Example 1: Design of a square footing for different codes

1 Description of the problem

An example is carried out to design a spread footing according to EC 2, DIN 1045, ACI and ECP.

A square footing of 0.5 [m] thickness with dimensions of 2.6 [m] × 2.6 [m] is chosen. The footing is supported to a column of 0.4 [m] × 0.4 [m], reinforced by 8 Φ 16 and carries a load of 1276 [kN]. The footing rests on *Winkler* springs that have modulus of subgrade reaction of k_s = 40 000 [kN/ m^3]. A thin plain concrete of thickness 0.15 [m] is chosen under the footing and is not considered in any calculations.

2 Footing material and section

The footing material and section are supposed to have the following parameters:

2.1 Material properties

Concrete grade according to ECP	C 250			
Steel grade according to ECP	S 36/52			
Concrete cube strength	f_{cu} = 250	[kg/ cm^2]	= 25	[MN/ m^2]
Concrete cylinder strength	$f0_c = 0.8\ f_{cu}$	[-]	= 20	[MN/ m^2]
Compressive stress of concrete	f_c = 95	[kg/ cm^2]	= 9.5	[MN/ m^2]
Tensile stress of steel	f_s = 2000	[kg/ cm^2]	= 200	[MN/ m^2]
Reinforcement yield strength	f_y = 3600	[kg/ cm^2]	= 360	[MN/ m^2]
Young's modulus of concrete	$E_b = 3 \times 10^7$	[kN/ m^2]	= 30000	[MN/ m^2]
Poisson's ratio of concrete	ν_b = 0.15	[-]		
Unit weight of concrete	γ_b = 0.0	[kN/ m^3]		

Unit weight of concrete is chosen γ_b = 0.0 to neglect the own weight of the footing.

2.2 Section properties

Width of the section to be designed	b = 1.0	[m]
Section thickness	t = 0.50	[m]
Concrete cover + 1/2 bar diameter	c = 5	[cm]
Effective depth of the section	$d = t - c$ = 0.45	[m]
Steel bar diameter	Φ = 18	[mm]

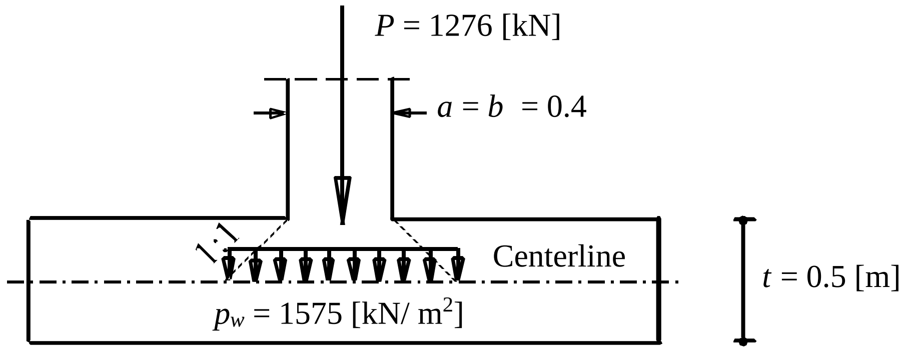
3 Analysis of the footing

To carry out the analysis, the footing is subdivided into 64 square elements. Each has dimensions of 0.325 [m] × 0.325 [m] as shown in Figure 13.

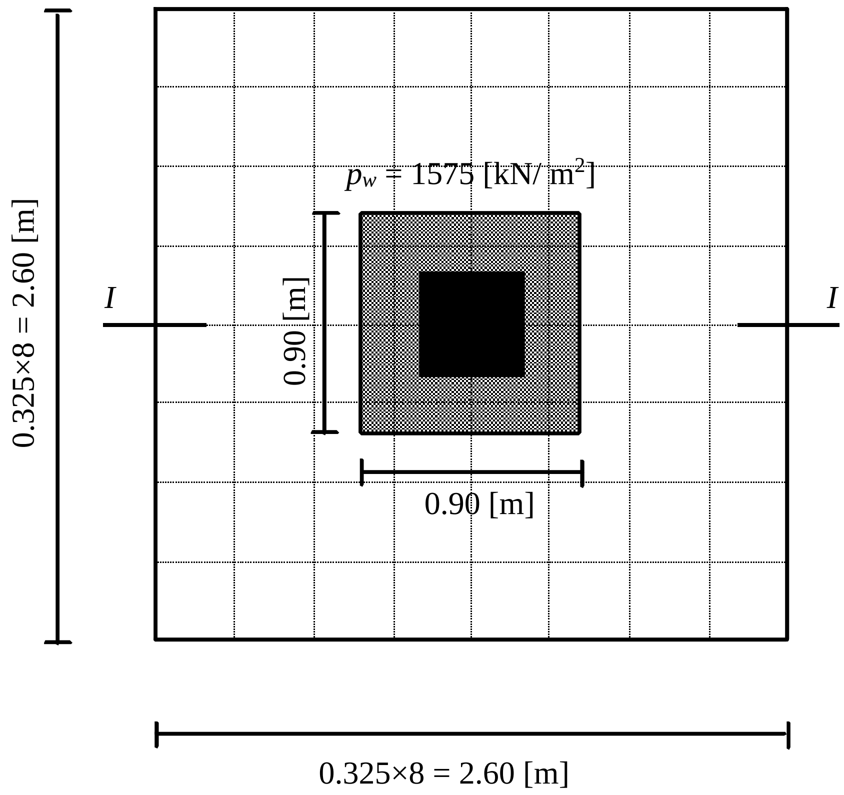
If a point load represents the column load on the mesh of finite elements, the moment under the column will be higher than the real moment. In addition, to take effect of the load distribution through the footing thickness, the column load is distributed outward at 45 [°] from the column until reaching the center line of the footing. Therefore, using the option "Distribute column load" when defying load data in *ELPLA*, distributes the column load automatically at center line of the footing on an area of $(a + d)^2$ as shown in Figure 13.

Figure 14 shows the calculated contact pressure q [kN/ m^2], while Figure 15 shows the bending moment m_x [kN.m/ m] at the critical section *I-I* of the footing.

For the different codes, the footing is designed to resist the bending moment and punching shear. Then, the required reinforcement is obtained. Finally, a comparison among the results of the four codes is presented.

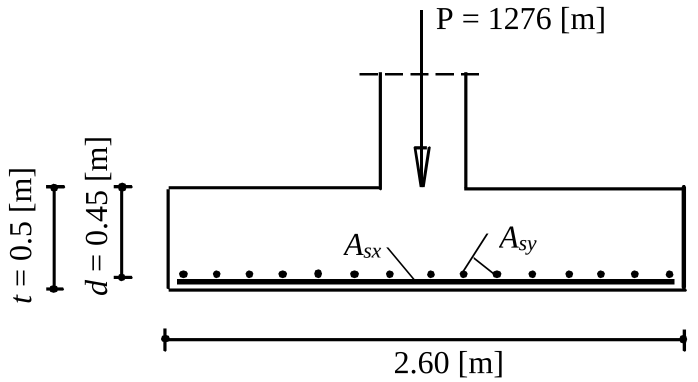


b) Section *I-I*



a) Plan

Figure 13 Footing dimensions and distribution of column load through the footing



Section *I-I*

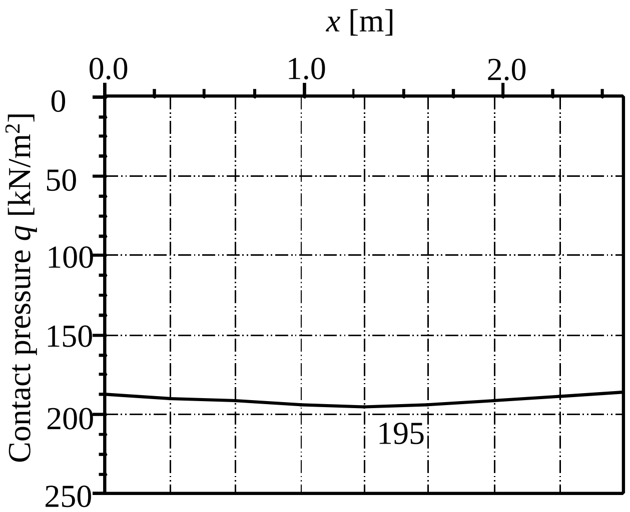


Figure 14 Contact pressure q [kN/ m^2] at section *I-I*

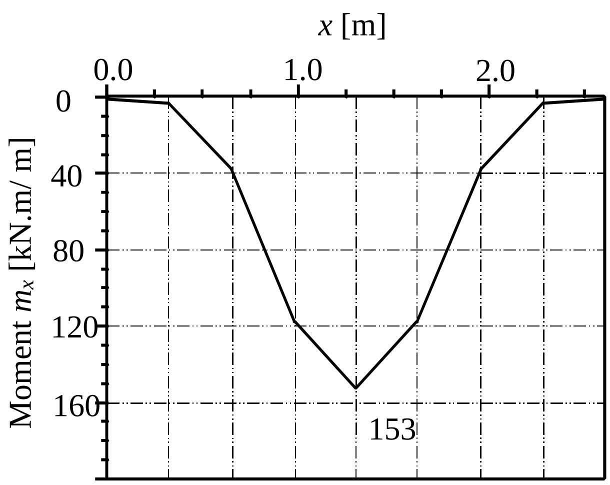


Figure 15 Moment m_x [kN.m/ m] at section *I-I*

4 Design for EC 2

4.1 Design for flexure moment

Material

Concrete grade	C 250 (ECP) = C 20/25 (EC 2)
Steel grade	S 36/52 (ECP) = BSt 360 (EC 2)
Characteristic compressive cylinder strength of concrete	$f_{ck} = 20$ [MN/ m^2]
Characteristic tensile yield strength of reinforcement	$f_{yk} = f_y = 360$ [MN/ m^2]
Partial safety factor for concrete strength	$\gamma_c = 1.5$
Design concrete compressive strength	$f_{cd} = f_{ck}/\gamma_c = 20/1.5 = 13.33$ [MN/ m^2]
Partial safety factor for steel strength	$\gamma_s = 1.15$
Design tensile yield strength of reinforcing steel	$f_{yd} = f_{yk}/\gamma_s = 360/1.15 = 313$ [MN/ m^2]

Factored moment

Moment per meter at critical section obtained from analysis $M = 153$ [kN.m] = 0.153 [MN.m]
Total load factor for both dead and live loads $\gamma = 1.5$
Factored moment $M_{sd} = \gamma M = 1.5 \times 0.153 = 0.2295$ [MN.m]

Geometry

Effective depth of the section	$d = 0.45$ [m]
Width of the section to be designed	$b = 1.0$ [m]

Check for section capacity

The limiting value of the ratio x/d is $\xi_{\lim} = 0.45$ for $f_{ck} \leq 35$ [MN/ m^2].
The normalized concrete moment capacity $\mu_{sd,\lim}$ as a singly reinforced section is

$$\mu_{sd,\,lim} = 0.8\xi_{\lim}(1 - 0.4\xi_{\lim})$$

$$\mu_{sd,\,lim} = 0.8 \times 0.45(1 - 0.4 \times 0.45) = 0.295$$

The normalized design moment μ_{sd} is

$$\mu_{sd} = \frac{M_{sd}}{bd^2(0.85 f_{cd})}$$

$$\mu_{sd} = \frac{0.2295}{1.0 \times 0.45^2(0.85 \times 13.33)} = 0.1$$

$\mu_{sd} = 0.1 < \mu_{sd,\lim} = 0.295$, then the section is designed as singly reinforced section.

Determination of tension reinforcement

The normalized steel ratio ω is

$$\omega = 1 - \sqrt{1 - 2\mu_{sd}}$$

$$\omega = 1 - \sqrt{1 - 2 \times 0.1} = 0.106$$

The required area of steel reinforcement per meter A_s is

$$A_s = \omega \left(\frac{(0.85 f_{cd})bd}{f_{yd}} \right)$$

$$A_s = 0.106 \left(\frac{(0.85 \times 13.33) \times 1.0 \times 0.45}{313} \right) = 0.001727 [\mathrm{m}^2/\,\mathrm{m}]$$

$$A_s = 17.27\ [\mathrm{cm}^2/\,\mathrm{m}]$$

Chosen steel 7 Φ 18/ m = 17.8 [cm^2/ m]

4.2 Check for punching shear

The critical section for punching shear is at a distance r = 1.5 d around the circumference of the column as shown in Figure 16.

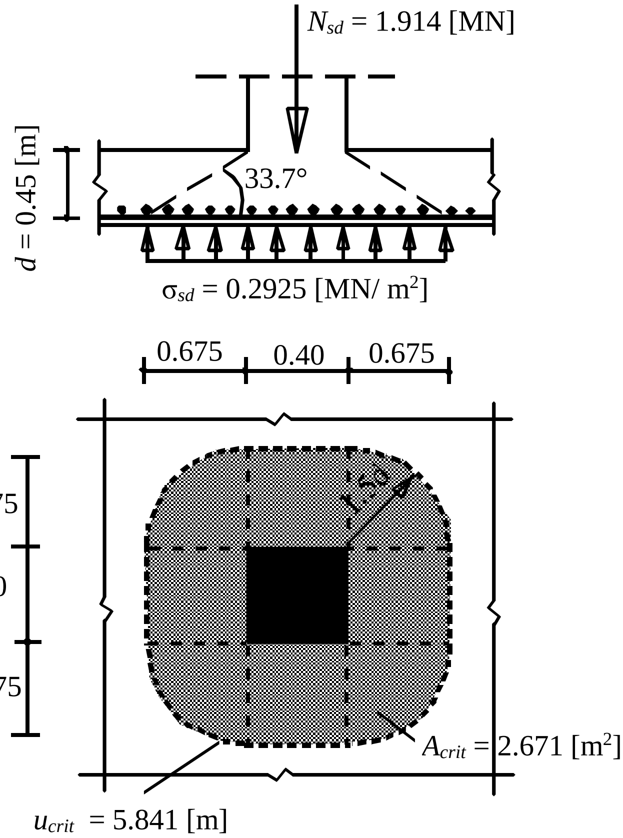


Figure 16 Critical section for punching shear according to EC 2

Geometry (Figure 16)

Effective depth of the section $d = d_x = d_y = 0.45$ [m]
Column side $c_x = c_y = 0.4$ [m]
Distance of critical punching section from circumference of the column
$r = 1.5\ d = 1.5 \times 0.45 = 0.675$ [m]
Area of critical punching shear section
$A_{crit} = c_x^{\,2} + 4\ r\ c_x + \pi\ r^2 = (0.4)^2 + 4 \times 0.675 \times 0.4 + \pi\ 0.675^2 = 2.671$ [m^2]
Perimeter of critical punching shear section $u_{crit} = 4c_x + 2\ \pi\ r = 4 \times 0.4 + 2\ \pi\ 0.675 = 5.841$ [m]
Width of punching section $b_x = b_y = c_x + 2r = 0.4 + 2 \times 0.675 = 1.75$ [m]
Correction factor (where no eccentricity is expected) $\beta = 1.0$
Coefficient for consideration of the slab thickness $k = 1.6 - d = 1.6 - 0.45 = 1.15$ [m] > 1.0 [m]
Reinforcement under the column per meter $A_s = 17.8$ [cm^2/ m]
Reinforcement at punching section $A_{sx} = A_{sy} = b_x\ A_s = 1.75 \times 17.8 = 31.15$ [cm^2]
Steel ratio $\rho_1 = \rho_{1x} = \rho_{1y} = A_{sx} / (b_y\ d_x) = (31.15 \times 10^{-4}) / (1.75 \times 0.45) = 0.004 = 0.4$ [%]

Loads and stresses

Column load	N = 1276 [kN] = 1.276 [MN]
Soil pressure under the column	σ_o= 195 [kN/ m^2] = 0.195 [MN/ m^2]
Total load factor for both dead and live loads	γ = 1.5
Factored column load	$N_{sd} = \gamma\ N$ = 1.5 × 1.276 = 1.914 [MN]
Factored upward soil pressure under the column	$\sigma_{Sd} = \gamma\ \sigma_o$ = 1.5 × 0.195 = 0.2925 [MN/ m^2]

Main value of shear strength for concrete C 20/25 according to Table 1

τ_{Rd} = 1.2 × 0.24 = 0.288 [MN/ m]

Check for section capacity

The punching force at ultimate design load V_{Sd} is

$$V_{Sd} = N_{sd} - \sigma_{Sd}\, A_{crit}$$

$$V_{Sd} = 1.914 - 0.2925 \times 2.671 = 1.133 \text{ [MN]}$$

The design value of the applied shear ν_{Sd} is

$$\nu_{Sd} = \frac{V_{Sd}\beta}{u_{crit}}$$

$$\nu_{Sd} = \frac{1.133 \times 1.0}{5.841} = 0.194 \text{[MN/ m]}$$

Design shear resistance from concrete alone ν_{Rd1} is

$$\nu_{Rd1} = \tau_{Rd}\, k(1.2 + 40\rho_1)d$$

$$\nu_{Rd1} = 0.288 \times 1.15\ (1.2 + 40 \times 0.004)\ 0.45 = 0.203 \text{ [MN/ m]}$$

ν_{Rd1} = 0.203 [MN/ m] > ν_{sd} = 0.194 [MN/ m], the section is safe for punching shear.

5 Design for DIN 1045

5.1 Design for flexure moment

Material

Concrete grade	C 250 (ECP) = B 25 (DIN 1045)
Steel grade	S 36/52 (ECP) = BSt 360 (DIN 1045)
Concrete compressive strength	β_R = 17.5 [MN/ m^2]
Tensile yield strength of steel	β_S = 360 [MN/ m^2]
Concrete strength reduction factor for sustained loading	α_R = 0.95
Safety factor	γ = 1.75

Moment

Moment per meter at critical section obtained from analysis M_s = 153 [kN.m] = 0.153 [MN.m]

Geometry

Effective depth of the section	h = 0.45 [m]
Width of the section to be designed	b = 1.0 [m]

Check for section capacity

The normalized design moment m_s is

$$m_s = \frac{M_s}{bh^2\left(\dfrac{\alpha_R\beta_R}{\gamma}\right)}$$

$$m_s = \frac{0.153}{1.0\times 0.45^2\left(\dfrac{0.95\times 17.5}{1.75}\right)} = 0.07953$$

The limiting value of the ratio k_x of neutral axis to effective depth is

$$k_x = \left(\frac{\varepsilon_{b1}}{\varepsilon_{b1} - \varepsilon_{s2}}\right)$$

$$k_x = \left(\frac{0.0035}{0.0035 + 0.003}\right) = 0.53846$$

The normalized concrete moment capacity m^*_s as a singly reinforced section is

$$m^*_s = \chi k_x (1 - \frac{\chi}{2} k_x)$$

$$m^*_s = 0.8 \times 0.53846(1 - \frac{0.8}{2} \times 0.53846) = 0.337987$$

$m_s = 0.07953 < m^*_s = 0.337987$, then the section is designed as singly reinforced section.

Determination of tension reinforcement

The normalized steel ratio ω_M is

$$\omega_M = 1 - \sqrt{1 - 2m_s}$$

$$\omega_M = 1 - \sqrt{1 - 2 \times 0.07953} = 0.08297$$

The required area of steel reinforcement per meter A_s is

$$A_s = \omega_M \left(\frac{(\alpha_R \beta_R) bh}{\beta_S} \right)$$

$$A_s = 0.08297 \left(\frac{(0.95 \times 17.5) 1.0 \times 0.45}{360} \right) = 0.001724 [\mathrm{m}^2 / \mathrm{m}]$$

$$A_s = 17.24 \ [\mathrm{cm}^2 / \mathrm{m}]$$

Chosen steel 7 Φ 18/ m = 17.8 [cm^2/ m]

5.2 Check for punching shear

The critical section for punching shear is a circle of diameter d_r = 0.902 [m] around the circumference of the column as shown in Figure 17.

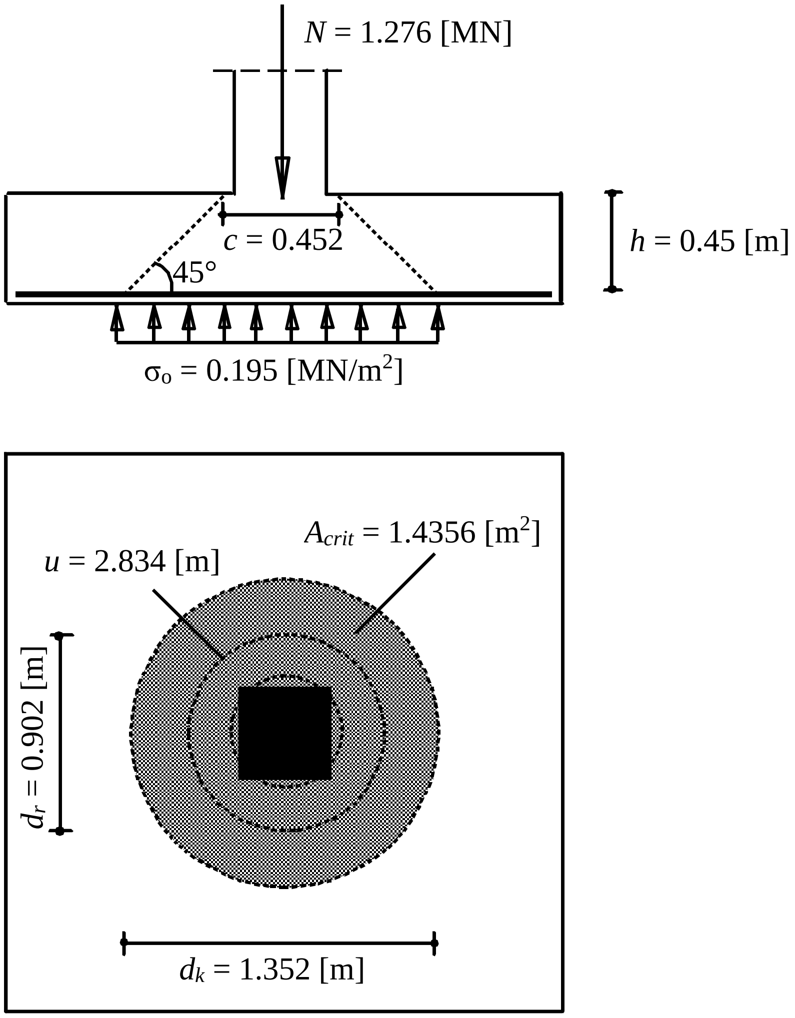


Figure 17 Critical section for punching shear according to DIN 1045

Geometry (Figure 17)

Effective depth of the section	h = 0.45 [m]
Column side	$c_x = c_x$ = 0.4 [m]
Average diameter of the column	$c = 1.13 \times 0.4 = 0.452$ [m]
Diameter of loaded area	$d_k = 2\,h + c = 2 \times 0.45 + 0.452 = 1.352$ [m]
Diameter of critical punching shear section	$d_r = c + h = 0.452 + 0.45 = 0.902$ [m]
Area of critical punching shear section	$A_{crit} = \pi\, d_k^2/ 4 = \pi\ 1.352^2/ 4 = 1.4356$ [m^2]
Perimeter of critical punching shear section	$u = \pi\, d_r = \pi\ 0.902 = 2.834$ [m]
Reinforcement in x-direction	$A_{sx} = A_{sy} = 0.00178$ [m^2/ m]

Loads and stresses

Column load $N = 1276$ [kN] = 1.276 [MN]
Soil pressure under the column $\sigma_o = 195$ [kN/ m^2] = 0.195 [MN/ m^2]
Main value of shear strength for concrete B 25 according to Table 2
$\tau_{011} = 0.5$ [MN/ m^2]
Factor depending on steel grade according to Table 6 $\alpha_s = 1.3$

Check for section capacity

The punching shear force Q_r is

$$Q_r = N - \sigma_o A_{crit}$$

$$Q_r = 1.276 - 0.195 \times 1.4356 = 0.9961 \text{ [MN]}$$

The punching shear stress τ_r is

$$\tau_r = \frac{Q_r}{uh}$$

$$\tau_r = \frac{0.9961}{2.834 \times 0.45} = 0.781 [\text{MN/ m}^2]$$

Reinforcement grade μ_g is

$$\mu_g = \frac{A_{sx} + A_{sy}}{2h}$$

$$\mu_g = \frac{0.00178 + 0.00178}{2 \times 0.45} = 0.00396 = 0.396 [\%]$$

Coefficient for consideration of reinforcement κ_1 is

$$\kappa_1 = 1.3 \alpha_s \sqrt{\mu_g}$$

$$\kappa_1 = 1.3 \times 1.3 \sqrt{0.396} = 1.063$$

The allowable concrete punching strength τ_{r1} [MN/ m^2] is given by

$$\tau_{r1} = \kappa_1 \tau_{011}$$

$$\tau_{r1} = 1.063 \times 0.5 = 0.532 [\text{MN/ m}^2]$$

τ_{r1} = 0.532 [MN/ m^2] < τ_r = 0.781 [MN/ m^2], the section is unsafe for punching shear. Such situation can be conveniently rectified by increasing the depth of the footing. It will be noticed that the required increase here is 10 [cm].

6 Design for ACI

6.1 Design for flexure moment

Material

Concrete grade	C 250 (ECP)
Steel grade	S 36/52 (ECP)
Specified compressive strength of concrete	$f0_c$ = 20 [MN/ m^2]
Specified yield strength of flexural reinforcement	f_y = 360 [MN/ m^2]
Strength reduction factor for flexure	φ = 0.9

Factored moment

Moment per meter at critical section obtained from analysis M = 153 [kN.m] = 0.153 [MN.m]

Total load factor for both dead and live loads	γ = 1.5
Factored moment	$M_u = \gamma M$ = 1.5 × 0.153 = 0.2295 [MN.m]

Geometry

Effective depth of the section	d = 0.45 [m]
Width of the section to be designed	b = 1.0 [m]

Check for section capacity

The depth of the compression block a is

$$a = d - \sqrt{d^2 - \frac{2|M_u|}{(\alpha f_c')\varphi b}}$$

$$a = 0.45 - \sqrt{0.45^2 - \frac{2|0.2295|}{(0.85 \times 20)0.9 \times 1.0}} = 0.0347[\mathrm{m}]$$

The factor for obtaining depth of compression block in concrete β_1 is

$$\beta_1 = 0.85 - 0.05\left(\frac{f_c' - 28}{7}\right), 0.65 \le \beta_1 \le 0.85$$

$$\beta_1 = 0.85 - 0.05\left(\frac{20 - 28}{7}\right) = 0.91 > 0.85$$

$$\beta_1 = 0.85$$

The depth of neutral axis at balanced condition c_b is

$$c_b = \left(\frac{\varepsilon_{max}}{\varepsilon_{max} + \dfrac{f_y}{E_s}} \right) d$$

$$c_b = \left(\frac{0.003}{0.003 + \dfrac{360}{203900}} \right) 0.45 = 0.283 [\text{m}]$$

The maximum allowed depth of compression block a_{max} is

$$a_{max} = 0.75 \beta_1 c_b$$

$$a_{max} = 0.75 \times 0.85 \times 0.283 = 0.18 [\text{m}]$$

a_{max} = 0.18 [m] > a = 0.0347 [m], then the section is designed as singly reinforced section.

Determination of tension reinforcement

$$A_s = \frac{M_u}{\varphi f_y \left(d - \dfrac{a}{2} \right)}$$

$$A_s = \frac{0.2295}{0.9 \times 360 \left(0.45 - \dfrac{0.0347}{2} \right)} = 0.001637 [\text{m}^2/\text{m}]$$

A_s = 16.37 [cm^2/ m]

Chosen steel 7 Φ 18/ m = 17.8 [cm^2/ m]

6.2 Check for punching shear

The critical punching shear section on a perimeter at a distance $d/2 = 0.225$ [m] from the face of the column is shown in Figure 18.

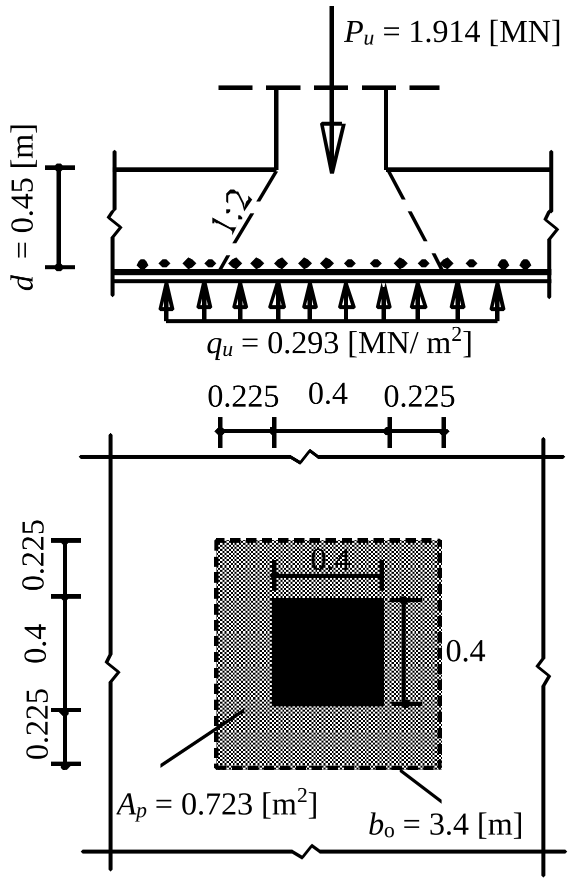


Figure 18 Critical section for punching shear according to ACI

Geometry (Figure 18)

Effective depth of the section	$d = 0.45$ [m]
Column side	$a_c = b_c = 0.4$ [m]
Area of critical punching shear section	$A_p = (a_c + d)^2 = (0.4 + 0.45)^2 = 0.723$ [m^2]
Perimeter of critical punching shear section	$b_o = 4\,(a_c + d) = 4\,(0.4 + 0.45) = 3.4$ [m]
Ratio of long side to short side of the column	$\beta_c = 1.0$

Loads and stresses

Specified compressive strength of concrete	f'_c = 20 [MN/ m^2]
Strength reduction factor for punching shear	φ = 0.85
Total load factor for both dead and live loads	γ = 1.5
Column load	P_c = 1276 [kN] = 1.276 [MN]
Soil pressure under the column	q = 195 [kN/ m^2] = 0.195 [MN/ m^2]
Factored column load	$P_u = \gamma\, P_c$ = 1.5 × 1.276 = 1.914 [MN]
Factored soil pressure under the column	$q_u = \gamma\, q$ = 1.5 × 0.195 = 0.293 [MN/ m^2]

Check for section capacity

The nominal concrete punching strength ν_c is

$$\nu_c = 0.083\left(2+\frac{4}{\beta_c}\right)\sqrt{f'_c}, \leq 0.34\sqrt{f'_c}$$

$$\nu_c = 0.083\left(2+\frac{4}{1.0}\right)\sqrt{20}, \leq 0.34\sqrt{20}$$

$$\nu_c = 1.521 \text{ [MN/ m}^2\text{]}$$

The allowable concrete punching shear capacity V_c is

$$V_c = \nu_c\, b_o d$$

$$V_c = 1.521 \times 3.4 \times 0.45 = 2.327 \text{ [MN]}$$

The factored punching shear force V_u is

$$V_u = P_u - q_u\, A_p$$

$$V_u = 1.914 - 0.293 \times 0.723 = 1.702 \text{ [MN]}$$

The available shear strength is

$$\varphi\, V_c = 0.85 \times 2.327 = 1.978 \text{ [MN]}$$

$\varphi\, V_c$ = 1.978 [MN] > V_u = 1.702 [MN], the section is safe for punching shear.

7 Design for ECP (limit state method)

7.1 Design for flexure moment

Material

Concrete grade	C 250
Steel grade	S 36/52
Concrete cube strength	f_{cu} = 25 [MN/ m^2]
Reinforcement yield strength	f_y = 360 [MN/ m^2]
Partial safety factor for concrete strength	γ_c =1.5
Partial safety factor for steel strength	γ_s = 1.15

Factored moment

Moment per meter at critical section obtained from analysis M = 153 [kN.m] = 0.153 [MN.m]

Total load factor for both dead and live loads	γ = 1.5
Factored moment	$M_u = \gamma M = 1.5 \times 0.153 = 0.2295$ [MN.m]

Geometry

Effective depth of the section	d = 0.45 [m]
Width of the section to be designed	b = 1.0 [m]

Check for section capacity

The max value of the ratio ξ_{max} is

$$\xi_{max} = \beta\left(\frac{\varepsilon_{max}}{\varepsilon_{max} + \dfrac{f_y}{\gamma_s E_s}}\right)$$

$$\xi_{max} = \frac{2}{3}\left(\frac{0.003}{0.003 + \dfrac{360}{1.15 \times 200000}}\right) = 0.438$$

The max concrete capacity R_{max} as a singly reinforced section is

$$R_{max} = 0.544\, \xi_{max}\, (1 - 0.4\, \xi_{max})$$

$$R_{max} = 0.544 \times 0.438\, (1 - 0.4 \times 0.438) = 0.197$$

The maximum moment $M_{u,\ max}$ as a singly reinforced section is

$$M_{u,\ max} = R_{max} \frac{f_{cu}}{\gamma_c} b d^2$$

$$M_{u,\ max} = 0.197 \times \frac{25}{1.5} \times 1.0 \times 0.45^2 = 0.665 [\text{MN.m}]$$

$M_{u,\ max}$ = 0.665 > M_u = 0.2295, then the section is designed as singly reinforced section.

Determination of tension reinforcement

The concrete capacity R_1 is

$$R_1 = \frac{M_u}{f_{cu} b d^2}$$

$$R_1 = \frac{0.2295}{25 \times 1.0 \times 0.45^2} = 0.045$$

The normalized steel ratio ω is

$$\omega = 0.521\left(1 - \sqrt{1 - 4.41 R_1}\right)$$

$$\omega = 0.521\left(1 - \sqrt{1 - 4.41 \times 0.045}\right) = 0.055$$

The required area of steel reinforcement per meter A_s is

$$A_s = \omega \frac{f_{cu}}{f_y} b d$$

$$A_s = 0.055 \times \frac{25}{360} \times 1.0 \times 0.45 = 0.001719 [\text{m}^2/\text{ m}]$$

$$A_s = 17.19\ [\text{cm}^2/\text{ m}]$$

Chosen steel 7 Φ 18/ m = 17.8 [cm^2/ m]

7.2 Check for punching shear

The critical punching shear section on a perimeter at a distance $d/2 = 0.225$ [m] from the face of the column is shown in Figure 19.

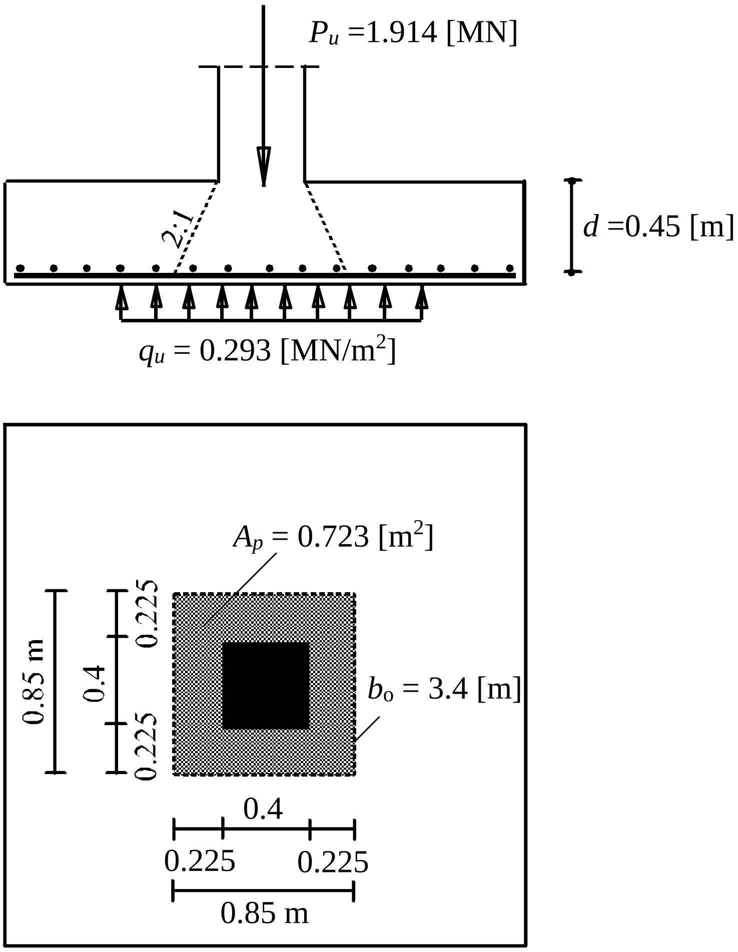


Figure 19 Critical section for punching shear according to ECP

Geometry (Figure 19)

Effective depth of the section	$d = 0.45$ [m]
Column side	$a = b = 0.4$ [m]
Area of critical punching shear section	$A_p = (a + d)^2 = (0.4 + 0.45)^2 = 0.723$ [m^2]
Perimeter of critical punching shear section	$b_o = 4\,(a + d) = 4\,(0.4 + 0.45) = 3.4$ [m]

Loads and stresses

Concrete cube strength	f_{cu} = 25 [MN/ m^2]
Total load factor for both dead and live loads	γ = 1.5
Partial safety factor for concrete strength	γ_c = 1.5
Column load	P = 1276 [kN] = 1.276 [MN]
Soil pressure under the column	q_o = 195 [kN/ m^2] = 0.195 [MN/ m^2]
Factored column load	$P_u = \gamma\ P$ = 1.5 × 1.276 = 1.914 [MN]
Factored soil pressure under the column	$q_u = \gamma\ q_o$ = 1.5 × 0.195 = 0.293 [MN/ m^2]

Check for section capacity

The factored punching shear force Q_{up} is

$$Q_{up} = P_u - q_u\, A_p$$

$$Q_{up} = 1.914 - 0.293 \times 0.723 = 1.702 \text{ [MN]}$$

The punching shear stress q_{up} is

$$q_{up} = \frac{Q_{up}}{b_o d}$$

$$q_{up} = \frac{1.702}{3.4 \times 0.45} = 1.112 \text{ [MN/ m}^2\text{]}$$

The nominal concrete punching strength q_{cup} is

$$q_{cup} = 0.316\left(0.5 + \frac{a}{b}\right)\sqrt{\frac{f_{cu}}{\gamma_c}}, \leq 0.316\sqrt{\frac{f_{cu}}{\gamma_c}}$$

$$q_{cup} = 0.316\left(0.5 + \frac{0.4}{0.4}\right)\sqrt{\frac{25}{1.5}}, \leq 0.316\sqrt{\frac{25}{1.5}}$$

$$q_{cup} = 1.29 \text{ [MN/ m}^2\text{]}$$

q_{cup} = 1.29 [MN/ m^2] > q_{up} = 1.112 [MN/ m^2], the section is safe for punching shear.

8 Design for ECP (working stress method)

8.1 Design for flexure moment

Material

Concrete grade	C 250	
Steel grade	S 36/52	
Compressive stress of concrete	f_c = 95 [kg/ cm^2]	= 9.5 [MN/ m^2]
Tensile stress of steel	f_s = 2000 [kg/ cm^2]	= 200 [MN/ m^2]

Moment

Moment per meter at critical section obtained from analysis M = 153 [kN.m] = 0.153 [MN.m]

Geometry

Effective depth of the section	d = 0.45 [m]
Width of the section to be designed	b = 1.0 [m]

Check for section capacity

The value of the ratio ξ is

$$\xi = \left(\frac{n}{n + \frac{f_s}{f_c}} \right)$$

$$\xi = \left(\frac{15}{15 + \frac{200}{9.5}} \right) = 0.416$$

The coefficient k_1 to obtain the section depth at balanced condition is

$$k_1 = \sqrt{\frac{2}{f_c \xi \left(1 - \frac{\xi}{3}\right)}}$$

$$k_1 = \sqrt{\frac{2}{9.5 \times 0.416\left(1 - \frac{0.416}{3}\right)}} = 0.767$$

The maximum depth d_m as a singly reinforced section is

$$d_m = k_1 \sqrt{\frac{M}{b}}$$

$$d_m = 0.767\sqrt{\frac{0.153}{1.0}} = 0.3 [\text{m}]$$

d = 0.45 [m] > d_m = 0.3 [m], then the section is designed as singly reinforced section.

Determination of tension reinforcement

Determine the neutral axis z corresponding to the depth d by iteration from

$$z = \sqrt{\frac{30M(d-z)}{bf_s\left(d - \frac{z}{3}\right)}}$$

$$z = \sqrt{\frac{30 \times 0.153(0.45 - z)}{1.0 \times 200\left(0.45 - \frac{z}{3}\right)}} = 0.134 [\text{m}]$$

The value of the ratio ξ corresponding to the depth d is given by

$$\xi = \frac{z}{d}$$

$$\xi = \frac{0.13}{0.45} = 0.298$$

The coefficient k_2 [MN/ m^2] to obtain the tensile reinforcement for singly reinforced section is

$$k_2 = f_s\left(1-\frac{\xi}{3}\right)$$

$$k_2 = 200\left(1-\frac{0.298}{3}\right) = 180.13$$

The required area of steel reinforcement per meter A_s is

$$A_s = \frac{M}{k_2 d}$$

$$A_s = \frac{0.153}{180.13 \times 0.45} = 0.001888 [\mathrm{m}^2/\mathrm{m}]$$

A_s = 18.88 [cm^2/ m]

Chosen steel 8 Φ 18/ m = 20.4 [cm^2/ m]

8.2 Check for punching shear

The critical punching shear section on a perimeter at a distance $d/2 = 0.225$ [m] from the face of the column is shown in Figure 20.

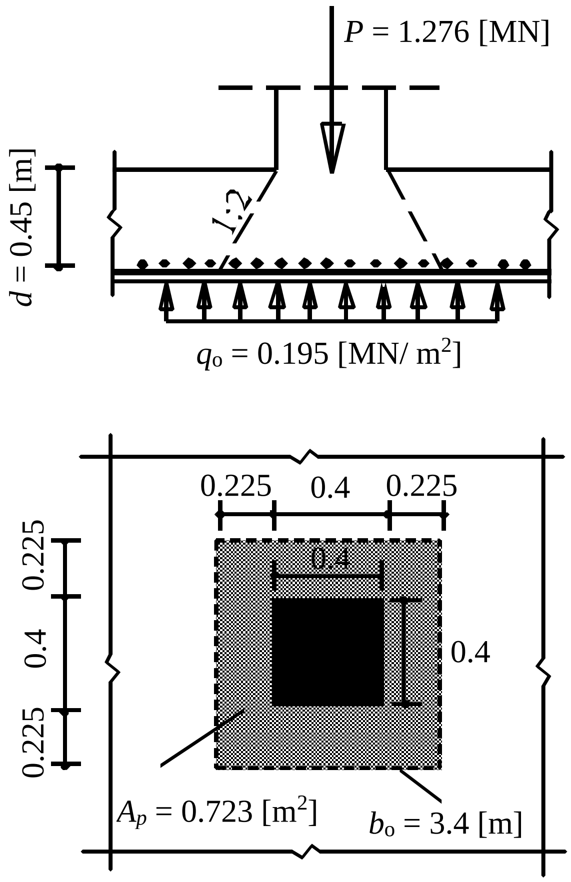


Figure 20 Critical section for punching shear according to ECP

Geometry (Figure 20)

Effective depth of the section	$d = 0.45$ [m]
Column side	$a = b = 0.4$ [m]
Area of critical punching shear section	$A_p = (a + d)^2 = (0.4 + 0.45)^2 = 0.723$ [m^2]
Perimeter of critical punching shear section	$b_o = 4\,(a + d) = 4\,(0.4 + 0.45) = 3.4$ [m]

Loads and stresses

Column load	$P = 1276$ [kN] $= 1.276$ [MN]
Soil pressure under the column	$q_o = 195$ [kN/ m^2] $= 0.195$ [MN/ m^2]

Main value of shear strength for concrete C 250 according to Table 4

$q_{cp} = 0.9$ [MN/ m^2]

Check for section capacity

The punching shear force Q_o is

$$Q_p = P - q_o A_p$$

$$Q_p = 1.276 - 0.195 \times 0.723 = 1.135 \text{ [MN]}$$

The punching shear stress q_p is given by

$$q_p = \frac{Q_p}{b_o d}$$

$$q_p = \frac{1.135}{3.4 \times 0.45} = 0.742 [\text{MN/ m}^2]$$

The allowable concrete punching strength q_{pall} [MN/ m^2] is given by

$$q_{pall} = \left(0.5 + \frac{a}{b}\right) q_{cp}, \leq q_{cp}$$

$$q_{pall} = \left(0.5 + \frac{0.4}{0.4}\right) 0.9, \leq 0.9$$

$$q_{pall} = 0.9 \text{ [MN/ m}^2]$$

$q_{pall} = 0.9$ [MN/ m^2] > $q_p = 0.742$ [MN/ m^2], the section is safe for punching shear.