Design of Spread RC Footings:

Step 1: Size of footing and factored net pressure

$q_n = q_a - (\gamma h + \gamma_s h_s + q_0)$ $\rightarrow$ *Allowable net soil pressure*

$A_{req.} = \frac{P_{DL} + P_{LL}}{q_n}$ $\rightarrow$ *Required area of footing based on service load*

$q_{nu} = \frac{1.4P_{DL} + 1.7P_{LL}}{A_{prov.}}$ $\rightarrow$ *Factored net soil pressure*

Step 2: Check thickness for two-way shear

$d = h - cover - d_b$ $\rightarrow$ *effective depth of footing*

$b_0 = 2(c_1 + d) + 2(c_2 + d)$ $\rightarrow$ *critical shear perimeter*

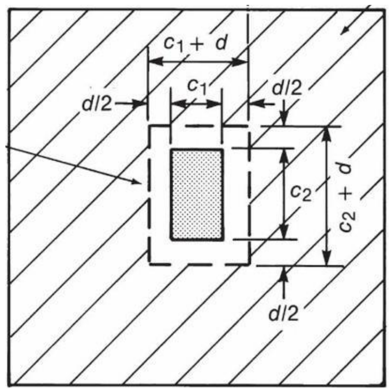
$A_c = (c_1 + d) \times (c_2 + d)$ $\rightarrow$ *Area enclosed by critical shear perimeter*

$V_u = q_{nu} \times (A - A_c)$ $\rightarrow$ *Ultimate shear force on critical section*

$\beta = \frac{c_2}{c_1}$ $\rightarrow$ *ratio of the long side to the short side of the column*

$$\alpha_s = \begin{cases} 40 \text{ for columns in the center of footing} \\ 30 \text{ for columns at end edge of a footing} \\ 20 \text{ for columns at a corner of a footing} \end{cases}$$ $\rightarrow$ *factors, SBC 304 − 18, 22.6.5.3*

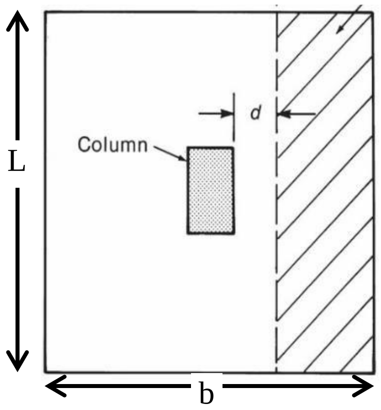
$$V_c = min \begin{cases} 2\left(\frac{\sqrt{f_c'}}{6} b_0 d\right) \\ \left(1 + \frac{2}{\beta}\right)\left(\frac{\sqrt{f_c'}}{6} b_0 d\right) \\ \left(2 + \frac{\alpha_s d}{b_0}\right)\left(\frac{\sqrt{f_c'}}{12} b_0 d\right) \end{cases}$$ $\rightarrow$ *nominal two way shear strength, SBC 304 − 18, 22.6.5.2*



Step 3: Check for One way Shear

$V_u = Tributary\ area \times q_{nu}$ $\rightarrow$ *Ultimate shear force on critical section*

$$V_c = \frac{\sqrt{f_c'}}{6} bd$$ $\rightarrow$ *nominal one way shear strength*



Step 4: Design Reinforcement

$$x = \frac{L - c_2}{2}$$ $\rightarrow$ *distance from face of column to the end of footing*

$w_u = q_{nu} b$ $\rightarrow$ *Load applied on the footing on (L) direction*

$$M_u = w_u \frac{x^2}{2}$$ $\rightarrow$ *Ulimate moment resulting on the footing from the* q_{nu}

$$R_n = \frac{M_u}{\emptyset b d^2}$$ $\rightarrow$ *factor*

$$\rho = \frac{0.85 f_c'}{f_y}\left(1 - \sqrt{1 - \frac{4R_n}{1.7 f_c'}}\right)$$ $\rightarrow$ *steel ratio, for design purpose*

$$\rho_{max} = \left(\frac{0.85 \beta_1 f_c'}{f_y}\right)\left(\frac{3}{8}\right)$$ $\rightarrow$ *maximum steel ratio corresponding to* $\varepsilon_t = 0.005$

$A_{s\,req.} = \rho \times bd$ $\rightarrow$ *required reinforcement*

$A_{s\,min} = 0.0018 \times bh$ $\rightarrow$ *minimum reinforcement*, $SBC304-18, 24.4.3.2$

$$s = \frac{L - 2c - \emptyset}{\#bars - 1}$$ $\rightarrow$ *spacing between bars*

$s_{max} = \min(3h, 450)$ $\rightarrow$ *maximum spacing between bars*, $SBC304-18, 7.7.2.3$

Step 5: Check for development length l_d

Same as in beams

Step 6: Design Dowels

$$P_{all\ col} = \emptyset\left(0.85 f'_{c,col} A_1\right) \quad \rightarrow \textit{Allowable bearing force in concrete at base of column}$$

$$P_{all\ foot} = \emptyset\left(0.85 f'_{c,foot} A_1\right)\left(\sqrt{\frac{A_2}{A_1}} \le 2\right) \quad \rightarrow \textit{Allowable bearing force in footing concrete}$$

$$Excess\ load = P_u - \min\left(P_{all\ col}, P_{all\ foot}\right) \quad \rightarrow \textit{only if } P_u > \textit{the smaller of } P_{all\ col}, P_{all\ foot}$$

$$A_s = \frac{Excess\ load}{\emptyset f_y} \quad \rightarrow \textit{Area of dowels}$$

$$A_{s\ min} = 0.005 A_1 \quad \rightarrow \textit{minimum Area of dowels}$$

Step 7: Development length of Dowels

$$l_{dc} = \max\left(\frac{0.24 f_y \Psi_r}{\lambda\sqrt{f'_{c,col}}} d_b, 0.043 f_y \Psi_r d_b, 200\right) \quad \rightarrow \textit{development length up into column}$$

$$l_{dc} = \max\left(\frac{0.24 f_y \Psi_r}{\lambda\sqrt{f'_{c,foot}}} d_b, 0.043 f_y \Psi_r d_b, 200\right) \quad \rightarrow \textit{development length down into column}$$

Design an 850 mm thick square spread footing supports a square column 400 × 400 mm transferring a service axial dead load of 1400 kN and a service live load of 1200 kN. The footing supports also a 500 mm soil layer and a 5 kN/m² top surcharge. Soil Bearing pressure is 300 kN/m². Soil unit weight is 19 kN/m³.

Use f'_c = 25 MPa, f_y = 420 MPa and d_b = 25 mm

Step 1: Size of footing and factored net pressure:

$$q_n = q_a - (\gamma h + \gamma_s h_s + q_0) = 300 - (24 \times 0.85 + 19 \times 0.5 + 5) = 265.1\ kN/m^2$$

$$A_{req.} = \frac{P_{DL} + P_{LL}}{q_n} = \frac{1400 + 1200}{265.1} = 9.81\ m^2$$

$$b = L = \sqrt{9.81} = 3.13\ m$$

Use 3.5 m × 3.5 m footing ➔ A_{prov} = 12.25 m²

$$q_{nu} = \frac{1.4P_{DL} + 1.7P_{LL}}{A_{prov.}} = \frac{1.4 \times 1400 + 1.7 \times 1200}{12.25} = 326.53\ kN/m^2$$

Step 2: Check thickness for two-way shear

$$d = h - cover - d_b = 850 - 75 - 25 = 750\ mm$$

$$b_0 = 2(c_1 + d) + 2(c_2 + d) = 2(400 + 750) + 2(400 + 750) = 4600\ mm$$

$$A_c = (c_1 + d) \times (c_2 + d) = (400 + 750) \times (400 + 750) = 1322500\ mm^2 = 1.3225\ m^2$$

$$V_u = q_{nu} \times (A - A_c) = 326.53 \times (12.25 - 1.3225) = 3568.16\ kN$$

$$\beta = \frac{c_2}{c_1} = \frac{400}{400} = 1$$

$$\alpha_s = 40 \quad columns\ in\ the\ center\ of\ footing$$

$$V_c = min\begin{cases} 2\left(\frac{\sqrt{f'_c}}{6} b_0 d\right) = 2\left(\frac{\sqrt{25}}{6} \times 4600 \times 750\right) & = 5750000\ N = 5750\ kN \\ \left(1 + \frac{2}{\beta}\right)\left(\frac{\sqrt{f'_c}}{6} b_0 d\right) = \left(1 + \frac{2}{1}\right)\left(\frac{\sqrt{25}}{6} \times 4600 \times 750\right) & = 8625000\ N = 8625\ kN \\ \left(2 + \frac{\alpha_s d}{b_0}\right)\left(\frac{\sqrt{f'_c}}{12} b_0 d\right) = \left(2 + \frac{40 \times 750}{4600}\right)\left(\frac{\sqrt{25}}{12} \times 4600 \times 750\right) & = 12250000\ N = 12250\ kN \end{cases}$$

$$V_c = 5750\ kN$$

$$ØV_c = 0.75 \times 5750 = 4312.5\ kN \quad > V_u = 3568.16\ kN \rightarrow OK$$

Step 3: Check for One way Shear

$$\text{The distance the footing extends to each side from the column face} = \frac{3.5 - 0.4}{2} = 1.55\ m$$

$$Tributary\ area = (1.55 - 0.75) \times 3.5 = 2.8\ m^2$$

$$V_u = Tributary\ area \times q_{nu} = 2.8 \times 326.53 = 914.23\ kN$$

$$V_c = \frac{\sqrt{f_c'}}{6} bd = \frac{\sqrt{25}}{6} \times 3500 \times 750 = 2187500\ N = 2187.5\ kN$$

$$\text{Ø}V_c = 0.75 \times 2187.5 = 1640.63\ kN > V_u = 914.23\ kN \rightarrow OK$$

Step 4: Design Reinforcement

$$x = \frac{L - c_2}{2} = \frac{3.5 - 0.4}{2} = 1.55\ m$$

$$w_u = q_{nu} b = 326.53 \times 3.5 = 1142.83\ kN/m$$

$$M_u = w_u \frac{x^2}{2} = 1142.83\ \frac{1.55^2}{2} = 1372.83\ kN.m$$

$$R_n = \frac{M_u}{\text{Ø}bd^2} = \frac{1372.83 \times 10^6}{0.9 \times 3500 \times 750^2} = 0.77481$$

$$\rho = \frac{0.85 f_c'}{f_y}\left(1 - \sqrt{1 - \frac{4R_n}{1.7 f_c'}}\right) = \frac{0.85 \times 25}{420}\left(1 - \sqrt{1 - \frac{4 \times 0.77481}{1.7 \times 25}}\right) = 0.00188$$

$$A_{s\,req.} = \rho \times b \times d = 0.00188 \times 3500 \times 750 = 4934.2\ mm^2$$

$$A_{s\,min} = 0.0018 \times bh = 0.0018 \times 3500 \times 850 = 5355\ mm^2$$

Since $A_{s\,min} > A_{s\,req}$ ➔ use $A_{s\,min}$

Using Ø25 ➔ A_b = 491 mm^2 ➔ # bars = 5355/491 = 10.9

Use 11 Ø 25 ➔ $A_{s\,prov}$ = 5400 mm^2 ➔ ρ_{prov}= 5400/(3500 × 850) = 0.00182

$$\rho_{max} = \left(\frac{0.85\beta_1 f_c'}{f_y}\right)\left(\frac{3}{8}\right) = \left(\frac{0.85 \times 0.85 \times 25}{420}\right)\left(\frac{3}{8}\right) = 0.0161$$

Since ρ_{prov}=0.00182 < ρ_{max}= 0.0161 ➔ steel yielded, and it is tension controlled

$$s = \frac{L - 2c - d_b}{\#bars - 1} = \frac{3500 - 2 \times 75 - 25}{11 - 1} = 332.5\ mm$$

$$s_{max} = \min(3h, 450) = \min(3 \times 850, 450) = 450\ mm\ > s\ (OK)$$

Step 5: Check for development length l_d

$$\lambda = 1.0 \qquad always\ normal\ weight\ concrete\ in\ footings$$

$$\Psi_t = 1.0 \quad alway\ 1.0\ since\ the\ bars\ are\ at\ bottom\ in\ footings$$

$$\Psi_e = 1.0 \qquad uncoated$$

$$\Psi_s = 1.0 \qquad d_b = 25 \geq 22$$

$$K_{tr} = 0 \quad always\ 0\ since\ no\ shear\ reinforcemnt\ in\ footing$$

$$c_b = min \begin{cases} distance\ to\ bar\ centroid = cover + \dfrac{d_b}{2} = 75 + 12.5 = 87.5\ mm \\ \dfrac{1}{2}\ center\ to\ center\ bar\ spacing = \dfrac{1}{2}(332.5) = 166.25\ mm \end{cases}$$

$$c_b = 87.5\ mm$$

$$\frac{c_b + K_{tr}}{d_b} = \frac{87.5 + 0}{25} = 3.5 > 2.5 \rightarrow use\ 2.5$$

$$l_d = \left[\frac{f_y}{1.1\lambda\sqrt{f_c'}} \frac{\Psi_t \Psi_e \Psi_s}{\left(\frac{c_b + K_{tr}}{d_b}\right)}\right] d_b = \left[\frac{420}{1.1 \times 1 \times \sqrt{35}} \frac{1.0 \times 1.0 \times 1.0}{2.5}\right] d_b$$

$$l_d = 30.55 d_b = 30.55 \times 25 = 763.64\ mm$$

$$available\ length = x - c = 1550 - 75 = 1475\ mm\ > l_d\ (OK)$$

Step 6: Design Dowels

$$P_{all\ col} = \text{Ø}\left(0.85 f_{c,col}' A_1\right) = 0.65\left(0.85 \times 25 \times (400 \times 400)\right) = 2210000\ N = 2210\ kN$$

$$\sqrt{\frac{A_2}{A_1}} = \sqrt{\frac{3500 \times 3500}{400 \times 400}} = 8.75 > 2.0 \rightarrow use\ 2.0$$

$$P_{foot} = \text{Ø}\left(0.85 f_{c,foot}' A_1\right)\left(\sqrt{\frac{A_2}{A_1}} \leq 2\right) = 0.65\left(0.85 \times 25 \times (400 \times 400)\right)(2) = 4420000N = 4420kN$$

$$P_u = 1.4 \times 1400 + 1.7 \times 1200 = 4000\ kN$$

$$Excess\ load = P_u - \min\left(P_{all\ col}, P_{all\ foot}\right) = 4000 - 2210 = 1790\ kN$$

$$A_s = \frac{Excess\ load}{\text{Ø} f_y} = \frac{1790 \times 10^3}{0.65 \times 420} = 6557\ mm^2$$

Use 14 Ø 25 for dowels, $A_{s\ prov}$ = 6874 mm^2

Step 7: Development length of Dowels

$$\Psi_r = 1.0 \qquad \textit{assumed since no available information}$$

$$\lambda = 1.0 \qquad \textit{always normal weight concrete in footings}$$

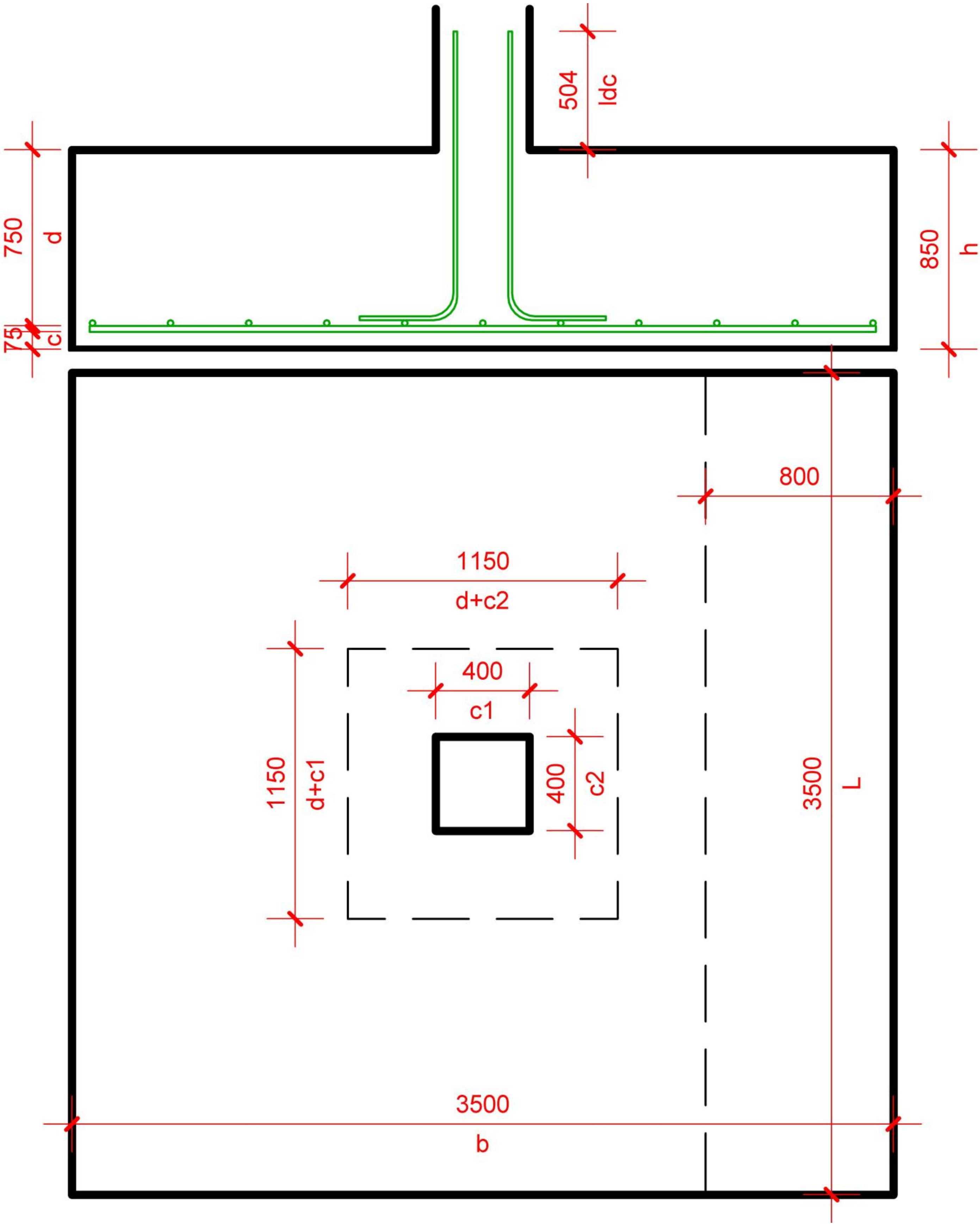
Up into the Column:

$$l_{dc} = \max\left(\frac{0.24 f_y \Psi_r}{\lambda\sqrt{f'_{c,col}}} d_b, 0.043 f_y \Psi_r d_b, 200\right) = \max\left(\frac{0.24 \times 420 \times 1}{1\sqrt{25}} \times 25, 0.043 \times 420 \times 1 \times 25, 200\right)$$

$$l_{dc} = \max(504, 451.5, 200) = 504\ mm$$

Down into the footing:

The same since they have the same f_c'


504
ldc
750
d
75
cl
850
h
800
1150
d+c2
400
c1
1150
d+c1
400
c2
3500
L
3500
b

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