STRUCTURAL DESIGN OF PILED FOUNDATION: WORKED EXAMPLE

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WORKED EXAMPLE

Figure 1 is the column application plan at the base of an 8-story building, showing the loads at serviceability limit state. It is required to found this building on a pile foundation. Using the pile catalogue, carry out sufficient calculation to establish the pile layout and quantity of reinforcing steels required in the pile caps using concrete C25/30 and grade 460 steel.

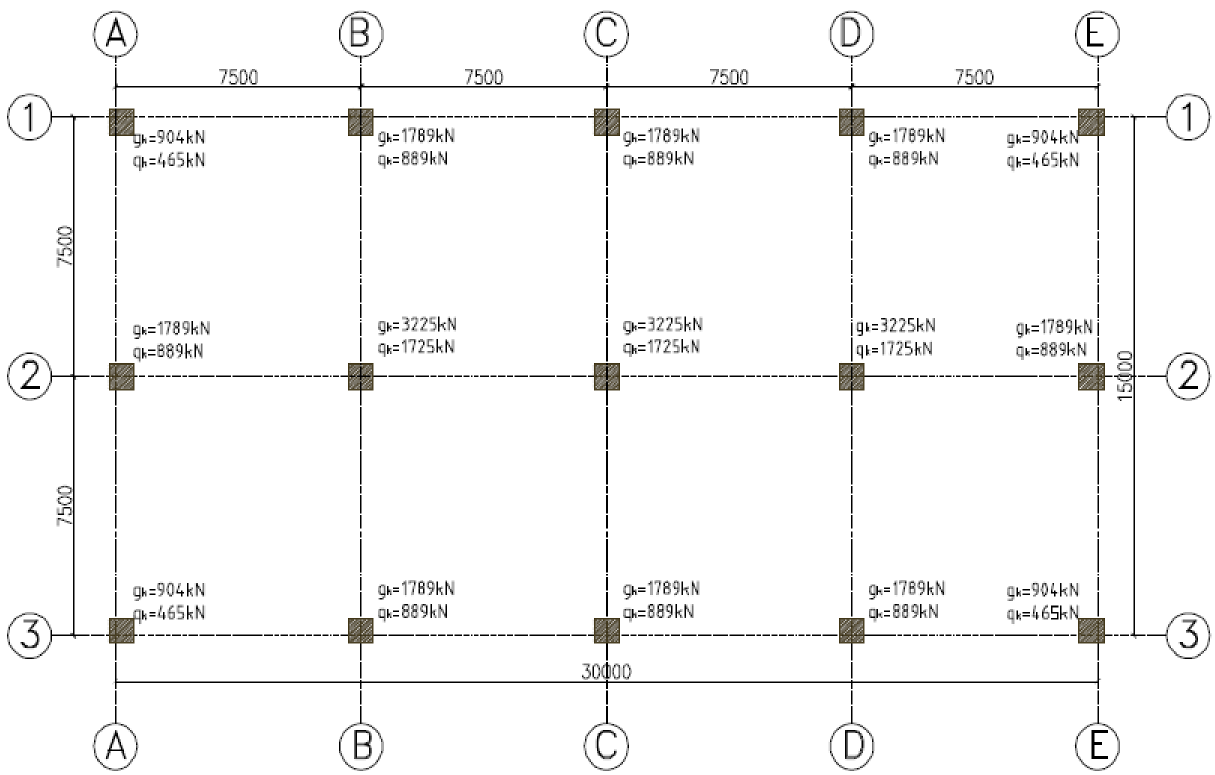

Figure 1: Load Application Plan @ Base

Table 1: Pile Catalogue

Pile Diameter (mm)	400	500	600	750
Safe Working Load (kN)	**806**	**1343**	**1668**	**2452**

Column A1 (Typical for A5, E1 & E5)

Assuming, we want to use two piles for this column, we can determine the pile type required by dividing the loads on the column at serviceability by the number of piles required, which is 2, and then select a suitable pile type from the pile catalogue.

$$\text{no. of piles} = \frac{Loads\ (Unfactored)}{2} = \frac{(904 + 465)}{2} = 684.5kN$$

Hence, we can adopt, 2-400mm diameter piles

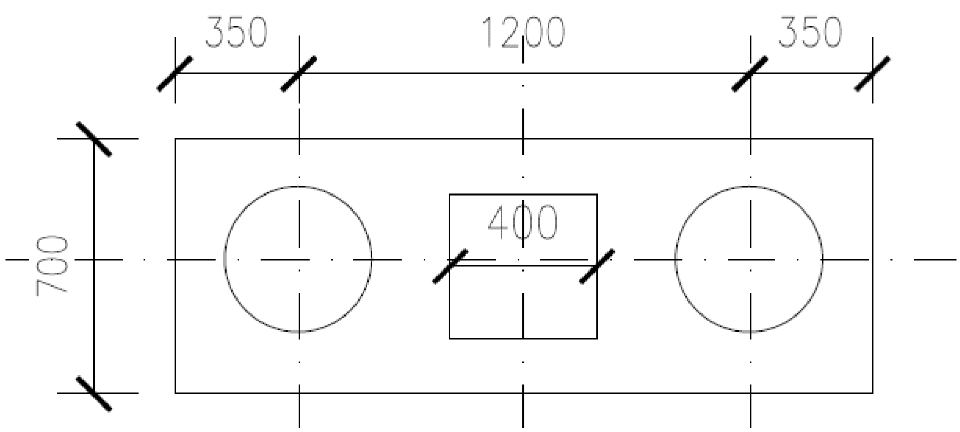

Figure 2: Pile Cap (Type 1)

Geometry of the Pile-Cap

- Try an overall depth, h=1000mm, effective depth =900mm
- Spacing between pile = 3×400 = 1200mm
- Overhangs from edge of piles = 150mm
- Length of pile = 1200+400/2+400/2+150+150 =1900mm
- Width of pile cap = 400+150+150 = 700mm

Actions @ ULS

$N_{ULS} = 1.35G_k + 1.5Q_k = 1.35(904) + 1.5(465) = 1917.9kN$

$self\ weight\ of\ pile - cap = (1.9 \times 0.7 \times 1 \times 25) = 33.25kN$

$N = 1917.9 + 33.25 = 1951kN$

Tension Reinforcement

$$\mathrm{T} = \frac{\mathrm{Nl}}{2\mathrm{d}} = \frac{1951 \times (\frac{1200}{2})}{2 \times 900} = 650.33\mathrm{kN}$$

$$A_s = \frac{T}{0.87f_{yk}} = \frac{650.33 \times 10^3}{0.87 \times 460} = 1625.01mm^2$$

The total area of reinforcement required in both direction $A_{s,req} = 2 \times 1625.01 = 3250.02mm^2$

<u>*Try 18T16mm@100mm c/c Bars ($A_{s,\ prov}$ =3618mm^2)*</u>

<u>Verify Area of Steel</u>

$$\mathrm{A_{s,min}} = 0.26\frac{\mathrm{f_{ctm}}}{\mathrm{f_{yk}}}bd \geq 0.0013\mathrm{bd}$$

$$\mathrm{f_{ctm}} = 0.30\mathrm{f_{ck}^{\frac{2}{3}}} = 0.3 \times 25^{\frac{2}{3}} = 2.56\mathrm{Mpa}$$

$$\mathrm{A_{s,min}} = 0.26 \times \frac{2.56}{460} \times 1900 \times 900 \geq 0.0013 \times 1900 \times 900$$

$$= 2474.5\mathrm{mm^2} < (A_{s,prov} = 3618mm^2)$$

Shear Verification

Shear force per pile $V = \frac{1951}{2} = 976kN$

Distance to shear plane $a_v = \frac{1900}{2} - \frac{400}{2} - (150 + 400) + \frac{400}{5} = 280mm$

$$V_{Ed} = a_v \frac{V}{2d} = \frac{976 \times 280}{2 \times 900} = 151.8kN$$

$$V_{Rd,c} = \left(\frac{0.18}{\gamma_c}\right) k(100\rho_1 f_{ck})^{\frac{1}{3}} b_w d \ \geq \ 0.035k^{\frac{3}{2}}\sqrt{f_{ck}} b_w d$$

$$k = 1 + \sqrt{\frac{200}{900}} = 1 + \sqrt{\frac{200}{900}} = 1.47 < 2$$

$$A_s = 3618mm^2$$

$$b = 1900mm$$

$$\rho_1 = \frac{A_s}{b_w d} = \frac{3618}{1900 \times 900} = 0.0021$$

$$V_{Rd,c} = \left(\frac{0.18}{1.5}\right) \times 1.47 \times (100 \times 0.0021 \times 25)^{\frac{1}{3}} \cdot 900 \times 1900$$

$$\geq 0.035 \times 1.24^{\frac{3}{2}} \times \sqrt{30} \times 900 \times 1900 = 524.3\text{kN}$$

Since $V_{Ed} < V_{Rd,c}$ $(151.8kN < 524.3kN)$ therefore shear reinforcement is not required.

Punching Verification

Pile spacing has being deliberately chosen at exactly 3 times the pile diameter to avoid further punching checks except at the column face

At the column face:

$$\text{N}_{\text{Ed}} \leq \text{V}_{\text{Rd,max}}$$

$$\text{V}_{\text{Rd,max}} = 0.2\left(1 - \frac{f_{ck}}{250}\right) f_{ck} pd = 0.2\left(1 - \frac{25}{250}\right) 25 \times (4 \times 400) \times 900 = 6480kN$$

$$(\text{N}_{\text{Ed}} = 1951\text{kN}) < (\text{V}_{\text{Rd,max}} = 6480kN)\ o.k$$

Column B1 (Typical for C1, D1, A2, E2, B3, C3 &D3)

Let’s use three piles for this column, we can determine the pile type required by dividing the loads on the column at serviceability by the number of piles required, which is 3, and then select a suitable pile type from the pile catalogue.

$$\text{no. of piles} = \frac{Loads\ (Unfactored)}{3} = \frac{(1789 + 889)}{3} = 892.66kN$$

Hence, we can adopt, 3-500mm diameter piles

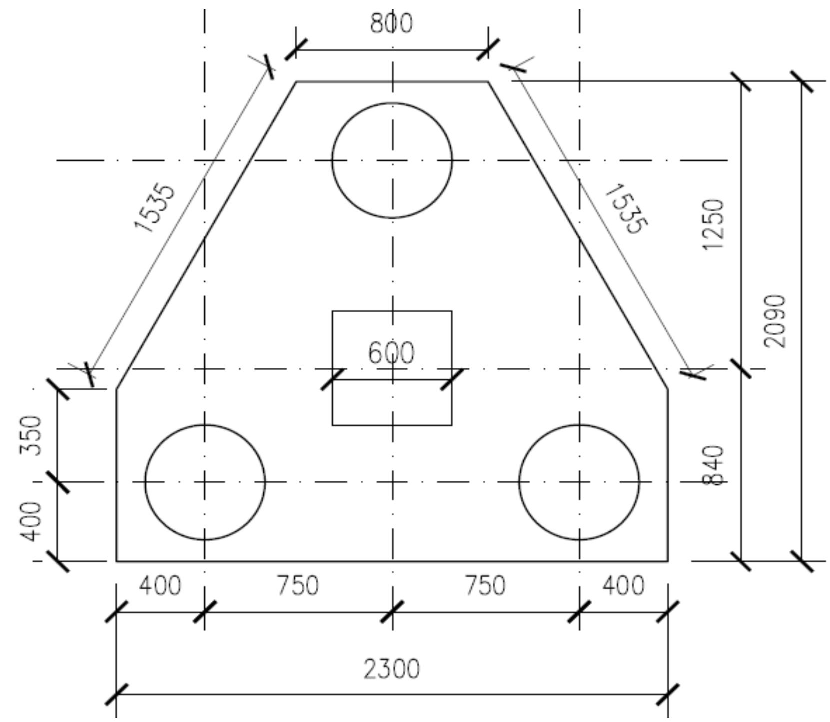

Figure 3: Pile-Cap (Type 2)

Geometry of the Pile-Cap

- Try an overall depth, h=1000mm, effective depth =900mm
- Spacing between pile = 3×500 = 1500mm
- Overhangs from edge of piles = 150mm
- Length of pile = 1500+500/2+500/2+150+150 =2300mm
- Width of pile cap = 500+150+150 = 800mm

Actions @ ULS

$N_{ULS} = 1.35G_k + 1.5Q_k = 1.35(1789) + 1.5(889) = 3748.65kN$

$self\ weight\ of\ pile - cap = (3.86m^2 \times 1 \times 25) = 96.5kN$

$N = 3748.65 + 96.5 = 3845.2kN$

Tension Reinforcement

$$T = \frac{2Nl}{9d} = \frac{2 \times 3845.2 \times (\frac{1500}{2})}{2 \times 900} = 712.07kN$$

$$A_s = \frac{T}{0.87f_{yk}} = \frac{712.07 \times 10^3}{0.87 \times 460} = 1779.3mm^2$$

The total area of reinforcement required in both direction $A_{s,req} = 2 \times 1779.3 = 3558.6mm^2$

Try 18T16mm@100mm c/c Bars ($A_{s,\,prov}$ =3618mm²)

Verify Area of Steel

$$A_{s,min} = 0.26\frac{f_{ctm}}{f_{yk}}bd \geq 0.0013bd$$

$$f_{ctm} = 0.30f_{ck}^{\frac{2}{3}} = 0.3 \times 25^{\frac{2}{3}} = 2.56Mpa$$

$$A_{s,min} = 0.26 \times \frac{2.56}{460} \times 2300 \times 900 \geq 0.0013 \times 1900 \times 900$$

$$= 2995.2mm^2 < (A_{s,prov} = 3618mm^2)$$

Shear Verification

Shear force per pile $V = \frac{3845.2}{3} = 1281.7kN$

Distance to shear plane $a_v = \frac{2300}{2} - \frac{600}{2} - (150 + 500) + \frac{500}{5} = 300mm$

$$V_{Ed} = a_v\frac{V}{2d} = \frac{1281.7 \times 300}{2 \times 900} = 213.6kN$$

$$V_{Rd,c} = \left(\frac{0.18}{\gamma_c}\right)k(100\rho_1 f_{ck})^{\frac{1}{3}}bd \;\geq\; 0.035k^{\frac{3}{2}}\sqrt{f_{ck}}bd$$

$$k = 1 + \sqrt{\frac{200}{900}} = 1 + \sqrt{\frac{200}{900}} = 1.47 < 2$$

$$A_s = 3618mm^2$$

$b = 2300mm$

$$\rho_1 = \frac{A_s}{bd} = \frac{3618}{2300 \times 900} = 0.0017$$

$$V_{Rd,c} = \left(\frac{0.18}{1.5}\right) \times 1.47 \times (100 \times 0.0017 \times 25)^{\frac{1}{3}} \cdot 900 \times 2300$$

$$\geq 0.035 \times 1.24^{\frac{3}{2}} \times \sqrt{30} \times 900 \times 1900 = 591.5\text{kN}$$

Since $V_{Ed} < V_{Rd,c}$ $(213.6kN < 591.5kN)$ therefore shear reinforcement is not required.

Punching Verification

Pile spacing has being deliberately chosen at exactly 3 times the pile diameter to avoid further punching checks except at the column face

<u>At the column face:</u>

$\text{N}_{\text{Ed}} \leq \text{V}_{\text{Rd,max}}$

$$\text{V}_{\text{Rd,max}} = 0.2\left(1 - \frac{f_{ck}}{250}\right) f_{ck}pd = 0.2\left(1 - \frac{25}{250}\right) 25 \times (4 \times 600) \times 900 = 9720kN$$

$(\text{N}_{\text{Ed}} = 3845.2\text{kN}) < (\text{V}_{\text{Rd,max}} = 9720kN)\ o.k$

Column B2 (Typical for C2 & D2)

Let's assume four piles for this column, we can determine the pile type required by dividing the loads on the column at serviceability by the number of piles required, which is 4, and then select a suitable pile type from the pile catalogue.

$$\text{no. of piles} = \frac{Loads\ (Unfactored)}{4} = \frac{(3225 + 1725)}{4} = 1237.5kN$$

Hence, we can adopt, 4-500mm diameter piles

Geometry of the Pile-Cap

- Try an overall depth, h=1500mm, effective depth =1400mm
- Spacing between pile = 3×500 = 1500mm

- Overhangs from edge of piles = 150mm
- Length of pile = 1500+500/2+500/2+150+150 =2300mm
- Width of pile cap = 1500+500/2+500/2+150+150 =2300mm

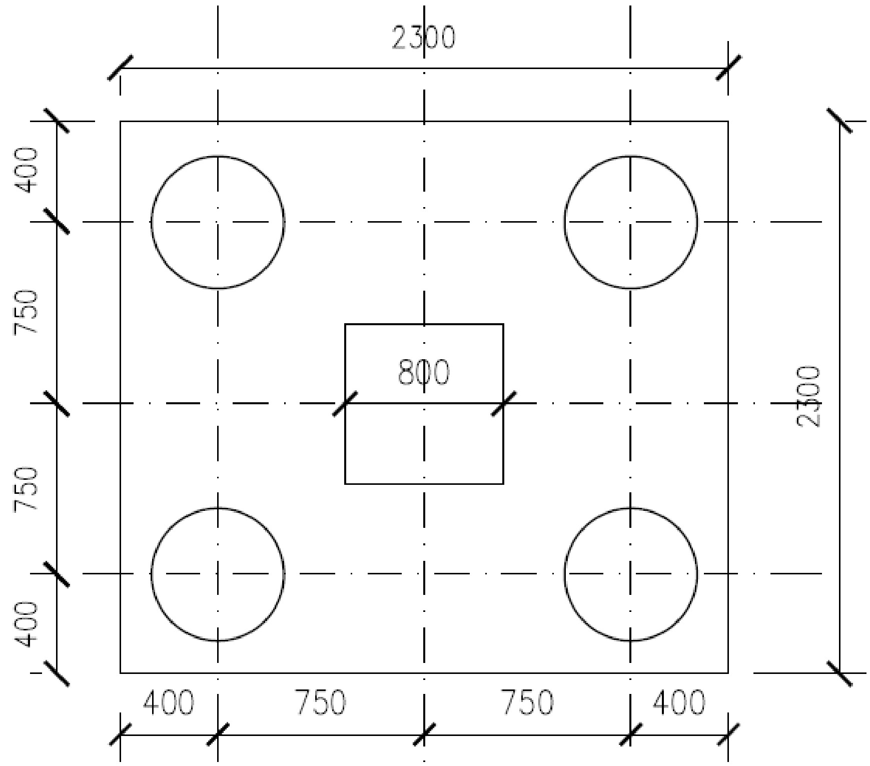

Figure 4: Pile-cap (Type 3)

Actions @ ULS

$$N_{ULS} = 1.35G_k + 1.5Q_k = 1.35(3225) + 1.5(1725) = 6941.25kN$$

$$self\ weight\ of\ pile - cap = (2.3 \times 2.3 \times 1 \times 25) = 132.25kN$$

$$N = 6941.25 + 132.25 = 7073.5kN$$

Tension Reinforcement

$$\mathrm{T} = \frac{\mathrm{Nl}}{\mathrm{4d}} = \frac{7073.5 \times (\frac{1500}{2})}{4 \times 1400} = 947.3\mathrm{kN}$$

$$A_s = \frac{T}{0.87f_{yk}} = \frac{947.3 \times 10^3}{0.87 \times 460} = 2367.1mm^2$$

The total area of reinforcement required in both direction $A_{s,req} = 2 \times 2367.1 = 4734.2mm^2$

Try 18T20mm@125mm c/c Bars ($A_{s,\,prov}$ =5652mm^2)

Verify Area of Steel

$$A_{s,min} = 0.26\frac{f_{ctm}}{f_{yk}}bd \geq 0.0013bd$$

$$f_{ctm} = 0.30f_{ck}^{\frac{2}{3}} = 0.3 \times 25^{\frac{2}{3}} = 2.56Mpa$$

$$A_{s,min} = 0.26 \times \frac{2.56}{460} \times 2300 \times 1400 \geq 0.0013 \times 1900 \times 1400$$

$$= 4659.2mm^2 < (A_{s,prov} = 5652mm^2)$$

Shear Verification

Shear force per pile $V = \frac{7073.5}{2} = 3536.8kN$

Distance to shear plane $a_v = \frac{2300}{2} - \frac{800}{2} - (150 + 500) + \frac{500}{5} = 200mm$

$$V_{Ed} = a_v\frac{V}{2d} = \frac{3536.8 \times 200}{2 \times 1400} = 252.6kN$$

$$V_{Rd,c} = \left(\frac{0.18}{\gamma_c}\right)k(100\rho_1 f_{ck})^{\frac{1}{3}}b_w d \ \geq \ 0.035k^{\frac{3}{2}}\sqrt{f_{ck}}b_w d$$

$$k = 1 + \sqrt{\frac{200}{1400}} = 1 + \sqrt{\frac{200}{1400}} = 1.38 < 2$$

$$A_s = 5652mm^2$$

$$b = 2300mm$$

$$\rho_1 = \frac{A_s}{bd} = \frac{5652}{2300 \times 1400} = 0.0018$$

$$V_{Rd,c} = \left(\frac{0.18}{1.5}\right) \times 1.47 \times (100 \times 0.0018 \times 25)^{\frac{1}{3}} \cdot 2300 \times 1400$$

$$\geq 0.035 \times 1.24^{\frac{3}{2}} \times \sqrt{30} \times 2300 \times 1400 = 791kN$$

Since $V_{Ed} < V_{Rd,c}$ $(252.6kN < 937.8kN)$ therefore shear reinforcement is not required.

Punching Verification

Pile spacing has being deliberately chosen at exactly 3 times the pile diameter to avoid further punching checks except at the column face

At the column face:

$N_{Ed} \leq V_{Rd,max}$

$$V_{Rd,max} = 0.2\left(1 - \frac{f_{ck}}{250}\right) f_{ck}pd = 0.2\left(1 - \frac{25}{250}\right) 25 \times (4 \times 800) \times 1400 = 20{,}160kN$$

$(N_{Ed} = 7073.5kN) < (V_{Rd,max} = 20{,}160kN)\ o.k$

SUMMARY

Pile- Cap (Type 1)

Main Bars*: 18T16mm @100 c/c Bars*

Distribution Bars*: T16mm Bars @ 100 c/c*

Anti-Bust Steel*: T1mm Bars @200 c/c*

Pile- Cap (Type 2)

Main Bars*: 18T16mm @100 c/c Bars*

Distribution Bars*: T16mm Bars @ 100 c/c*

Anti-Bust Steel*: T1mm Bars @200 c/c*

Pile- Cap (Type 3)

Main Bars*: 18T20mm @125 c/c Bars*

Distribution Bars*: T16mm Bars @ 100 c/c*

Anti-Bust Steel*: T12mm Bars @200 c/c*