck.

93,600/3 = 31,200 #/pile

31,200 x 8 = 249,700 #

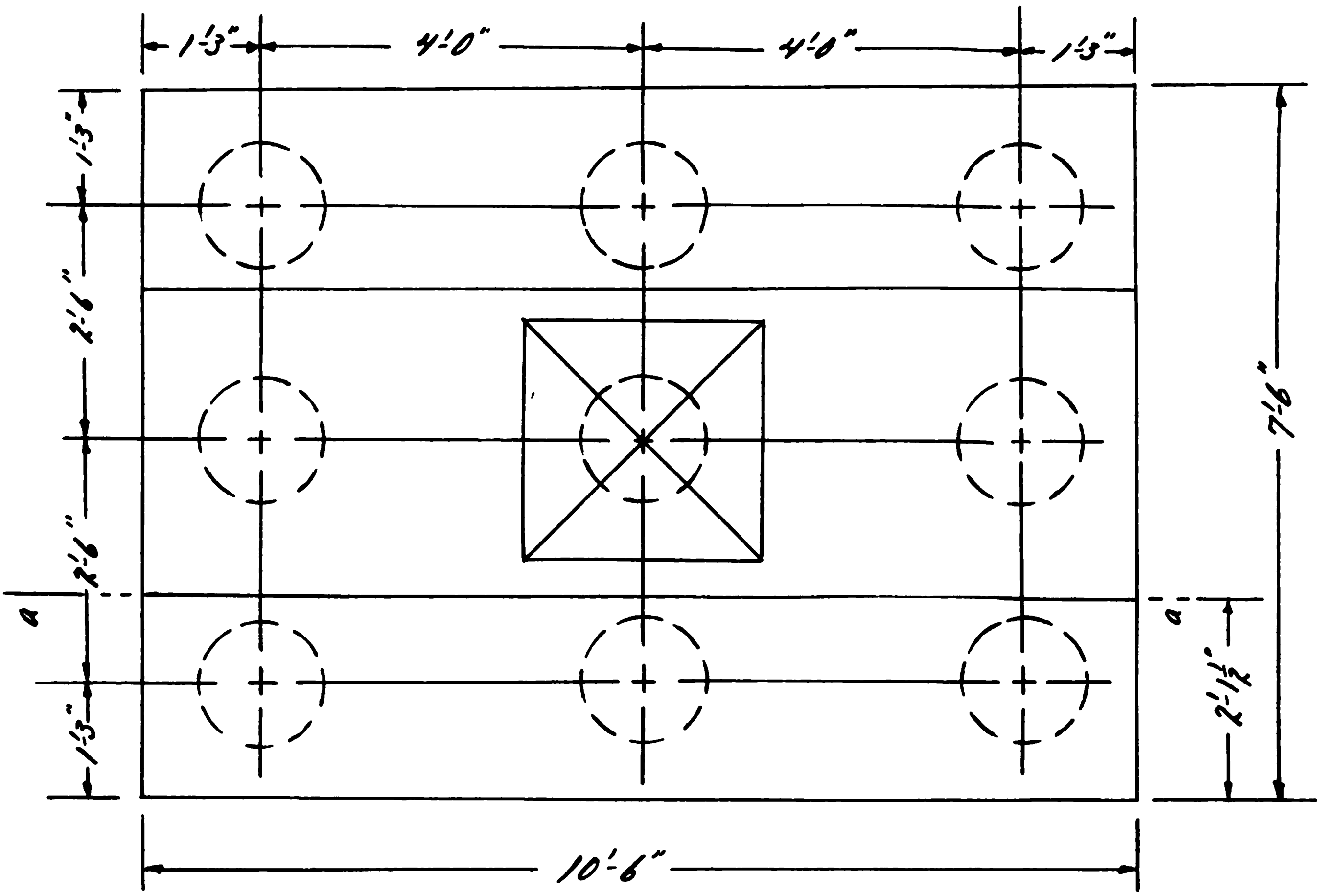
249,700 - 21,200 = 228,500 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s) j d A(s)$	$V = ubjd$	$V = \Sigma o u j d$		P x L
20- $\frac{3}{4}$" ∅ @ $4\frac{1}{2}$" cc.	280,000#'	124,000#	93,600#	93,600#	70,000#' ck.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
31,200 #	249,700 #	21,200 #	228,500 #

DESIGN H

9 Piles



Column size 30" x 30"

Wt.

Footing cap	150 x 1.5 x 10.5 x 3.3 =	7,650
Pile cap	150 x 2.5 x 7.5 x 10.5 =	29,600

37,200

Use this design for footings no.

101, 102

Total

2 Footings --- 18 Piles

28-3/4" Ø

A(s)	12.3 in.^{2}
Σ(o)	66.0 in.^{2}

M = 20,000 x 1.02 x 1.75 x 12.3

440,000 #'

V = 125 x 1.02 x 21 x 66

174,000 #

V = 75 x .866 x 24 x 90

140,000 #

140,000 x .92 = 129,000 # ' ck.

140,000/3 = 46,667 #/ pile

46,700 x 9 = 420,000 #

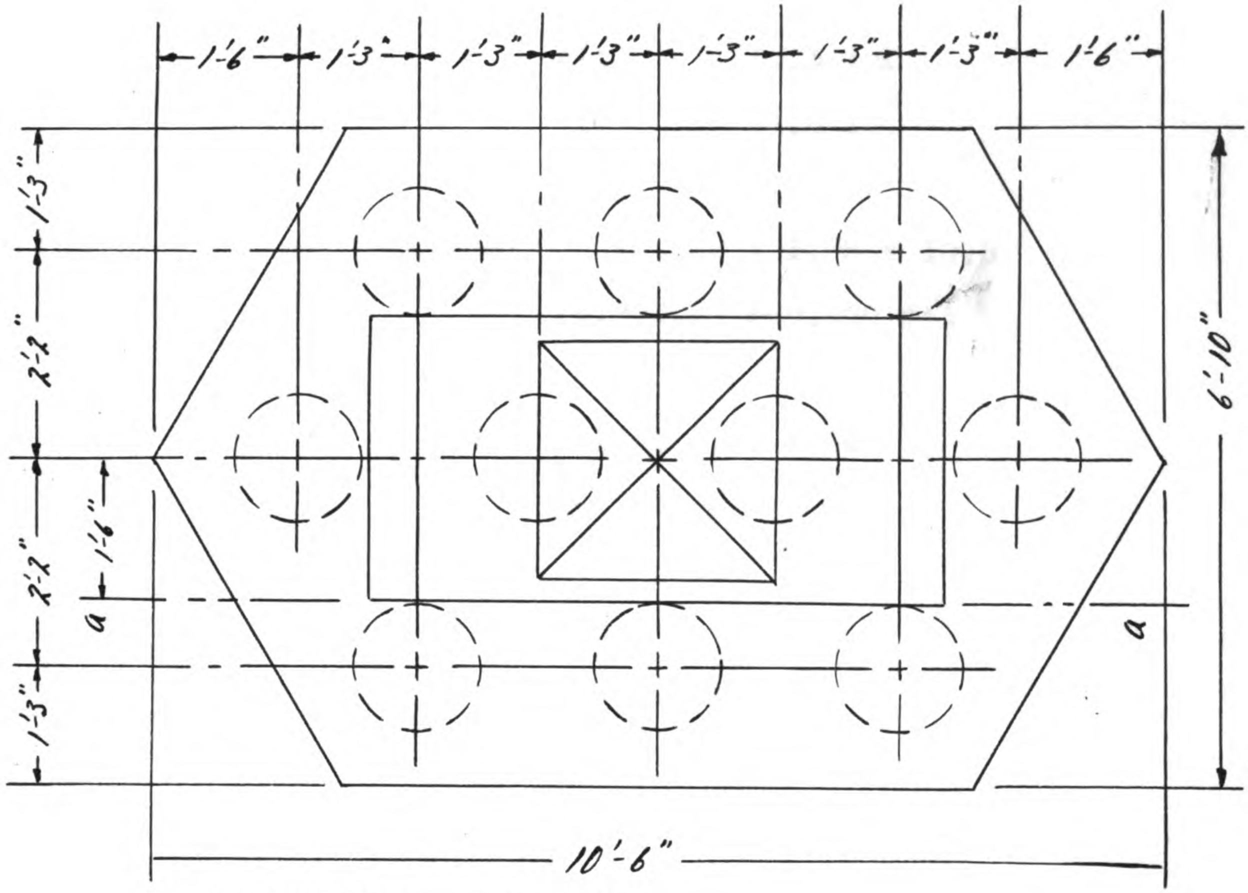
420,000 - 37,200 = 382,800 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma oujd$		$P \times L$
28 - $\frac{3}{4}$" ø @ $4\frac{1}{2}$" cc.	440,000#'	174,000#	140,000#	140,000#	129,000#' ck.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
46,700 #	420,000 #	37,200 #	382,800 #

DESIGN I

10 Piles



Column size 30" x 30"

Wt.

Footing cap	150 x 1.5 x 6 x 3 =	4,050
Pile cap	150 x 2.5 x 6.8 x 8.6 =	22,000

26,000 #

Use this design for footings no.

33, 42, 43, 52,

53, 62, 63, 72.

Total

8 Footing --- 80 Piles

23-3/4" ø

A(s)	10.3 in^2
Σ(o)	54.0 $in.^2$

M = 20,000 x 1.02 x 1.75 x 10.3

~~36,00000~~ 360,000 #'

V = 125 x 1.02 x 21 x 54

142,000 #

V = 75 x .866 x 24 x 88

137,000 #

137,000(.67) = 92,000 #' ck.

137,000/3 = 44,250 #/ pile

44,250 x 10 = 442,500 #

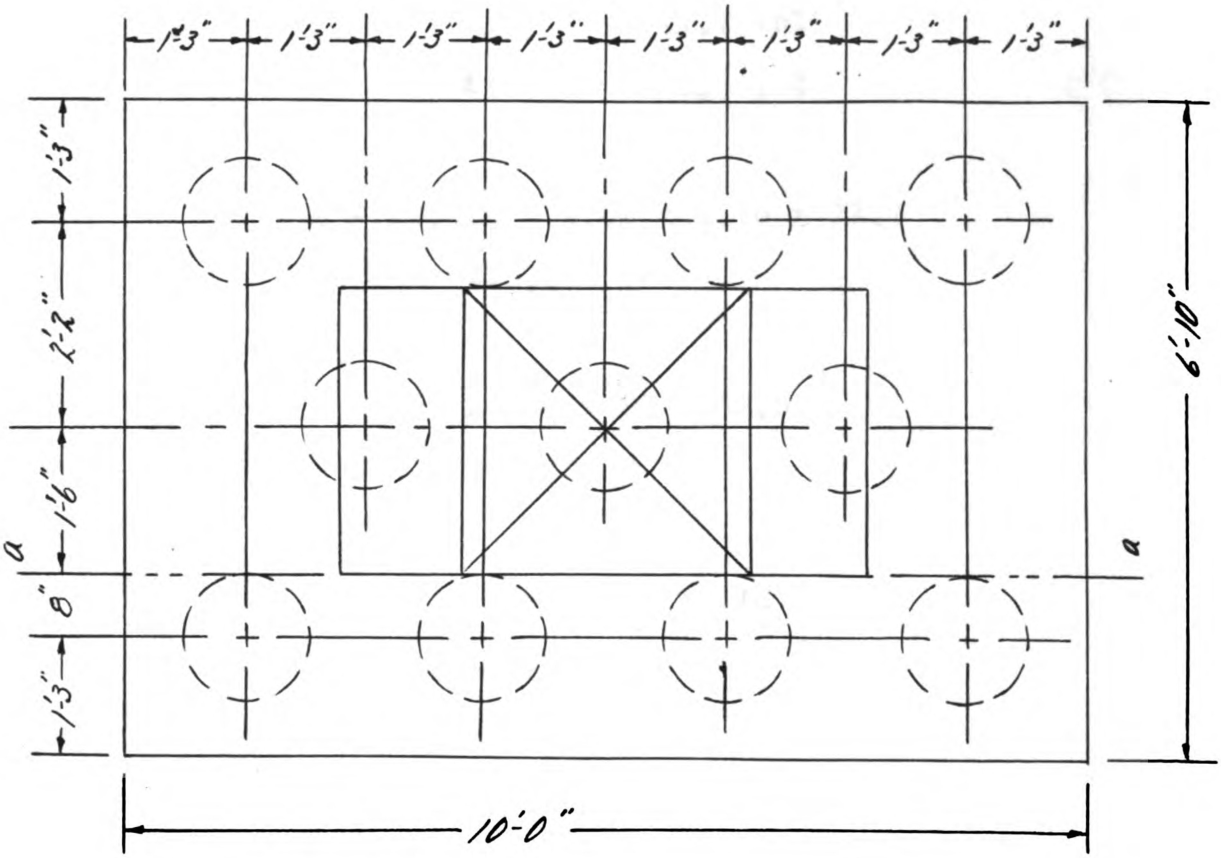
442,500 - 26,100 = 416,400 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma oujd$		$P \times L$
23- $\frac{3}{4}$" ø @ $4\frac{1}{2}$" cc.	360,000 #'	142,000#	137,000#	137,000#	92,000#' ck.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
44,250 #	442,500 #	26,050#	416,400#

DESIGN J

11 Piles



Column size 36" x 36"

Wt.

Footing cap 150 x 1.5 x 5.5 x 3 = 3,700

Pile cap 150 x 2.5 x 10 x 6.8 = 38,400

42,100 #

Use this design for footings no.

23, 32, 73, 82.

Total

4 Footings ---44 Piles

26-3/4" Ø

$A(s)$ 11.7 in^2

$\Sigma(o)$ 62.5 in^2

$M = 20{,}000 \times 1.02 \times 1.75 \times 11.7$

410,000 #'

$V = 125 \times 1.02 \times 21 \times 62.5$

165,000 #

$V = 75 \times .866 \times 24 \times 110$

171,000 #

$M = 165{,}000\ (.67)$

110,000 #'

165,000/4 = 41,250 #/pile

41,250 x 11 = 455,000 #

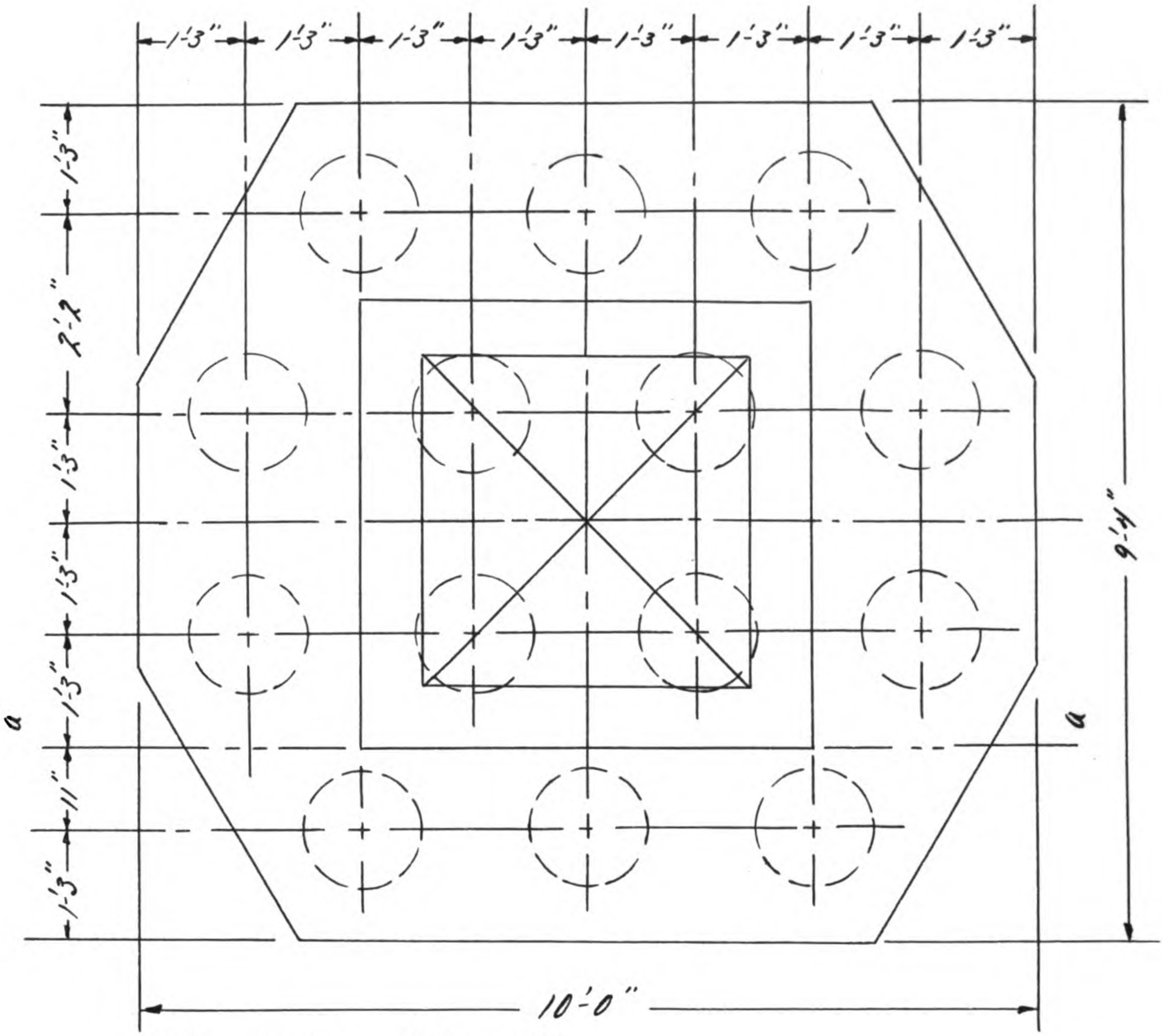
455,000 - 38,400 = 416,600 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	m = f(s)jdA(s)	V=ubjd	V=Σoujd		P x L
26- $\frac{3}{4}$" ∅ @ 4$\frac{1}{2}$" cc.	410,000 #'	165,000 #	171,000#	165,000#	43,334 #' ck.

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
41,250 #	455,000 #	38,400 #	416,600#

DESIGN K

14 Piles



Column size 44" x 44"

Wt.

Footing cap 150 x 1.5 x 5 x 5 = 5,625

Pile cap 150 x 2.5 x 8.5 x 6.3 = 20,000

25, 600 #

Use this design for footings no.

89, 90

Total

2 Footings --- 28 Piles

21-3/4" Ø

$A(s)$ 9.4in.^{2}

$Z(o)$ 50.5in.^{2}

M = 20,000 x 1.02 x 1.75 x 9.4

330,000#'

V = 125 x 1.02 x 21 x 50.5

130,000#

V = 75 x .866 x 24 x 82

128,000#

128,000/3 = 42,867#/pile

L = 42,867 x 14 = 600,000#

600,000 - 25,600 = 574,400 #

Reinforcing	Max. Moment from A(s)	Max. Shear from unit shear	Max. Shear from bond	Max. design shear	Moment Check
	$m = f(s)jdA(s)$	$V = ubjd$	$V = \Sigma oujd$		P x L
21- $\frac{3}{4}$" ø @ $4\frac{1}{2}$" cc.	330,000#'	130,000#	128,000#	128,000#	117,700#'

Allowable Load per pile	Total Load	Wt. of Footing	Net Load
42,867#	600,000#	25,600#	574,400"

CONCLUSION

The results of this analysis are shown on the footing layout as the allowable load that each footing will support. However if there were more time a further investigation could have been made as to just how the load of the building was actually distributed and in this way the footings which were over loaded and those that were underloaded could have been determined.

This particular topic was chosen as a thesis with the idea of gaining more knowledge of the theory of pile footings. During the study and especially during the investigation in the way of interviews , the thesis was of great interest.

[redacted]

[redacted]

Pocket has: 1 Plan

121
396
THS
Plan

SUPPLEMENTARY
MATERIAL