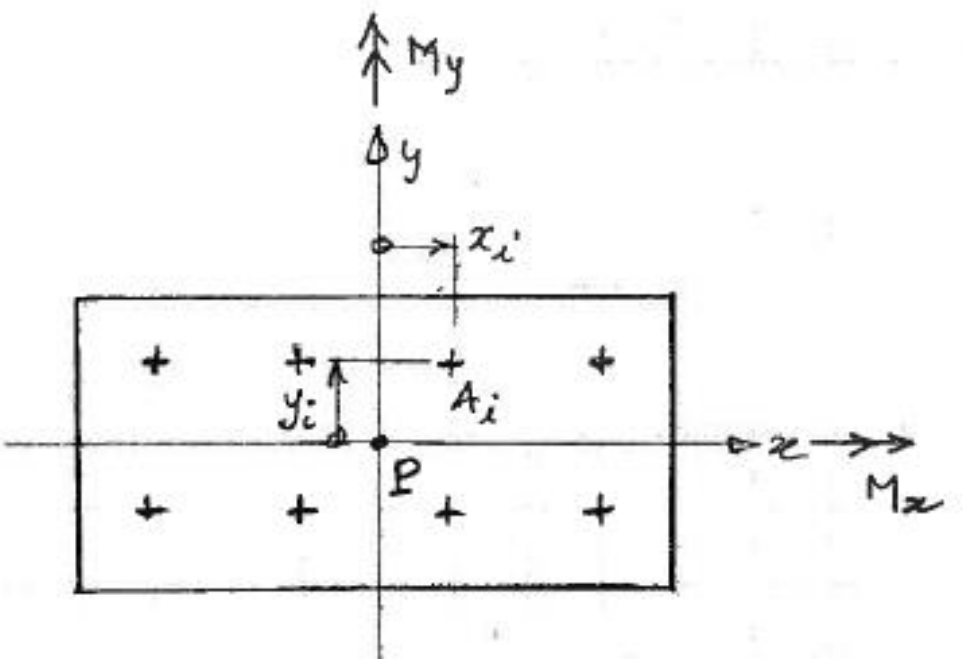
Forces in Piles (1)

Forces in piles are computed assuming the cap acts as a rigid (stiff) plate. For a symmetrical arrangement & same pile type,



Forces in Piles (2)

For a pile/shaft group arrangement, first we determine the centroid of the pile group arrangement. The forces in a pile are then,

force in pile i, $p_i = \frac{P}{n_{piles}} + \frac{M_x}{S_{xi}} + \frac{M_y}{S_{yi}}$

$$S_{xi} = \frac{\sum_i y_i^2}{y_i}; \quad S_{yi} = \frac{\sum_i x_i^2}{x_i}$$

x_i & y_i measured from the centroidal axis of the pile/shaft group

For piles in compression (LRFD):

Max factored force in pile $\leq \phi_c$ Pile soil capacity

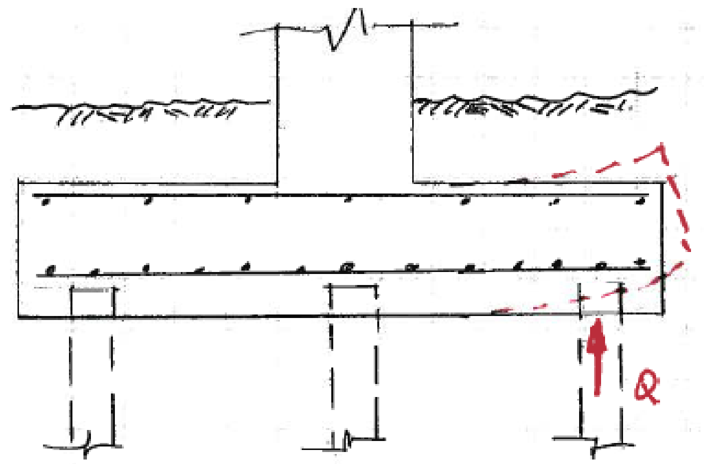
If piles are engaged in tension (LRFD):

Max factored force in pile (tension) $\leq \phi_t$ Pile soil capacity

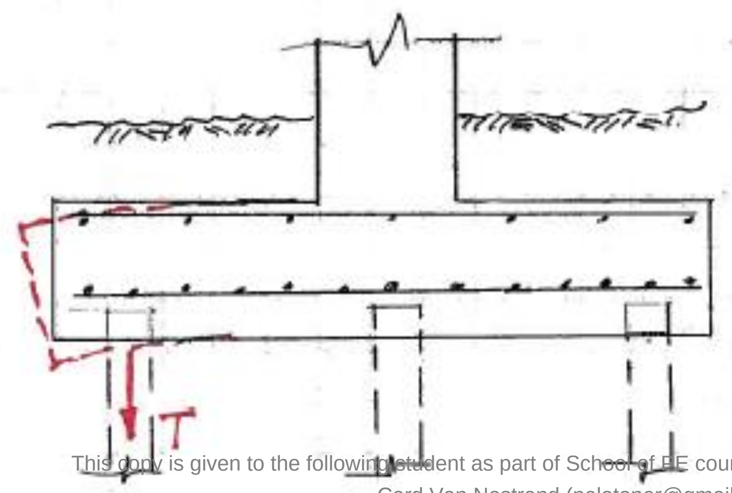
Pile-cap design (IBC 1810.3.10 & AASHTO)

- Pile-cap depth controlled by punching shear (pile trying to perforate cap).
- Edge (perimeter) piles carry largest compressive load in pile group. Edge piles also tend to produce large tensile pile forces.
- Critical sections for flexure and one-way shear are same as spread footers.
- Compressive force in piles will produce (+)ve moments in pile-cap. Tensile force in pile will induce (-)ve moment in pile-cap.

Forces in Pile-cap

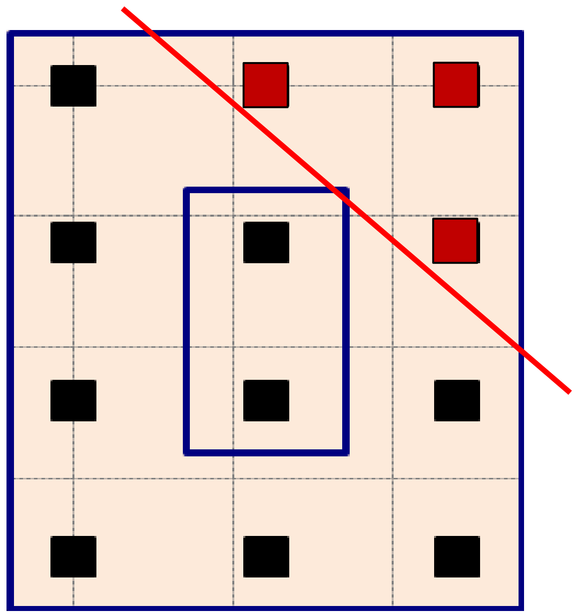


M(+) in cap



M(-) in cap

Special Critical Sections



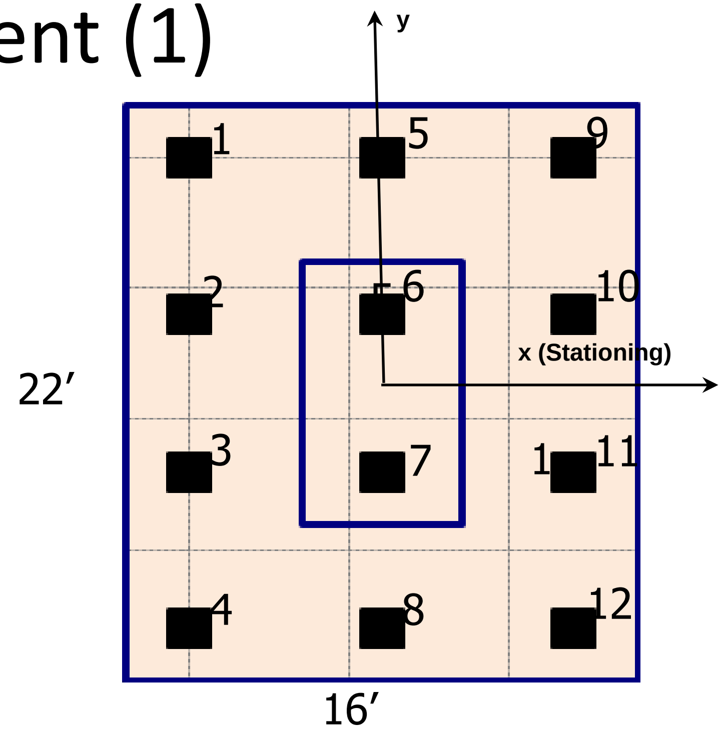
Pile Layout

- There may be special conditions that warrant investigating other critical sections
- Piles in red (NE corner of pile-cap) may be in tension or compression, thus, it is important to consider a diagonal critical section.

Problem Statement (1)

The foundation of a 5'x10' bridge pier is made of a 22'x16' pile-cap & 12- 24" precast prestressed piles, both made of normal weight concrete. Piles spacing is 6' o.c. Foundation data is shown below.

Footing Data		
Concrete f'_c =	5.5	ksi
Reinforcing Steel f_y =	60	ksi
Column x-dim. =	5.00	ft
Column y-dim. =	10.00	ft
Column eccentric x-dir. =	0	ft
Column eccentric y-dir. =	0	ft
Footing thickness =	5.5	ft
Pile Embedment =	12	in
Ground EL =	29.0	ft
Top of Footing EL =	27.0	ft
Ground Water Elevation =	20.8	ft
Soil Weight =	0.12	kcf
Footing Effective Depth, de =	4.13	ft
Footing Shear Depth, dv =	3.72	ft



Pile Layout (z-axis up)

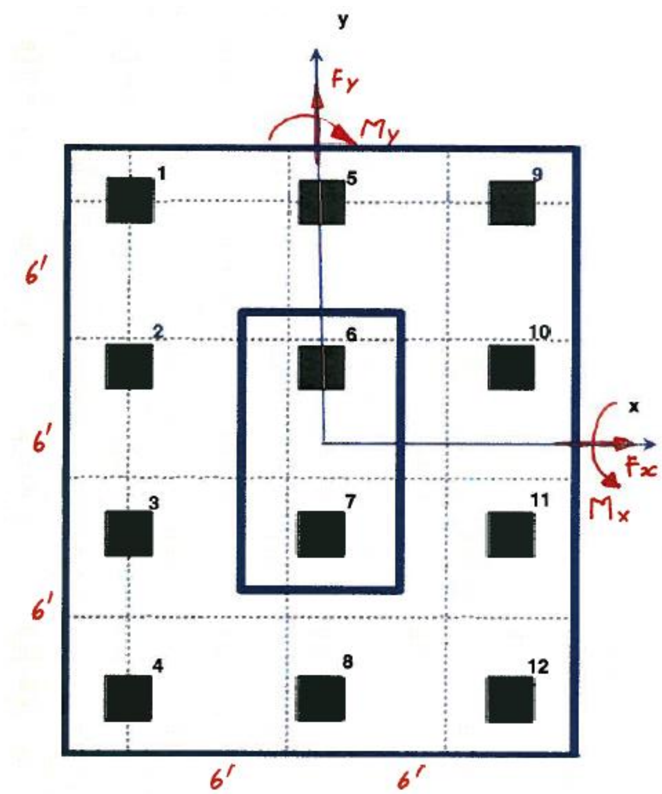
Pile Layout			
X - Direction		Y - Direction	
# of Piles	Spacing (ft)	# of Piles	Spacing (ft)
3	6	4	6
0	0	0	0

Problem Statement (2)

Pile Data		
Pile Size =	24	in
Max. Pile Driving Resistance =	450	tons
Boring =	B-2	
Pile Tip Elevation =	-40	ft
Soil Davisson Capacity =	450	tons
Soil Ultimate Side Friction =	150	tons
Soil Reduction Factor, ϕ =	0.65	

Factored Footing Loads at Top of Footer at Column				
Fx (k)	**Fy (k)**	**Fz (k)**	**Mx (k-ft)**	**My (k-ft)**
39	0	-4175	-8689	1303

Moments follow right-hand rule



Sign convention

Problem 8:

The maximum and minimum factored pile loads are most nearly (compressive pile force is positive). Consider that the factored footing loads provided correspond to a load combination which produces maximum effects.

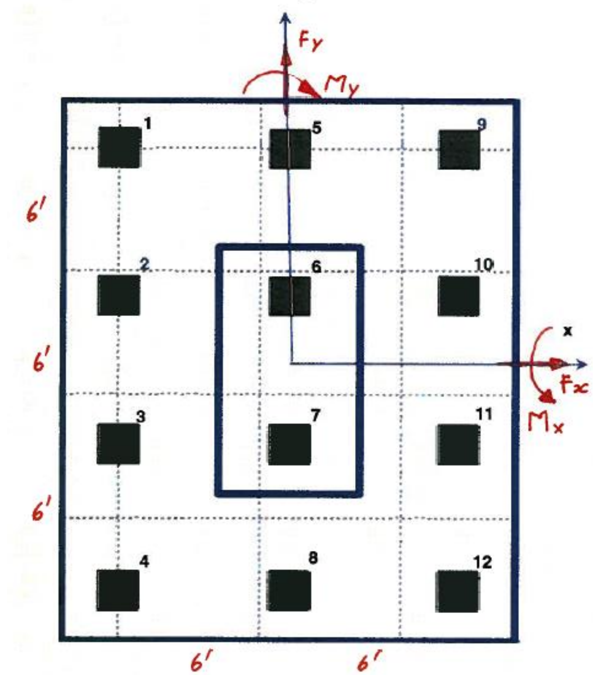
Design Code: AASHTO LRFD Bridge Design Specifications, 7th Ed., 2014

(A) 460 k/100 k

(B) 561 k/210 k

(C) 560 k/-229 k

(D) 460 k/-100 k

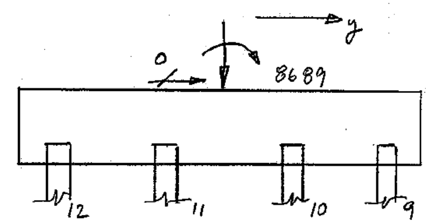


Solution:

Piles are embedded 1’ into the pile-cap
Cap wt= [16’x22’x5.5’-12(2’x2’x1’)] 0.15=283.2 k
Soil wt=(16’x22’-5’x10’) 2x0.12=72.5 k
For concrete cap: γ_{DC}=1.25 (permanent loads)
For soil wt.: γ_{EV}=1.35 (vertical earth pressure)
Forces at top of piles:
P_u=1.25(283.2)+1.35(72.52)+4175=4627 k
M_{ux}=-8689 k-ft
M_{uy}=1303 + 39 x 4.5’=1479 k-ft

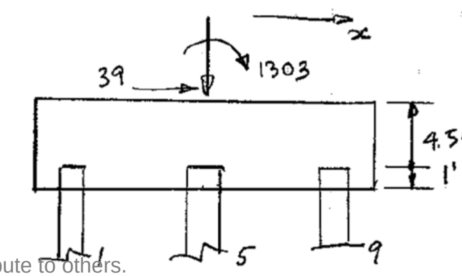
By inspection, Pile 9 takes the max load and Pile 4 the min load; for the factored loads provided:

Pile 9: $P_9=\frac{P_u}{n}+\frac{M_{ux}}{S_x}+\frac{M_{uy}}{S_y}=\frac{4627}{12}+\frac{8689}{60}+\frac{1479}{48}=561\ k$



$$S_x=\frac{\sum y^2}{y_i}=\frac{(3x9^2+3x3^2)2}{9}=60'; \text{ same for Pile 4}$$

$$S_y=\frac{\sum x^2}{x_i}=\frac{(4x6^2)2}{6}=48'; \text{ same for Pile 4}$$



Pile 4: $P_4=\frac{P_u}{n}-\frac{M_{ux}}{S_x}-\frac{M_{uy}}{S_y}=\frac{4627}{12}-\frac{8689}{60}-\frac{1479}{48}=210\ k$

Problem 9:

Given the factored loads on the piles. The one-way shear in the longitudinal (x-x) and transverse (y-y) direction are most nearly.

Design Code: AASHTO LRFD Bridge Design Specifications, 7th Ed., 2014

(A) 970 k, 595 k

(B) 190 k, 500 k

(C) 900 k, 495 k

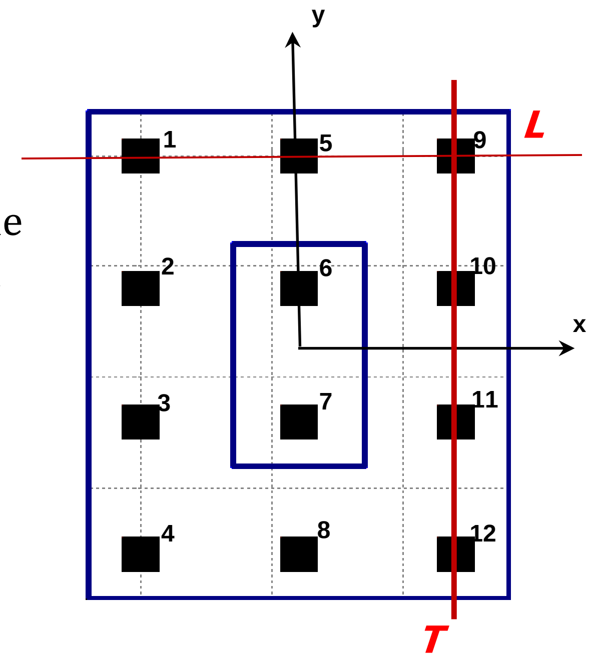
(D) 870 k, 375 k

Factored Pile Loads		
Pile No.	Min. (k)	Max. (k)
1	498	498
2	402	402
3	305	305
4	209	209
5	529	529
6	432	432
7	336	336
8	239	239
9	560	560
10	463	463
11	367	367
12	270	270

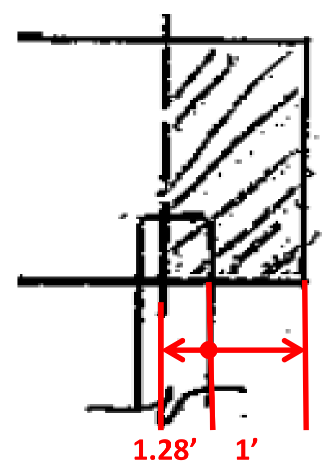
Solution:

a) Longitudinal one-way shear:

In the longitudinal direction (x-x), piles 1,5 and 9 will carry the higher loads than 4,8,12. Critical section is at $d_v = 3.72'$ from the face of column. Critical section is 1.28' inside pile. According to AASHTO 5.13.3.6, pile load inside critical section should be considered uniformly distributed.



Pile 1= 498 k
Pile 5=529 k
Pile 9=560 k
$\sum piles$=1587 k



Shear due to pile loads=$\frac{1.28}{2}x1587 = 1015.6\ k$

Wt of cap in 2.28'=2.28'x16'x5.5'x0.150=30.1 k

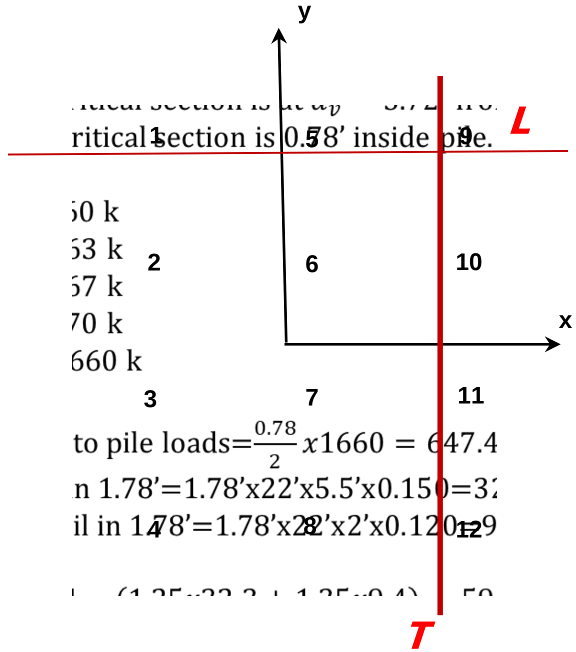
Wt of 2' soil in 2.28'=2.28'x16'x2'x0.120=8.8 k

$V_u = 1015.6 - (1.25x30.1 + 1.35x8.8) = 966\ k$

Solution (cont'd):

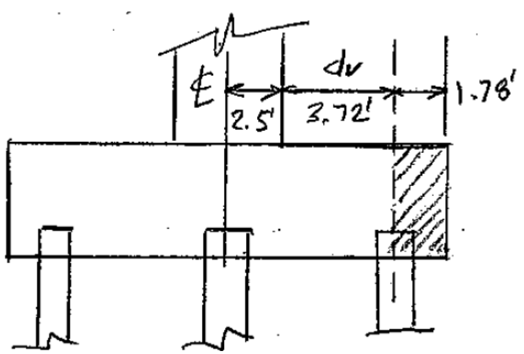
b) Transverse one-way shear:

In the transverse direction (y-y), piles 9 thru12 will carry the higher loads so transverse shear will be higher at this section. Critical section is at $d_v = 3.72'$ from the face of column. Critical section is 0.78' inside pile.



Pile 9= 560 k
Pile 10=463 k
Pile 11=367 k
Pile 12=270 k
$\sum piles$=1660 k

Shear due to pile loads=$\frac{0.78}{2} x1660 = 647.4\ k$
Wt of cap in 1.78'=1.78'x22'x5.5'x0.150=32.3 k
Wt of 2' soil in 1.78'=1.78'x22'x2'x0.120=9.4 k



$V_u = 647.4 - (1.25x32.3 + 1.35x9.4) = 594$

Problem 10:

Considering the piles loads provided in Problem 8, the controlling pile-cap positive bending moment in the transverse axis in k-ft is most nearly.

Design Code: AASHTO LRFD Bridge Design Specifications, 7th Ed., 2014

(A) 4300

(B) 6300

(C) 5370

(D) 4000

Solution:

In the transverse axis (y), larger loads are in piles 9 thru 12,

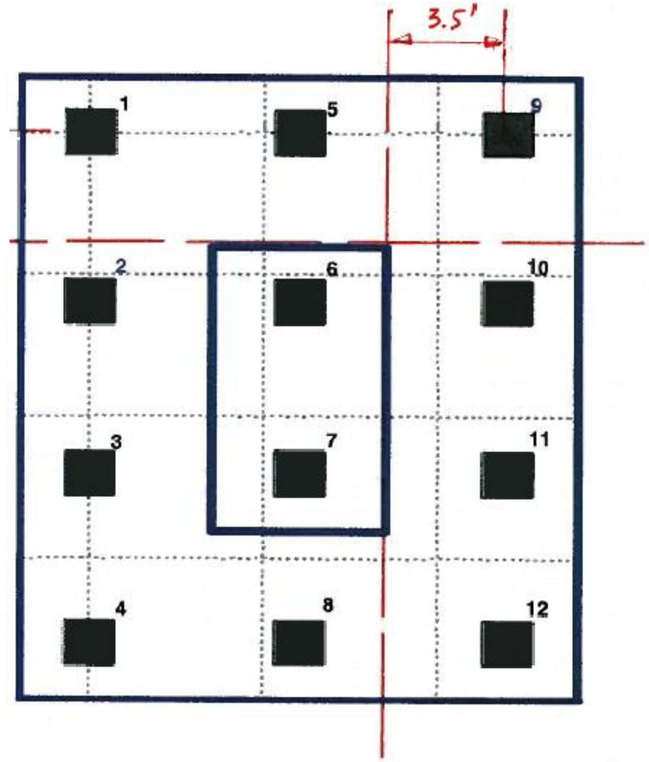
$\sum piles\ loads$=560+463+367+270=1660 k

Critical section is at face of column (3.5' from piles);

Wt of cap in (8.5'-2.5'=5.5') = 5.5'x5.5'x22'x0.15=99.8 k

Wt of 2' soil in 5.5' = 5.5'x22'x2'x0.12=29 k

M_{xu} = *1660x3.5-(1.25x99.8+1.35x29)*$\frac{5.5}{2}$ = 5360 $k-ft$



Problem 11:

Using #11 bars in the transverse direction (Problem 10), the reinforcing spacing in the transverse direction is most nearly. Concrete is normal weight.

Design Code: AASHTO LRFD Bridge Design Specifications, 7th Ed., 2014

(A) 6”

(B) 9”

(C) 11”

(D) 15”

Solution:

M_{yu} =*5360 k-ft in 22' or* $M_{yu} = \frac{5360}{22} = 244$ *k –ft/ft*

Check minimum moment:

$\mathrm{M_{yu\,min}} = \min(1.33\,\mathrm{M_{yu}}, 1.072\mathrm{M_{cr}})$ for CIP concrete and Gr. 60 steel (AASHTO 5.7.3.3.2)

$1.33\,M_{yu} = 1.33x244 = 325.3\ \mathrm{k-ft/ft}$

$$1.072M_{cr} = 1.072\left(\frac{bh^2}{6}f_r\right);\ \ f_r = 0.24\sqrt{f_c'} = 0.56\ ksi\ (normal\ wt\ conc. - AASHTO\ 5.4.2.6)$$

$$1.072M_{cr} = 1.072\left(\frac{1x5.5^2}{6}x0.56x144\right) = 436\ k-ft$$

$\mathrm{M_{yu\,min}} = \min(325.3, 436) = 325.3$

$$A_{s\,req'd} = 0.85\frac{f_c'}{f_y}bd_e\left(1-\sqrt{1-\frac{4M_{yu}}{1.7\varphi f_c' b d_e^2}}\right);\ d_e = 4.13' = 49.56"$$

$$A_{s\,req'd} = 0.85\frac{5.5}{60}(12\mathrm{x}49.56)\left(1-\sqrt{1-\frac{4x325.3x12}{1.7x0.9x5.5x12x49.56^2}}\right) = 1.48\frac{in^2}{ft}$$

With # 11 bars $A_s = 1.56\ in^2$; *Spacing*= $\frac{1.56}{1.48}x12 = 12.5$“

Solution (cont'd):

Distribution of steel (5.7.3.4):

$s \leq \frac{700\,\gamma_e}{\beta_s f_{se}} - 2d_c$ where $\gamma_e = 1.0\ for\ Class\ 1\ or\ 0.75\ for\ Class\ 2$

$$\beta_s = 1 + \frac{d_c}{0.7(h - d_c)}$$

$$f_{se} = \frac{M}{jd\ A_s}$$

Problem 12:

A 24 sq-in precast prestress pile has a compression capacity of 450 tons. The strength reduction factor is 0.65. The piles are spaced at 6' o.c. and the distance from the perimeter piles to the cap edge is 2'. Pile embedment into the cap is 1 ft. Both pile and footing are normal weight concrete with f'c= 5.5 ksi. The minimum footing depth to control two-way shear is most nearly.

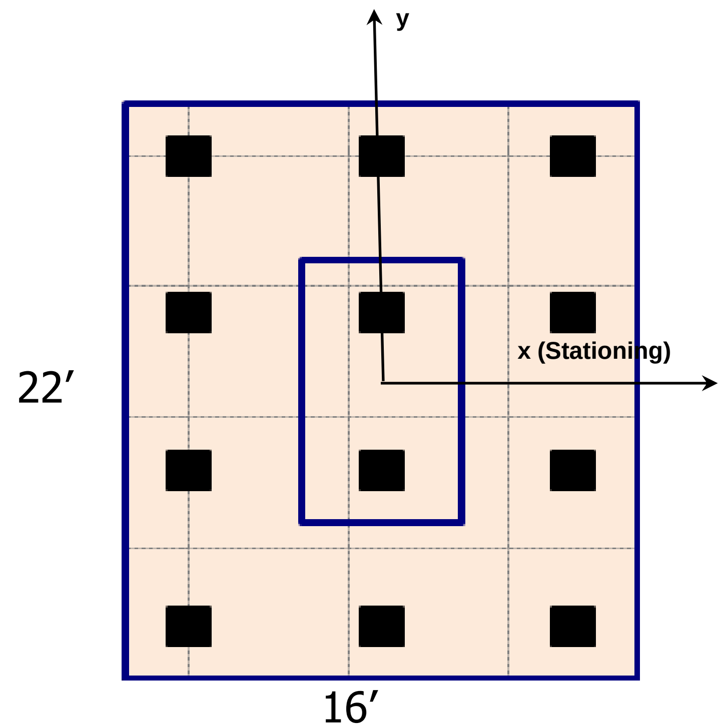
Design Code: AASHTO LRFD Bridge Design Specifications, 7th Ed., 2014

(A) 23"

(B) 32"

(C) 44"

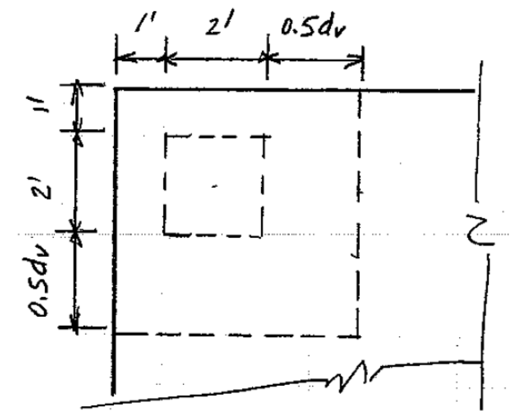
(D) 48"



Pile Layout

Solution:

From inspection the corner pile will control as it offers the minimum concrete perimeter. For a 450 ton pile capacity, the maximum pile reaction is



P_u= φ $Capacity$ = 0.65 (450 tons x2) = 585 kips

Note that the pile will tend to punch through the cap

$\beta_c = \frac{long\ side}{short\ side} = 1$ (square pile), then,

$\varphi\ V_n = \varphi 0.126\sqrt{f'_c}\, b_0 d_v = 585$ k (AASHTO 5.13.3.6)

For the corner pile $b_0 = 2(36" + 0.5d_v) = 72 + d_v$

$0.9x\ 0.126\sqrt{5.5}(72 + d_v)\, d_v = 585$

$(72 + d_v)\, d_v = 2199.69$, *solving for* d_v

$d_v = 23.1$”

Per AASHTO5.8.2.9, d_v shall not be taken less than the greater of $0.9d_e$ or $0.72h$

$d_e = \frac{23.1}{0.9} = 25.6$”

$h = \frac{23.1}{0.72} = 32$” controls

Cap depth = 32”+12” (pile embedment)= 44”