Pad foundation design

Geotechnical design

Allowable bearing capacity by Brinch Hansen

$$q_{all} = \frac{1.3cN_c + q'_o N_q R_{w1} + 0.4\gamma B N_\gamma R_{w2}}{\gamma_f}$$

where :

q' is the effective over- burden pressure $q'_o = \gamma D_f$

where :

γ is the unit weight of the soil

D_f is depth of the foundation base from the ground level

B is the width of the foundation

γ_f is factor of safety against bearing capacity failure (2.0 – 3.0)

c is the cohesion (for the drained or undrained case under consideration) and

Nc, Nq and N are shallow bearing capacity factors *(the calculator selects equivalent allowable bearing capacity factors from internal angle of shear in the Table 1)*

R_{w1} and R_{w2} is factors of water table effect

When the water table is above the base of foundation at a distance ‘a’ the correction R_{w1} is

$$R_{w1} = 1 - 0.5\left(\frac{a}{D_f}\right) \leq 1$$

When the water table is below the base of foundation at a distance ‘b’ the correction R_{w2} is

$$R_{w2} = 0.5 + 0.5\left(\frac{b}{B}\right) \leq 1$$

Preliminary sizing of pad footing

$$Area = V_d \,/\, q_{all}$$

$$Area, pad\ footing = b * l$$

where :

V_d is design vertical load, $V_d = dead\ load + 1.3 * live\ load$;

q_{all} allowable bearing capacity

b and l are the width and length of the foundation

Ultimate bearing pressure

$$ULS, q = factored\ load / Area$$

Where:

factored load is dead load * safety factor + live load * safety factor

Area is the pad foundation area

Flexure design

Design load

$$Design\ load = Live\ load * SF, q_k + Dead\ load * SF, g_k$$

where :

SF,q_k and SF,g_k are safety factors for live load and dead load respectively

Design moment at the face of the column

$$M_{ED1} = \frac{ULS_{,q}\ l \left[\frac{b - c_x}{2}\right]^2}{2}$$

$$M_{ED2} = \frac{ULS_{,q}\ b \left[\frac{l - c_y}{2}\right]^2}{2}$$

where :

$ULS_{,q}$ is ultimate bearing pressure

b and l are the width and length of the foundation

c_x and c_y is column cross sectional dimension

Determine K for respective M_{ED}

$$K_1 = M_{ED1} / (l * d_1^2 f_{ck})$$

$$K_2 = M_{ED2} / (b * d_2^2 f_{ck})$$

where :

M_{ED1} , M_{ED2} are bending moment at the face of the column

b and l are the width and length of the foundation

d_1 and d_2 the effective depths in orthogonal directions

d_1= h - cover - $Ø_1/2$

d_2= h - cover - $Ø_1$ - $Ø_2/2$

where :

h is depth of the pad foundation

Ø is diameter of the reinforcement bar

f_{ck} is characteristic compressive strength

$$K' = 0.6\,\delta - 0.18\delta^2 - 0.21 = 0.16955$$

(δ=1.0 means no redistribution and δ = 0.85 means 15% moment redistribution).

If K ≤ K', no compression steel needed. If K ≥ K', compression reinforcement required – not recommended for typical foundation, thus redesign the section of the foundation.

Lever arm (z)

$$z_1 = \frac{d_1}{2}\left(1 + \sqrt{1 - 3.53K_1}\,\right) \leq 0.95d_1$$

$$z_2 = \frac{d_2}{2}[\,1 + \sqrt{1 - 3.53\,K_2}] \leq 0.95d_2$$

where :

d_1 and d_2 are effective depth in orthogonal directions

Area of tensile reinforcement (A_s)

$$\mathrm{A_{s,1}} = \frac{M_{ED}}{\mathrm{f_{yd}} * z_1}$$

$$\mathrm{A_{s,2}} = \frac{M_{ED2}}{\mathrm{f_{yd}} * z_2}$$

where :

M_{ED1} , M_{ED2} are bending moment at the face of the column

z_1 and z_2 are lever arms in orthogonal directions

f_{yd} is deign yield strength of steel = f_{yk} / γ_s

where :

f_{yk} is characteristic yield strength of steel

γ_s partial safety factor for steel

Number of reinforcement bars

$$n_1 = \frac{A_{s,1}}{a_s}$$

$$n_2 = \frac{A_{s,2}}{a_s}$$

where :

$A_{s,1}$ and $A_{s,2}$ are areas of the tensile reinforcement

a_s is area of a single reinforcement bar

Spacings (s)

$$s_1 = \frac{l}{(\frac{\mathrm{A_{s,1}}}{a_s} - 1)} \leq s_{limit}$$

$$s_2 = \frac{b}{(\frac{\mathrm{A_{s,2}}}{a_s} - 1)} \leq s_{limit}$$

where :

$A_{s,1}$ and $A_{s,2}$ are areas of the tensile reinforcement

a_s is area of a single reinforcement bar

b and l are the width and length of the foundation

S_{limit} is the maximum spacing $\{2h, 250\}$

where :

h is the foundation depth

Minimum reinforcement requirements

$$A_{s-1,min} \geq \frac{0.26 f_{ctm} l d_1}{f_{yk}} \geq 0.0013 l d_1$$

$$A_{s-2,min} \geq \frac{0.26\ f_{ctm} b_t d_2}{f_{yk}} \geq 0.0013 b_t d_2$$

where $f_{ck} \geq 25$

where :

f_{ctm} is tensile strength of the concrete

$f_{ctm} = 0.3 f_{ck}^{2/3}$ for concrete class $\leq$ C50/C60

f_{yk} is characteristic yield strength of steel

b_t and l are breadth and length of the tension zone

d_1 and d_2 are effective depth in orthogonal directions

Maximum reinforcement requirement

$$A_{s,max} \leq 0.04 A_c$$

where:

A_c is area of concrete

$$A_c = b * h \text{ and } l * h$$

Check minimum spacing between bars

$$Spacing > \emptyset_{bar} > 20 > A_{gg} + 5 \text{ (mm)}$$

where :

A_{gg} is size of the course aggregate

Table 1 Bearing capacity factors for a given internal angle of shear

Internal angle of shear φ	Bearing capacity factors*		
	N_c	N_q	N_γ
0	5.0	1.0	0.0
5	6.5	1.5	0.0
10	8.5	2.5	0.0
15	11.0	4.0	1.4
20	15.5	6.5	3.5
25	21.0	10.5	8.0
30	30.0	18.5	17.0
35	45.0	34.0	40.0
40	75.0	65.0	98.0

*Values from charts by Brinch Hansen (1961).

Shear design

Beam shear (at critical section - d distance away from column face)

$$V_{ED,1} = ULS,q * (\frac{b - c\,x - 2d}{2})$$

$$V_{ED,2} = ULS,q * (\frac{l - cy - 2d}{2})$$

where :

ULS,q is ultimate bearing pressure;

cx,cy are column width along x and y direction

d is average effective depth, $d = (d_1 + d_2)/2$

d_1= h - cover - $Ø_1/2$

d_2= h - cover - $Ø_1$ - $Ø_2/2$

where :

h is depth of the pad foundation

Ø is diameter of the reinforcement bar

$\frac{V_{ED,1}}{d_1}$;gives beam shear stress

$\frac{V_{ED,2}}{d_2}$;gives beam shear stress

Design punching shear stress (at face of column)

$$v_{ED,max} = \frac{\beta v_{ED}}{u_0 d}$$

where :

β is factor dealing with eccentricity

v_{ED}, is applied force minus net force within the area of the foundation column

v_{ED} = Applied load - ultimate bearing press * $(c_x * c_y)$

u_0 is perimeter of the column cross section

d is average effective depth, $d = (d_1 + d_2)/2$

Design punching shear stress (at basic control perimeter, u_1)

$$v_{ED} = \beta \frac{v_{ED}}{u_1 d}$$

where :

β is factor dealing with eccentricity

v_{ED}, is applied force minus net force within the area of the control perimeter on the foundation

v_{ED} = Applied load - ultimate bearing press $[(cx * cy) + \pi(2d)2 + 4d(cx + cy)]$

u_1 is $2(cx + cy) + 2\pi * 2d$

d is average effective depth, $d = (d_1 + d_2)/2$

Determine $v_{Rd,max}$ (refer to table 7:concise table for respective concrete grade)

$$v_{RD,max} = 0.5 v f_{cd}$$

where :

f_{cd} is design compressive strength, $f_{cd} = f_{ck}/\gamma_c$

$v = 0.6\,(1 - f_{ck}/250)\,\alpha_{cc}$

where :

f_{ck} is characteristic compressive strength of the concrete

α_{cc} is the coefficient taking account of long term effects on the compressive strength and of unfavourable effects resulting from the way the load is applied. It is recommended as 1.0

γ_c partial safety factor for concrete

If $v_{ED,max} \leq v_{Rd,max}$, proceed to the next step - otherwise redesign the section. (Increase the compressive strength of the slab)

Concrete shear capacity (without shear reinforcement) ($v_{Rd,c}$)

$$v_{RD,c} = C_{Rd,c}\, k(100\rho f_{ck})^{\frac{1}{3}} \geq V_{min}$$

$$V_{min} = 0.035\, k^{1.5} f_{ck}^{0.5}$$

$$\rho_x = \frac{A_{s,1}}{l * d_1}\ \rho_y = \frac{A_{s,2}}{b * d_2}$$

$$\rho = (\rho_x * \rho_y)^{\frac{1}{2}} \leq 0.02$$

where :

$C_{RD,c}$ is coefficient derived from test (0.18/ 1.5)

b and l are the width and length of the foundation

d is average effective depth, $d = (d_1 + d_2)/2$

k is size factor, $k = 1 + \sqrt{200/d} \leq 2.0$

ρ is steel ratio and ρ_x, ρ_y are steel ratio along x and y direction

f_{ck} is characteristic compressive strength in MPa

If $v_{ED} \leq v_{Rd,c}$, safe against shear(beam shear and punching shear).

If $v_{ED} \geq v_{Rd,c}$, Redesign foundation section !

(punching shear reinforcement is not recommended for foundation)

Table 7
Values for $v_{Rd,max}$

f_{ck}	$v_{Rd,max}$
20	3.68
25	4.50
28	4.97
30	5.28
32	5.58
35	6.02
40	6.72
45	7.38
50	8.00

Shear checks for pad foundations