RC PILE CAP DESIGN (BS8110:PART1:1997)

Pile Cap Design – Truss Method

Design Input - 3 Piles - No Eccentricity

Number of piles; \( N = 3 \)
ULS axial load; \( F_{ulb} = 1500.0 \) kN
The ultimate load per pile is; \( F_{ult,pile} = F_{ulb}/3 = 500.0 \) kN
Characteristic axial load; \( F_{char} = 1000.0 \) kN
The characteristic load per pile is;  
\[ F_{\text{char pile}} = \frac{F_{\text{char}}}{3} = 333.3 \text{ kN} \]

Pile diameter;  
\[ \phi = 250 \text{ mm} \]

Pile spacing;  
\[ s = 750 \text{ mm} \]

Pile cap overhang;  
\[ e = 150 \text{ mm} \]

Overall length of pile cap;  
\[ L = \sin(60) \times s + \phi + 2 \times e = 1200 \text{ mm} \]

Overall width of pile cap;  
\[ b = s + \phi + 2 \times e = 1300 \text{ mm} \]

Width at pile parallel to length, L;  
\[ w_1 = \phi + 2 \times e = 550 \text{ mm} \]

Width at pile parallel to overall width, b;  
\[ w_2 = \phi + 2 \times e = 550 \text{ mm} \]

Overall height of pile cap;  
\[ h = 450 \text{ mm} \]

Diagonal length of sides;  
\[ L_{\text{side diag}} = \sqrt{(L-w_1)^2 + \left(\frac{b-w_2}{2}\right)^2} = 750 \text{ mm} \]

Dimensions of loaded area;  
\[ x = 300 \text{ mm} \]
\[ y = 300 \text{ mm} \]

Cover
Concrete grade;  
\[ f_{\text{cu}} = 40.0 \text{ N/mm}^2 \]
Nominal cover;  
\[ c_{\text{nom}} = 40 \text{ mm} \]
Tension bar diameter;  
\[ D_t = 16 \text{ mm} \]
Link bar diameter;  
\[ L_{\text{dia}} = 12 \text{ mm} \]
Depth to tension steel;  
\[ d = h - c_{\text{nom}} - L_{\text{dia}} - D_t/2 = 390 \text{ mm} \]

Pile Cap Forces
Compression within pile cap;  
\[ F_c = \frac{F_{\text{uls}}}{3 \times \sin(\theta)} = 747.1 \text{ kN} \]
Tension within pile cap;  
\[ F_t = \frac{F_c \times \cos(\theta)}{2 \times \cos(30)} = 320.5 \text{ kN} \]

Compression In Pile Cap - Suggested Additional Check
Check compression diagonal as an unreinforced column, using a core equivalent to pile diameter
Compressive force in pile cap;  
\[ P_c = 0.4 \times f_{\text{cu}} \times \pi \times \phi^2/4 = 785.4 \text{ kN} \]

Pass Compression  
Cl. 3.8.4.3

Tension In One Truss Member
Characteristic strength of reinforcement;  
\[ f_y = 500 \text{ N/mm}^2 \]
Partial safety factor for strength of steel;  
\[ \gamma_{fs} = 1.15 \]
Required area of reinforcement;  
\[ A_{\text{req}} = F_t / (1/\gamma_{fs} \times f_y) = 737 \text{ mm}^2 \]
Provided area of reinforcement;  
\[ A_{\text{prov}} = A_{\text{st}} = 1005 \text{ mm}^2 \]
Tension in truss member;  
\[ P_t = (1/\gamma_{fs} \times f_y) \times A_{\text{prov}} = 437.1 \text{ kN} \]

Pass Tension  
Cl. 3.11.4.2

Max / Min Areas of Reinforcement - Considering A Strip Of Cap
Minimum required area of steel;  
\[ A_{\text{st min}} = k_t \times A_c = 293 \text{ mm}^2 \]
Maximum allowable area of steel;  
\[ A_{\text{st max}} = 4 \times A_c = 9000 \text{ mm}^2 \]

Area of tension steel provided OK  
Cl. 3.12.8 & Table 3.25
Beam Shear

Check shear stress on the sections at distance $\phi/5$ inside face of piles.

Cl. 3.11.4.3 & fig. 3.23

Applied shear stress

Applied shear force;

\[ V = \frac{F_{uls}}{3} = 500.0 \text{ kN} \]

Min effective width of pile cap along plane of shear;

\[ b_v = \min(b_{v1}, b_{v2}, 3 \times \phi) = 750 \text{ mm} \]

Design shear stress;

\[ v = \frac{V}{b_v \times d} = 1.71 \text{ N/mm}^2 \]

Allowable shear stress;

\[ v_{allowable} = \min\left((0.8 \text{ N/mm})^{1/2} \times \sqrt{f_{cu}}, 5 \text{ N/mm}^2\right) = 5.00 \text{ N/mm}^2 \]

Shear stress - OK

Cl. 3.4.5.2

Design concrete shear strength

From BS8110-1:1997 Table 3.8;

\[ v_{c,25} = 0.79 \times r^{1/3} \times \max(0.67, (400 \text{ mm/d})^{1/4}) \times 1.0 \text{ N/mm}^2 / 1.25 = 0.56 \text{ N/mm}^2 \]

Shear enhancement (Cl. 3.4.5.8 and fig. 3.5);

\[ v_c = v_{c,25} \times \left(\min(f_{cu}, 40 \text{ N/mm}^2) / 25 \text{ N/mm}^2\right)^{1/3} = 0.66 \text{ N/mm}^2 \]

0.1(mm)) = 208 mm

Enhanced shear stress;

\[ v_{c,enh} = \min\left(v_{allowable}, 2 \times d \times v_c / a_v\right) = 2.46 \text{ N/mm}^2 \]

Concrete shear strength - OK, no links reqd.

Table 3.16

Note: If no links are provided, the bond strengths for PLAIN bars must be used in calculations for anchorage and lap lengths.

Cl. 3.12.8.3

Local Shear At Concentrated Loads (Cl 3.7.7)

Total length of inner perim. at edge of loaded area;

\[ u_0 = 2 \times (x + y) = 1200 \text{ mm} \]

Assumed average depth to tension steel;

\[ d_{av} = d - D_t = 374 \text{ mm} \]

Max shear effective across perimeter;

\[ V_p = F_{uls} = 1500.0 \text{ kN} \]

Stress around loaded area;

\[ v_{max} = V_p / (u_0 \times d_{av}) = 3.34 \text{ N/mm}^2 \]

Allowable shear stress;

\[ v_{allowable} = \min((0.8 \text{ N/mm})^{1/2} \times \sqrt{f_{cu}}, 5 \text{ N/mm}^2) = 5.00 \text{ N/mm}^2 \]

Shear stress - OK

Cl. 3.4.5.2

Clear Distance Between Bars In Tension (Cl 3.12.11.2.4)

Maximum / Minimum allowable clear distances between tension bars considering a strip of cap

Actual bar spacing;

\[ \text{spacing}_{bars} = \max(0 \text{ mm}, (D_{ccs} - n_{surfaces} \times (c_{adopt} + L_{uls}) - D_t)/(L_{int} - 1) - D_t) = 92 \text{ mm} \]

Maximum allowable spacing of bars;

\[ \text{spacing}_{max} = \min((47000 \text{ N/mm})/f_s, 300 \text{ mm}) = 192 \text{ mm} \]

Minimum required spacing of bars;

\[ \text{spacing}_{min} = h_{agg} + 5 \text{ mm} = 25 \text{ mm} \]

Bar spacing OK

Clear Distance Between Face Of Beam And Tension Bars (Cl 3.12.11.2.5)
Distance to face of beam; \( \text{Dist}_{\text{edge}} = C_{\text{adopt}} + L_{\text{dis}} + D_t/2 = 60 \text{ mm} \)
Design service stress in reinforcement; \( f_s = 2 \times f_y \times A_{s_{\text{req}}} / (3 \times A_{s_{\text{prov}}} \times b_0) = 244.4 \text{ N/mm}^2 \)
Max allowable clear spacing; \( \text{Spacing}_{\text{max}} = \min(47000 \text{ N/mm} / f_s, 300 \text{ mm}) = 192 \text{ mm} \)
Max distance to face of beam; \( \text{Dist}_{\text{max}} = \text{Spacing}_{\text{max}} / 2 = 96 \text{ mm} \)

Anchorage Of Tension Steel
Anchorage factor; \( \phi_{\text{factor}} = 35 \)
Type of lap length; \( \text{lap}_{\text{type}} = \text{"tens\_lap"} \)
Type of reinforcement; \( \text{reft}_{\text{type}} = \text{"def2\_fy500"} \)
Minimum radius; \( R_{\text{bar}} = 32 \text{ mm} \)
Minimum anchorage length or lap length req’d; \( L_{\text{table}3.27} = \phi_{\text{factor}} \times D_t = 560 \text{ mm} \)
Check anchorage length to cl. 3.12.9.4 (b); \( L_{\text{cl.3.12.9.4}} = 12 \times D_t + d/2 = 387 \text{ mm} \)
Required minimum effective anchorage length; \( L_s = \max(L_{\text{table}3.27}, L_{\text{cl.3.12.9.4}}) = 560 \text{ mm} \)

Check minimum radius required on bend
Note that the bars must extend at least 4D past the bend
Force per bar at bend; \( F_{\text{lt}} = F_t / L_{\text{lt}} = 64.1 \text{ kN} \)
Edge bar centres; \( s_{\text{ext}} = C_{\text{adopt}} + D_t = 56 \text{ mm} \)
Edge maximum allowable bearing stress; \( f_{\text{bt}_{\text{max,ext}}} = 2 \times f_{\text{cu}} / (1 + 2 \times (D_t / s_{\text{ext}})) = 50.91 \text{ N/mm}^2 \)
Internal bar centres; \( s_{\text{int}} = \text{spacing}_{\text{bars}} + D_t = 108 \text{ mm} \)
Internal maximum allowable bearing stress; \( f_{\text{bt}_{\text{max,int}}} = 2 \times f_{\text{cu}} / (1 + 2 \times (D_t / s_{\text{int}})) = 61.71 \text{ N/mm}^2 \)
Design max allowable bearing stress; \( f_{\text{bt}_{\text{max}}} = \min(f_{\text{bt}_{\text{max,ext}}}, f_{\text{bt}_{\text{max,int}}}) = 50.91 \text{ N/mm}^2 \)
Minimum radius required; \( r_{\text{min}} = \max(r_{\text{bar}}, F_{\text{bt}} / (f_{\text{bt}_{\text{max}}} \times D_t)) = 78.7 \text{ mm} \)

Minimum radius of bend required = 79 mm