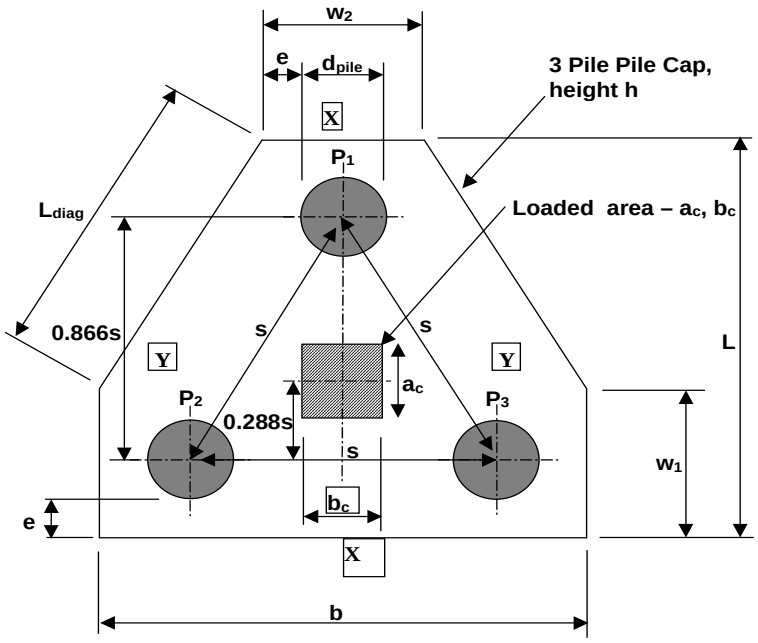
DAR GROUP	Project: The Pearl				Job Ref.: Q09077	
	Section: QQ				Sheet no./rev.: 1	
	Calc. by: Eng.TK	Date: 09-Mar-08	Chk'd by: Eng.IC	Date:	App'd by: Dr.AE	Date:



PILE CAP DESIGN

DESIGN INPUT - 3-PILE PILE CAP - CONCENTRICALLY LOADED

Pile details

Pile diameter d_{pile} = **450.0** mm

Pile capacity (service) P_{cap} = **750.00** kN

Pile spacing s = **1350.0** mm

Pile spacing OK

Pile cap overhang e = **500.0** mm

Edge distance OK

Pile cap details

Pile cap dimensions

dimension in x-x axis direction $L = \sin(60) \times s + d_{pile} + 2 \times e$ = **2.619** m

dimension in y-y axis direction $b = s + d_{pile} + 2 \times e$ = **2.800** m

$w_1 = d_{pile} + 2 \times e$ = **1.450** m

$w_2 = d_{pile} + 2 \times e$ = **1.450** m

Diagonal length of sides $L_{side_diag} = \sqrt{((L-w_1)^2 + ((b-w_2)/2)^2)}$ = **1.350** m

Overall thickness of pile cap h = **750.0** mm

Pile embedment distance e_c = **160.0** mm

Embedment distance OK

Concrete cover d_c = **75.0** mm

Trial bar diameter d_{bar} = **19.1** mm

Effective depth

$d_{bx} = h - e_c - d_c - d_{bar}/2 =$ **505** mm

$d_{by} = d_{bx} - 1.0 \times d_{bar} =$ **486** mm

$d_b = (d_{bx} + d_{by}) / 2 =$ **496** mm

Column details

Column width along x-x axis $a_c =$ **400.0** mm

Column width along y-y axis $b_c =$ **600.0** mm

Material properties

Yield strength of tension reinforcement $f_y =$ **415** N/mm^2

Concrete strength $f'_c =$ **40.000** N/mm^2

Concrete density $\rho_c =$ **24.0** kN/m^3

Loading details

Note: The following calculations assume that the centroid of the pile cap coincides with that of the pile group.

Column axial dead load $P_{dl} =$ **1250.000** kN

Area of pile cap $A_{cap} = L \times b - \sin(60) \times L_{side_diag}^2/2 =$ **6.54** m^2

Weight of pile cap

$P_{wt} = (A_{cap} \times h - 3 \times \pi \times d_{pile}^2 \times e_c/4) \times \rho_c =$ **115.967** kN

Surcharge pressure on cap $p_{sur} =$ **0.000** N/mm^2

Surcharge load

$P_{sur} = p_{sur} \times (L \times b - (\sin(60) \times L_{side_diag}^2)/2 - a_c \times b_c) =$ **0.000** kN

Column axial live load $P_{ll} =$ **425.000** kN

Total column load (unfactored) $P_n = P_{dl} + P_{ll} =$ **1675.000** kN

The service load per pile $P_{n_pile} = (P_n + P_{wt} + P_{sur})/3 =$ **596.989** kN

Pile capacity OK

Total column load (factored) $P_u = 1.2 \times P_{dl} + 1.6 \times P_{ll} =$ **2180.000** kN

The ultimate load per pile $P_{u_pile} = (P_u + 1.2 \times (P_{wt} + P_{sur}))/3 =$ **773.054** kN

PILE CAP FORCES – TIED ARCH METHOD

CRSI Fig. 13-13

$d_{cl_pl} = \sqrt{((s/2)^2 + (0.288*s)^2)} =$ **778.968** mm

$x_{cl_pl} = \sqrt{(d_{cl_pl}^2 + d_b^2)} =$ **923.448** mm

$\theta = \mathrm{atan}(d_{cl_pl}/(d_b)) =$ **57.516** deg

$\theta_1 = \mathrm{acos}((\sqrt{(d_b^2 + (0.288 * s)^2)})/x_{cl_pl}) =$ **46.967** deg

Compression within pile cap $C_{max} = P_{u_pile} / \cos(\theta) =$ **1439.409** kN

Tension within pile cap $T = C_{max} * \sin(\theta_1)/2 =$ **526.072** kN

COMPRESSION IN PILE CAP - SUGGESTED ADDITIONAL CHECKS

Check compression diagonal as an unreinforced column, using a core equivalent to 2 pile diameters

$P_c = 0.55 \times 0.60 \times f'_c \times \pi \times ((2 \times d_{pile})^2)/4 =$ **8397.477** kN

Compression - OK

ACI 22.5.2

Check bearing capacity of pilecap over piles

$A_1 = \pi \times d_{pile}^2/4 =$ **159043** mm^2

$A_2 = A_{cap} =$ **6544410** mm^2

$P_{brg} = 0.55 \times 0.85 \times f'_c \times A_1 \times \min(2, \text{sqrt}(A_2 / A_1)) =$ **5948.213** kN

Bearing - OK

ACI 22.5.5

Check bearing capacity of pilecap under column

$A_1 = a_c \times b_c =$ **240000** mm^2

$P_{brg} = 0.65 \times 0.85 \times f'_c \times A_1 \times \min(2, \text{sqrt}(A_2 / A_1)) =$ **10608.000** kN

Column Bearing - OK

ACI 10.17.1

TENSION STEEL IN PILE CAP

Area of tension steel required for tied-arch behavior

$A_{s_T} = T / (0.75 \times f_y) =$ **1690** mm^2

Moment at face of column

Distance from pile to face of column $x_{face} = \max(.577 \times s - \min(a_c,b_c) / 2, 0\ mm) =$ **579.0** mm

Pressure due to pile cap selfweight and surcharge $q_u = 1.2 \times (p_{sur} + P_{wt} / A_{cap}) =$ **0.021** N/mm^2

Width at column face $b_w = \text{if}(x_{face} < L - w_1, w_2 + 2 \times .577 \times x_{face}, b) =$ **2.12** m

Ultimate moment at column face

$M_{uy} = P_{u_pile} \times x_{face} - q_u \times (w_2 \times x_{face}^2 / 2 + 2 \times .577 \times x_{face}^3/3) =$ **440.8** kNm

Area of tension steel required for flexure

$\beta_1 = \text{if}(f'_c < 27.58\ N/mm^2, 0.85, \max(.65, 0.85 - 0.05 \times (f'_c - 27.58\ N/mm^2) / 6.89\ N/mm^2)) =$ **0.760**

$\omega_t = 0.319 \times \beta_1 =$ **0.242**

$R_u = \omega_t \times (1 - 0.588 \times \omega_t) =$ **0.208**

$R_{reqd} = M_{uy} / (f'_c \times d_b^2) / b_w =$ **0.021153**

Section dimensions are OK to be tension-controlled

$J = \text{sqrt}(\max(.25 - R_{reqd} / 0.85 / 2., 0)) + .5 =$ **0.9874**

$A_{sflex} = M_{uy} / (0.90 \times f_y \times J \times d_b) =$ **2410** mm^2

Minimum ratio of tension reinforcement for temperature and shrinkage

ACI 7.12.1

$\rho_{min} =$ **0.001800**

ACI 10.5.1

$A_{s_min} = \max(3 \times \sqrt{(f'_c)} \times b \times d_b / f_y, 200 \times b \times d_b / f_y)$

$A_{s_min} =$ **5272** mm^2

$A_{s_43} = (4/3 \times \max(A_{s_T}, A_{sflex}))$

$A_{st_min} = \text{if}(A_{s_min} > A_{s_43}, \max(\rho_{min} \times b \times h, A_{s_43}), \max(\rho_{min} \times b \times h, A_{s_min}))$

A_{st_min} = **3780** mm^2

$A_{s_req_normal}$ = max(A_{sflex}, A_{st_min}, A_{s_T}) = **3780** mm^2

A_{s_req} = $A_{s_req_normal}$ / (2 × cos(30)) = **2182** mm^2

Try 9 No #6 bar(s)

Each set of bars should be placed in the direction of axis connecting center of piles (triangular pattern)

A_{s_prov} = **2565** mm^2

d_{bar} = D_t = **19.0** mm

a_{con} = A_{s_prov} × f_y / (0.85 × f'_c × b) = **11.182** mm

c_{con} = a_{con} / β_1 = **0.048**

ε_t = 0.003 × ((d_{bx} – c_{con}) / c_{con}) = **0.100**

Pass - Ductility OK at ultimate strength.

Area of bars - OK

CLEAR DISTANCE BETWEEN BARS IN TENSION (ACI 7.6)

Assume reinforcing is put into a strip with a width equal to 3 pile diameters

Bar spacing, c-c sp_{cc} = max(0 mm, (3 × d_{pile} - d_{bar})/(L_{nt} - 1)) = **166.4** mm

Clear spacing sp_{clear} = max(0 mm, (sp_{cc} - d_{bar})) = **147.3** mm

sp_{min} = max(d_{bar}, 25.4 mm) = **25.4** mm

ACI 7.6.1

sp_{max} = 457.2 mm

ACI 7.6.5

Bar spacing - OK

DEVELOPMENT OF TENSION STEEL

All bars must be provided with standard 180° end hooks.

Check hook development length (ACI 12.5)

l_{dh_1} = (0.02 × β × λ × f_y / √(f'_c)) × d_{bar} = **301.076** mm

mod_1 = if((((d_{bar}<=35.814 mm)&&(d_c>=63.5 mm)),0.7, 1.0) = **0.7**

l_{dh} = max(l_{dh_1} × mod_1, 152.4 mm, 8 × d_{bar}) = **210.8** mm

Hook development length OK

SHEAR ACI 15.5

Shear checks

Punching of single pile must be checked

Punching of pile at corner must be checked

Punching of overlapping piles must be checked

One way shear @d distance in the section parallel to y-y axis is not applicable

One way shear @d distance in the section parallel to x-x axis is not applicable

Punching shear @ d/2 from column face is not applicable

One way shear @ column face in the section parallel to y-y axis direction must be checked

One way shear @ column face in the section parallel to x-x axis must be checked

Punching shear @ column face must be checked

CHECK PUNCHING OF SINGLE PILE (ACI 11.12.2)

$b_o = \pi \times (d_{pile} + d_b) =$ **2971.8** mm

$V_c = 4 \times \sqrt{(f'_c)} \times b_o \times d_b =$ **3096.086** kN

$V_s = 0$ kN

$\phi V_n = 0.75 \times (V_c + V_s) =$ **2322.065** kN

$V_{up} = P_{u_pile} =$ **773.1** kN

Pile punching capacity - OK

CHECK PUNCHING OF SINGLE PILE AT CORNER (ACI 11.12.2)

$b_o = \pi \times (d_{pile} + d_b)/4 + 2 \times (e + d_{pile} / 2) =$ **2192.9** mm

$V_c = 4 \times \sqrt{(f'_c)} \times b_o \times d_b =$ **2284.669** kN

$V_s = 0$ kN

$\phi V_n = 0.75 \times (V_c + V_s) =$ **1713.502** kN

$V_{up} = P_{u_pile} =$ **773.1** kN

Pile punching capacity at corner - OK

CHECK PUNCHING OF OVERLAPPING PILES (ACI 11.12.2)

$b_o = \pi \times (d_{pile} + d_b) + 2 \times s =$ **5671.8** mm

$V_c = 4 \times \sqrt{(f'_c)} \times b_o \times d_b =$ **5909.015** kN

$V_s = 0$ kN

$\phi V_n = 0.75 \times (V_c + V_s) =$ **4431.762** kN

$V_{up} = 2 \times P_{u_pile} =$ **1546.1** kN

Pile punching capacity at overlap - OK

ONE-WAY (BEAM) SHEAR – THREE PILE CAP (ACI 11.12, 15.5)

Design ultimate shear force @ column face

$x_d = \max((L - e - d_{pile}/2 - .288 \times s - a_c/2), 0 \text{ mm}) =$ **1305.3** mm

$b_x = \min((w_2 + 2 \times (e+d_{pile}/2) * \tan(30)),(\sqrt{(2 \times w_1^2)}))$

$b_x =$ **2050.6** mm

$V_{u_face} = P_{u_pile} =$ **773.054** kN

$VM_{rat} = M_{uy} / (V_{u_face} \times d_b) =$ **1.150**

Section shear capacity

Concrete strength $f'_c =$ **40.000** N/mm^2

$\rho_w = A_{s_prov} / (b_x \times d_b) =$ **0.002522**

$f_1 = (d_b/x_{face}) \times (3.5 - 2.5 \times VM_{rat}) =$ **0.536**

$f_2 = 1.9 \times \sqrt{(f'_c)} =$ **0.998** N/mm^2

$f_3 = 2500\ \rho_w / VM_{rat} =$ **0.038** N/mm^2

$V_{c1} = f_1 \times (f_2 + f_3) \times b_x \times d_b =$ **564.493** kN

$V_{c2} = \min(V_{c1}, 10 \times \sqrt{(f'_c)} \times b_x \times d_b) =$ **564.493** kN

CRSI Eq. 13-2

$V_c = \max(V_{c2}, 2 \times \sqrt{(f'_c)} \times b_x \times d_b) =$ **1068.189** kN

$V_s = 0$ kN

$\phi V_n = 0.75 \times (V_c + V_s) =$ **801.142** kN

One-way shear capacity - OK

TWO-WAY (PUNCHING) SHEAR CHECK (ACI 11.12.2)

Total length of shear perimeter at column face (CRSI Design Handbook)

Perimeter (@d/2)	$b_o = 2 \times (b_c + d_b + a_c + d_b) =$ **3983.8** mm
Perimeter (@face)	$b_s = 2 \times (a_c + b_c) =$ **2000.0** mm
Concrete strength	$f'_c =$ **40.000** N/mm^2
Punching shear	$V_{up} = P_u + (P_{sur} + P_{wt}) \times (s \times \min(b,s))/L^2 =$ **2210.810** kN

Shear capacity of concrete

$w = \max(\text{if}(N==3, .577 \times s, s/2) - a_c/2, s/2 - b_c/2, .001 \text{ mm}) =$ **579.0** mm

$V_{c1} = (d_b/w) \times (b_o/b_s) \times 2 \times \sqrt{(f'_c)} \times b_s \times d_b =$ **1777.704** kN

$V_{c2} = \min(V_{c1}, 32 \times \sqrt{(f'_c)} \times b_s \times d_b) =$ **1777.704** kN

$V_c = \max(V_{c2}, 4 \times \sqrt{(f'_c)} \times b_o \times d_b) =$ **4150.500** kN

$V_s = 0$ kN

$\phi V_n = 0.75 \times (V_c + V_s) =$ **3112.875** kN

Two-way shear capacity - OK