Pad footing design

Code: **Eurocode**

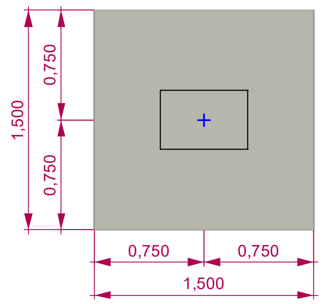
1. Soil parameters

Name	Description	Top level z_i $[m]$	Thickness h_i $[m]$	Density ρ_s $[kg/m^3]$	Angle of shear resistance φ [°]	Cohesion c $[KPa]$	Compression modulus of the soil layer E_s $[KPa]$
EST	Solid, dry, fine sand	0	0,3	1900	34,00	–	50000
BST	Solid, dry, sandy gravel	-0,3	1,3	2100	38,00	–	1*10^{5}
CST	Solid, dry sand	-1,6	20	2000	35,00	–	70000

2. Footing

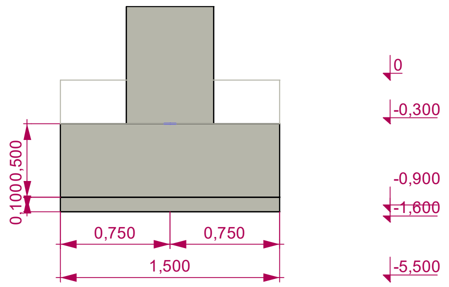
2.1. Footing design parameters

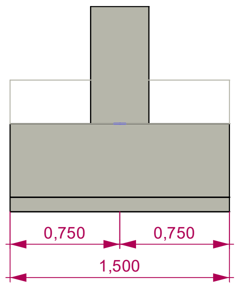
Geometry:



Materials

Concrete: C16/20
f_{ck} = 16 MPa
Density: ρ_C = 2200 kg/m³
Reinforced concrete:
Density: ρ_{RC} = 2500 kg/m³
Rebar steel
Longitudinal rebars: B500A
f_{yk} = 500 MPa
Punching reinforcement:B500A
f_{ywk} = 500 MPa





Embedment depth: $D = 0{,}9$ m

Characteristic value of weight density of materials:

Concrete: $\gamma_{C,k} = \rho_C \cdot g \cdot 10^{-3} = 2200 \cdot 9{,}810 \cdot 10^{-3} = 21{,}582$ kN/m³

Reinforced concrete: $\gamma_{RC,k} = \rho_{RC} \cdot g \cdot 10^{-3} = 2500 \cdot 9{,}810 \cdot 10^{-3} = 24{,}525$ kN/m³

2.2. Footing

Width of pad footing: $B = 1{,}5$ m

Length of pad footing: $L = 1{,}5$ m

Plate thickness $h = 0{,}5$ m

Inclination of the base: $\alpha = 0\,°$

Volume of the footing: $V_f = 1{,}125$ m³

Characteristic value of the weight of the footing: $G_{f,k} = V_f \cdot \gamma_{RC,k} = 1{,}125 \cdot 24{,}525 = 27{,}591$ kN $(\downarrow)$

2.3. Blind concrete

Thickness of the blind concrete: $h_b = 0{,}1$ m

Characteristic value of the weight of blind concrete: $G_{b,k} = B \cdot L \cdot h_b \cdot \gamma_{C,k} = 1{,}5 \cdot 1{,}5 \cdot 0{,}1 \cdot 21{,}582 = 4{,}8559$ kN $(\downarrow)$

2.4. Backfill

Material: Laza, száraz, finom homok (ESL)

Mass density of the backfill: $\rho_{bf} = 1500$ kg/m³

Weight density of the backfill: $\gamma_{bf,k} = \rho_{bf} \cdot g \cdot 10^{-3} = 1500 \cdot 9{,}810 \cdot 10^{-3} = 14{,}715$ kN/m³

Volume of the backfill: $V_{bf} = 0{,}603$ m³

Characteristic value of the weight of backfill: $G_{bf,k} = V_{bf} \cdot \gamma_{bf,k} = 0{,}603 \cdot 14{,}715 = 8{,}8731$ kN $(\downarrow)$

3. Bearing resistance calculation

Design Approach 1 Combination 1: {A1 "+" M1 "+" R1}
Design Approach 1 Combination 2: {A2 "+" M2 "+" R1} (Critical)
Design Approach 2: {A1 "+" M1 "+" R2}
Design Approach 3: {A2 "+" M2 "+" R3} EN-1997-1 Annex A

	Partial factors		
A2	Permanent, unfavourable actions	$\gamma_{G,unfav}$	1
	Permanent, favourable actions	$\gamma_{G,fav}$	1
	Variable, unfavourable actions	$\gamma_{Q,unfav}$	1,3
	Variable, favourable actions	$\gamma_{Q,fav}$	0
M2	Angle of effective shear resistance	γ_{φ}	1,25
	Effective cohesion	γ_{c}	1,25
	Undrained shear strength	γ_{cu}	1,4
	Unconfined strength	γ_{qu}	1,4
	Weight density	γ_{γ}	1
R1	Bearing resistance	$\gamma_{R,v}$	1
	Sliding resistance	$\gamma_{R,h}$	1
	Earth forces	$\gamma_{R,e}$	1

3.1. Design value of parameters of the soil below the foundation

Soil layer density: ρ_s = 2100 kg/m³

Weight density:

$$\gamma' = \rho_s \cdot g \cdot \gamma_\gamma \cdot 10^{-3} = 2100 \cdot 9{,}810 \cdot 1 \cdot 10^{-3} = 20{,}601 \text{ kN/m}^3$$

Angle of shear resistance φ'_k = 38,00 °

Angle of effective shear resistance:

$$\varphi' = \text{Arc tg}\,\frac{\tan\varphi'_k}{\gamma_\varphi} = \text{Arc tg}\,\frac{\tan 38{,}00°}{1{,}25} = 32{,}01\ °$$

Cohesion: c'_k = 0 KPa

Effective cohesion: $c' = \dfrac{c'_k}{\gamma_c} = \dfrac{0}{1{,}25} = 0$ KPa

Critical state angle of shearing resistance: φ_{cv} = 32,00 °

Characteristic effective overburden pressure at the level of the foundation base:

$$q'_k = g \cdot \sum \rho_{s,i} \cdot h_{s,i}$$

$$q'_k = g \cdot (\rho_{s,1} \cdot h_{s,1} + \rho_{s,2} \cdot h_{s,2}) \cdot 10^{-3} = 9{,}810 \cdot (1900 \cdot 0{,}5_{s,1} + 2100 \cdot 0{,}6) \cdot 10^{-3} = 17{,}952 \text{ KPa}$$

3.2. Design value of loads at the top of the footing - Nodal support internal forces

Load case: **[ST1+ST2+ST5+ST6] {1,3*ST3}** (A2(a,b))

Nodal support 1

F_x = 40 kN

$F_y = 10$ kN

$F_z = -980$ kN

$M_x = -20$ kNm

$M_y = 160$ kNm

$V = -F_z = -(-980) = 980$ kN

3.3. Design value of loads at the base of footing

$H_{dx} = F_x = 40$ kN

$H_{dy} = F_y = 10$ kN

$V_d = V + (G_{f,k} + G_{b,k} + G_{bf,k}) \cdot \gamma_{G,unfav} = 980 + (27{,}591 + 4{,}8559 + 8{,}8731) \cdot 1 = 1021{,}3$ kN

Eccentricity of the vertical load (V_d) relative to the center of the footing

$$e_x = \frac{V \cdot e_{0x} + M_y + F_x \cdot (h_b + h) + (G_{f,k} \cdot e_{fx} + G_{bf,k} \cdot e_{bfx}) \cdot \gamma_{G,unfav}}{V_d} =$$

$$= \frac{980 \cdot 0 + 160 + 40 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{1021{,}3} = 0{,}18 \text{ m}$$

$$e_y = \frac{V \cdot e_{0y} - M_x + F_y \cdot (h_b + h) + (G_{f,k} \cdot e_{fy} + G_{bf,k} \cdot e_{bfy}) \cdot \gamma_{G,unfav}}{V_d} =$$

$$= \frac{980 \cdot 0 - (-20) + 10 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{1021{,}3} = 0{,}025 \text{ m}$$

Effective width of the footing:

$B' = b_x - |e_x| \cdot 2 = 1{,}5 - |0{,}18| \cdot 2 = 1{,}14$ m

Effective length of the footing:

$L' = b_y - |e_y| \cdot 2 = 1{,}5 - |0{,}025| \cdot 2 = 1{,}45$ m

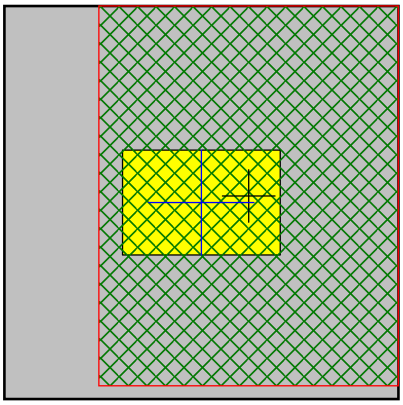
Effective area of the footing:

$A' = B' \cdot L' = 1{,}14 \cdot 1{,}45 = 1{,}653$ m²

$$q_{E,d} = \frac{V_d}{A'} = \frac{1021{,}3}{1{,}653} = 617{,}86 \text{ KPa}$$

$H_B = 40$ kN

$H_L = 10$ kN



The design value of the effective overburden pressure at the level of the base:

$$q' = \gamma_\gamma \cdot q'_k = 1 \cdot 17{,}952 = 17{,}952 \text{ KPa}$$

3.4. Drained conditions

Dimensionless factors for the calculation EN-1997-1 Annex D D.4

Bearing capacity factors:

$$N_q = e^{\pi \cdot \mathrm{tg}\varphi'} \cdot \mathrm{tg}^2\left(45° + \frac{\varphi'}{2}\right) = e^{3{,}1416 \cdot \mathrm{tg}32{,}01°} \cdot \mathrm{tg}^2\left(45° + \frac{32{,}01°}{2}\right) = 23{,}195$$

$$N_\gamma = 2 \cdot (N_q - 1) \cdot \mathrm{tg}\varphi' = 2 \cdot (23{,}195 - 1) \cdot \mathrm{tg}\,32{,}01° = 27{,}745$$

$$N_c = \frac{(N_q - 1)}{\mathrm{tg}\varphi'} = \frac{(23{,}195 - 1)}{\mathrm{tg}\,32{,}01°} = 35{,}51$$

Shape factors of the footing base:

$$s_\gamma = 1 - 0{,}3 \cdot \frac{B'}{L'} = 1 - 0{,}3 \cdot \frac{1{,}14}{1{,}45} = 0{,}76414$$

$$s_q = 1 + \frac{B'}{L'} \cdot \sin\varphi' = 1 + \frac{1{,}14}{1{,}45} \cdot \sin 32{,}01° = 1{,}4167$$

$$s_c = \frac{s_q \cdot N_q - 1}{N_q - 1} = \frac{1{,}4167 \cdot 23{,}195 - 1}{23{,}195 - 1} = 1{,}4355$$

Factors for the inclination of the base:

$\alpha = 0°$

$b_\gamma = 1$

$b_q = b_\gamma = 1$

$b_c = 1$

Factors for the inclination of the load:

$$m_B = \frac{2+\dfrac{B'}{L'}}{1+\dfrac{B'}{L'}} = \frac{2+\dfrac{1,14}{1,45}}{1+\dfrac{1,14}{1,45}} = 1,5598$$

$$m_L = \frac{2+\dfrac{L'}{B'}}{1+\dfrac{L'}{B'}} = \frac{2+\dfrac{1,45}{1,14}}{1+\dfrac{1,45}{1,14}} = 1,4402$$

$$m = m_B \cdot \left(\frac{H_B}{H}\right)^2 + m_L \cdot \left(\frac{H_L}{H}\right)^2 = 1,5598 \cdot \left(\frac{40}{41,231}\right)^2 + 1,4402 \cdot \left(\frac{10}{41,231}\right)^2 = 1,5528$$

$$i_\gamma = \left[1 - \frac{H}{V_d + A' \cdot c' \cdot \mathrm{cotg}\,\varphi'}\right]^{(m+1)} = \left[1 - \frac{41,231}{1021,3 + 1,653 \cdot 0 \cdot \mathrm{cotg}\,32,01°}\right]^{(1,5528+1)} = 0,90015$$

$$i_q = \left[1 - \frac{H}{V_d + A' \cdot c' \cdot \mathrm{cotg}\,\varphi'}\right]^{m} = \left[1 - \frac{41,231}{1021,3 + 1,653 \cdot 0 \cdot \mathrm{cotg}\,32,01°}\right]^{1,5528} = 0,93802$$

$$i_c = i_q - \frac{1-i_q}{N_c \cdot \mathrm{tg}\,\varphi'} = 0,93802 - \frac{1-0,93802}{35,51 \cdot \mathrm{tg}\,32,01°} = 0,93522$$

Factors		Cohesion c	Self weight γ	Overburden q
Bearing capacity factors	N	35,51	27,745	23,195
Shape factors of the footing base	s	1,4355	0,76414	1,4167
Factors for the inclination of the base	b	1	1	1
Factors for the inclination of the load	i	0,93522	0,90015	0,93802

Bearing resistance:

$$R_{d,V} = \frac{c' \cdot N_c \cdot s_c \cdot b_c \cdot i_c + q' \cdot N_q \cdot s_q \cdot b_q \cdot i_q + 0,5 \cdot \gamma' \cdot B' \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma}{\gamma_{R,v}} \cdot A' =$$

$$= \frac{0 \cdot 35,51 \cdot 1,4355 \cdot 1 \cdot 0,93522 + 17,952 \cdot 23,195 \cdot 1,4167 \cdot 1 \cdot 0,93802 + 0,5 \cdot 20,601 \cdot 1,14 \cdot 27,745 \cdot 1 \cdot 0,76414 \cdot 0,90015}{1} \cdot 1,653 =$$

$$= 1285,1 \text{ kN}$$

Bearing utilization:

$$\Lambda_{R,v} = \frac{V_d}{R_{d,V}} = \frac{1021,3}{1285,1} = 0,795 \;<\; \Lambda_{R,v,lim} \;=\; 1,000 \quad \text{passed}$$

3.5. The effect of layered subsoil

Slope of the load spread under the footing: **1 : 1** ($\cot\beta = 1$)

Soil layers below the base of the footing

Soil layers					Footing							
	Name	z_i $[m]$	h_i $[m]$	γ_i $[kN/m^3]$	B'_i $[m]$	L'_i $[m]$	A'_i $[m^2]$	q'_i $[KPa]$	$q_{Ed,i}$ $[KPa]$	R/A'_i $[KPa]$	$\Lambda_{R,v,i}$	✔ ✗
2.	BST	−0,9	0,7	20,601	1,14	1,45	1,653	17,952	617,86	777,44	0,79474	✔
3.	CST	−1,6	20	19,62	2,54	2,85	7,239	17,952	141,09	717,62	0,1966	✔

where:

$$B'_i = B' \cdot 2 \cdot \frac{1}{\cot\beta} \cdot (|z_i| - D)$$

$$L'_i = L' + 2 \cdot \frac{1}{\cot\beta} \cdot (|z_i| - D)$$

$$A'_i = B'_i \cdot L'_i$$

$B' = 1{,}14$ m

$L' = 1{,}45$ m

$D = 0{,}9$ m

$$q_{Ed,i} = \frac{V_d}{A'_i} + (q'_i - q')$$

$$R/A'_i = \frac{c'_i \cdot N_c \cdot b_c \cdot s_c \cdot i_c + q'_i \cdot N_q \cdot b_q \cdot s_q \cdot i_q + 0{,}5 \cdot \gamma_i \cdot B'_i \cdot N_\gamma \cdot b_\gamma \cdot s_\gamma \cdot i_\gamma}{\gamma_{R,v}}$$

Bearing utilization:

$\Lambda_{R,v,max} = 0{,}1966 < \Lambda_{R,v,lim} = 1{,}000$ passed

4. Eccentricity check

Eccentricity limit factor: $\gamma_{ecc,lim} = 0{,}33$

F_x F_y $[kN]$	F_z $[kN]$	M_x M_y $[kNm]$	V_d $[kN]$	e_x e_y $[m]$	γ_{ecc}	✔ ✗	Load case
31,5 13,5	−1170	−29,25 139,5	1211,3	0,131 0,031	0,089745	✔	[1,35*ST1+1,35*ST2+0,9*ST5+0,9*ST6]
45 10	−845	−19,5 177	886,32	0,23 0,029	0,15455	✔	[ST1+ST2+1,1*ST5+1,1*ST6]
31,5 13,5	−1275	−29,25 139,5	1316,3	0,12 0,028	0,082149	✔	[1,35*ST1+1,35*ST2+0,9*ST5 +0,9*ST6] {0,7*1,5*ST3}
41,5 13,5	−1160	−28,25 173,5	1201,3	0,165 0,03	0,1118	✔	[1,35*ST1+1,35*ST2+1,1*ST5+1,1*ST6]
35 10	−855	−20,5 143	896,32	0,183 0,03	0,12363	✔	[ST1+ST2+0,9*ST5+0,9*ST6]
45 10	−770	−19,5 177	811,32	0,251 0,031	0,1686	✔	[ST1+ST2+1,1*1*ST5+1,1*1*ST6] {1,5*ST4}
40 10	−850	−20 160	891,32	0,206 0,029	0,13869	✔	[ST1+ST2+ST5+ST6]
40 10	−980	−20 160	1021,3	0,18 0,025	0,12115	✔	[ST1+ST2+ST5+ST6] {1,3*ST3}
40 10	−785	−20 160	826,32	0,223 0,031	0,1501	✔	[ST1+ST2+ST5+ST6] {1,3*ST4}

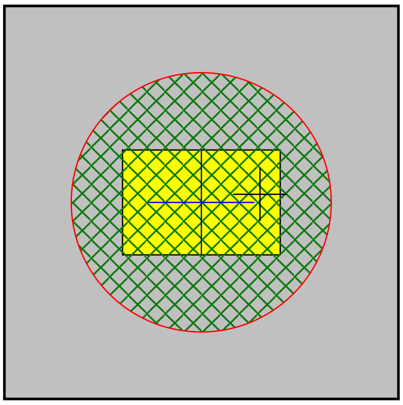
where:

$$V_d = -F_z + (G_{f,k} + G_{b,k} + G_{bf,k}) \cdot \gamma_{G,unfav}$$

$$\gamma_{ecc} = \sqrt{\left(\frac{e_x}{b_x}\right)^2 + \left(\frac{e_y}{b_y}\right)^2}$$ Eccentricity values take into account additional moment at the base of footing from horizontal loads

$\gamma_{G,unfav}$: Partial factor for footing self weight

$\gamma_{ecc,max} = 0{,}1686 \le \gamma_{ecc,lim} = 0{,}33$ passed!



5. Stability check

$\gamma_{G,dst} = 1{,}1$

$\gamma_{G,stb} = 0{,}9$

Design value of the weight of the footing: $G_{f,d} = G_{f,k} \cdot \gamma_{G,stb} = 27{,}591 \cdot 0{,}9 = 24{,}832$ kN (↓)

Design value of the weight of blind concrete: $G_{b,d} = G_{b,k} \cdot \gamma_{G,stb} = 4{,}8559 \cdot 0{,}9 = 4{,}3704$ kN (↓)

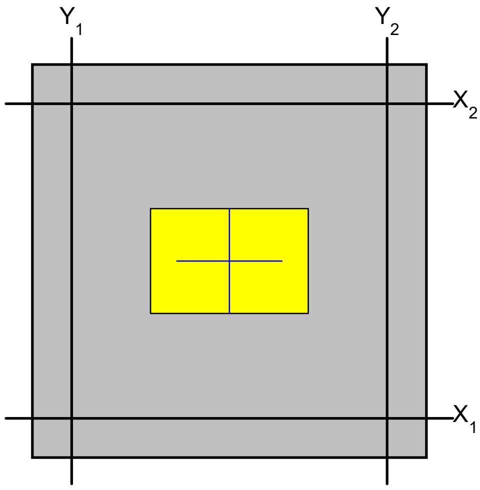
Design value of the weight of backfill: $G_{bf,d} = G_{bf,k} \cdot \gamma_{G,stb} = 8{,}8731 \cdot 0{,}9 = 7{,}9858$ kN (↓)

Ratio of distance between the axis of overturning and the footing edge to the footing size: $\gamma_\omega = 0{,}1$

Distance between the axis of overturning and the center of the footing

$$e_{EQUx} = \frac{b_x \cdot (1 - \gamma_\omega)}{2} = \frac{1{,}5 \cdot (1 - 0{,}1)}{2} = 0{,}675 \text{ m}$$

$$e_{EQUy} = \frac{b_y \cdot (1 - \gamma_\omega)}{2} = \frac{1{,}5 \cdot (1 - 0{,}1)}{2} = 0{,}675 \text{ m}$$



5.1. Checking rotation about the x_1 axis

Load case: **[0,9*ST1+0,9*ST2+1,1*ST5+1,1*ST6] {1,5*ST4}** (EQU)

Design value of loads at the top of the footing - Nodal support internal forces

$F_x = 46$ kN

$F_y = 9$ kN

$F_z = -680$ kN

$M_x = -17$ kNm

$M_y = 178$ kNm

$V = -F_z = -(-680) = 680$ kN (↓)

Stabilizing moment

$M_{x1,stb} = M_x + (-V) \cdot e_{EQUy} + (-G_{f,d}) \cdot e_{EQUy} + (-G_{b,d}) \cdot e_{EQUy} + (-G_{bf,d}) \cdot e_{EQUy} =$

$= (-17) + (-680) \cdot 0{,}675 + (-24{,}832) \cdot 0{,}675 + (-4{,}3704) \cdot 0{,}675 + (-7{,}9858) \cdot 0{,}675 = -501{,}1$ kNm

Destabilizing moment

$M_{x1,dst} = F_y \cdot h = 9 \cdot 0{,}5 = 4{,}5$ kNm

Stability usage factor

$$\Lambda_{EQU,x1} = \left| \frac{M_{x1,dst}}{M_{x1,stb}} \right| = \left| \frac{4{,}5}{(-501{,}1)} \right| = 0{,}0089802 \le \Lambda_{EQU,lim} = 1{,}000 \quad \text{passed!}$$

5.2. Checking rotation about the x_2 axis

Load case: **[0,9*ST1+0,9*ST2+1,1*ST5+1,1*ST6] {1,5*ST4}** (EQU)

Design value of loads at the top of the footing - Nodal support internal forces

$F_x = 46$ kN

$F_y = 9$ kN

$F_z = -680$ kN

$M_x = -17$ kNm

$M_y = 178$ kNm

$V = -F_z = -(-680) = 680$ kN (↓)

Stabilizing moment

$$M_{x2,stb} = F_y \cdot h + (-V)\cdot(-e_{EQUy}) + (-G_{f,d})\cdot(-e_{EQUy}) + (-G_{b,d})\cdot -e_{EQUy} + (-G_{bf,d})\cdot(-e_{EQUy}) =$$
$$= 9\cdot 0{,}5 + (-680)\cdot(-0{,}675) + (-24{,}832)\cdot(-0{,}675) + (-4{,}3704)\cdot -0{,}675 + (-7{,}9858)\cdot(-0{,}675) = 488{,}6 \text{ kNm}$$

Destabilizing moment

$M_{x2,dst} = M_x = (-17) = -17$ kNm

Stability usage factor

$$\Lambda_{EQU,x2} = \left|\frac{M_{x2,dst}}{M_{x2,stb}}\right| = \left|\frac{(-17)}{488{,}6}\right| = 0{,}034793 \le \Lambda_{EQU,lim} = 1{,}000 \quad \text{passed!}$$

5.3. Checking rotation about the y_1 axis

Load case: **[1,1*ST1+1,1*ST2+0,9*ST5+0,9*ST6]** (EQU)

Design value of loads at the top of the footing - Nodal support internal forces

$F_x = 34$ kN

$F_y = 11$ kN

$F_z = -945$ kN

$M_x = -23$ kNm

$M_y = 142$ kNm

$V = -F_z = -(-945) = 945$ kN (↓)

Stabilizing moment

$$M_{y1,stb} = M_y + F_x \cdot h + V\cdot e_{EQUx} + G_{f,d}\cdot e_{EQUx} + G_{b,d}\cdot e_{EQUx} + G_{bf,d}\cdot e_{EQUx} =$$
$$= 142 + 34\cdot 0{,}5 + 945\cdot 0{,}675 + 24{,}832\cdot 0{,}675 + 4{,}3704\cdot 0{,}675 + 7{,}9858\cdot 0{,}675 = 821{,}98 \text{ kNm}$$

Destabilizing moment

$M_{y1,dst} = 0$ kNm

Stability usage factor

$$\Lambda_{EQU,y1} = \left|\frac{M_{y1,dst}}{M_{y1,stb}}\right| = \left|\frac{0}{821{,}98}\right| = 0 \le \Lambda_{EQU,lim} = 1{,}000 \quad \text{passed!}$$

5.4. Checking rotation about the y_2 axis

Load case: **[0,9*ST1+0,9*ST2+1,1*ST5+1,1*ST6] {1,5*ST4}** (EQU)

Design value of loads at the top of the footing - Nodal support internal forces

$F_x = 46$ kN

$F_y = 9$ kN

$F_z = -680$ kN

$M_x = -17$ kNm

$M_y = 178$ kNm

$V = -F_z = -(-680) = 680$ kN $(\downarrow)$

Stabilizing moment

$M_{y2,stb} = V\cdot(-e_{EQUx}) + G_{f,d}\cdot(-e_{EQUx}) + G_{b,d}\cdot -e_{EQUx} + G_{bf,d}\cdot(-e_{EQUx}) =$

$= 680\cdot(-0{,}675) + 24{,}832\cdot(-0{,}675) + 4{,}3704\cdot -0{,}675 + 7{,}9858\cdot(-0{,}675) = -484{,}1$ kNm

Destabilizing moment

$M_{y2,dst} = M_y + F_x\cdot h = 178 + 46\cdot 0{,}5 = 201$ kNm

Stability usage factor

$$\Lambda_{EQU,y2} = \left|\frac{M_{y2,dst}}{M_{y2,stb}}\right| = \left|\frac{201}{(-484{,}1)}\right| = 0{,}4152 \le \Lambda_{EQU,lim} = 1{,}000 \quad \text{passed!}$$

Stability usage factor

$\Lambda_{EQU,max} = 0{,}415 \le \Lambda_{EQU,lim} = 1{,}000$ passed!

6. Sliding calculation

6.1. Sliding of the footing at the soil

Design Approach 1 Combination 1: {A1 "+" M1 "+" R1}

Design Approach 1 Combination 2: {A2 "+" M2 "+" R1} (Critical)

Design Approach 2: {A1 "+" M1 "+" R2}

Design Approach 3: {A2 "+" M2 "+" R3} EN-1997-1 Annex A

	Partial factors		
A2	Permanent, unfavourable actions	$\gamma_{G,unfav}$	1
	Permanent, favourable actions	$\gamma_{G,fav}$	1
	Variable, unfavourable actions	$\gamma_{Q,unfav}$	1,3
	Variable, favourable actions	$\gamma_{Q,fav}$	0
M2	Angle of effective shear resistance	γ_{φ}	1,25
	Effective cohesion	γ_c	1,25
	Undrained shear strength	γ_{cu}	1,4
	Unconfined strength	γ_{qu}	1,4
	Weight density	γ_{γ}	1
R1	Bearing resistance	$\gamma_{R,v}$	1
	Sliding resistance	$\gamma_{R,h}$	1
	Earth forces	$\gamma_{R,e}$	1

6.1.1. Design value of parameters of the soil below the foundation

Soil layer density: $\rho_s = 2100$ kg/m³

Weight density:

$\gamma' = \rho_s \cdot g \cdot \gamma_\gamma \cdot 10^{-3} = 2100 \cdot 9{,}810 \cdot 1 \cdot 10^{-3} = 20{,}601$ kN/m³

Angle of shear resistance $\varphi'_k = 38{,}00$ °

Angle of effective shear resistance:

$$\varphi' = \text{Arc tg}\,\frac{\tan\varphi'_k}{\gamma_\varphi} = \text{Arc tg}\,\frac{\tan 38{,}00°}{1{,}25} = 32{,}01\ °$$

Cohesion: $c'_k = 0$ KPa

Effective cohesion: $c' = \dfrac{c'_k}{\gamma_c} = \dfrac{0}{1{,}25} = 0$ KPa

Critical state angle of shearing resistance: $\varphi_{cv} = 32{,}00$ °

6.1.2. Design value of loads at the top of the footing - Nodal support internal forces

Load case: **[ST1+ST2+ST5+ST6] {1,3*ST4}** (A2(a,b))

Nodal support 1

$F_x = 40$ kN

$F_y = 10$ kN

$F_z = -785$ kN

$M_x = -20$ kNm

$M_y = 160$ kNm

$V = -F_z = -(-785) = 785$ kN

6.1.3. Design value of loads at the base of footing

$H_{dx} = F_x = 40$ kN

$H_{dy} = F_y = 10$ kN

$V_d = V + (G_{f,k} + G_{b,k} + G_{bf,k}) \cdot \gamma_{G,unfav} = 785 + (27{,}591 + 4{,}8559 + 8{,}8731) \cdot 1 = 826{,}32$ kN

Eccentricity of the vertical load (V_d) relative to the center of the footing

$$e_x = \frac{V \cdot e_{0x} + M_y + F_x \cdot (h_b + h) + (G_{f,k} \cdot e_{fx} + G_{bf,k} \cdot e_{bfx}) \cdot \gamma_{G,unfav}}{V_d} =$$

$$= \frac{785 \cdot 0 + 160 + 40 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{826{,}32} = 0{,}223 \text{ m}$$

$$e_y = \frac{V \cdot e_{0y} - M_x + F_y \cdot (h_b + h) + (G_{f,k} \cdot e_{fy} + G_{bf,k} \cdot e_{bfy}) \cdot \gamma_{G,unfav}}{V_d} =$$

$$= \frac{785 \cdot 0 - (-20) + 10 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{826{,}32} = 0{,}031 \text{ m}$$

Effective width of the footing:

$B' = b_x - |e_x| \cdot 2 = 1{,}5 - |0{,}223| \cdot 2 = 1{,}054$ m

Effective length of the footing:

$L' = b_y - |e_y| \cdot 2 = 1{,}5 - |0{,}031| \cdot 2 = 1{,}438$ m

Effective area of the footing:

$A' = B' \cdot L' = 1{,}054 \cdot 1{,}438 = 1{,}5157$ m²

6.1.4. Drained sliding resistance

$\delta_k = \varphi_{cv} = 32{,}00\ °$

Design value of the angle of shearing resistance for the structure-ground interface :

$$\delta_d = \text{Arc tg}\left(\frac{\text{tg}\,\delta_k}{\gamma_\varphi}\right) = \text{Arc tg}\left(\frac{\text{tg}\,32{,}00°}{1{,}25}\right) = 25{,}60\ °$$

Sliding resistance: EN-1997-1 6.5.3 (8)P (6.3a)

$R_{d,Hs} = V_d \cdot \text{tg}\,\delta_d = 826{,}32 \cdot \text{tg}\,25{,}60° = 395{,}91$ kN

Sliding ultilization: $\Lambda_{R,h,s} = \left|\frac{H_d}{R_{d,Hs}}\right| = \left|\frac{41{,}231_d}{395{,}91}\right| = 0{,}104 \le \Lambda_{R,h,s,lim} = 1{,}000$ passed!

6.2. Sliding of the footing on the blind concrete

Design Approach 1 Combination 1: {A1 "+" M1 "+" R1} (Critical)

Design Approach 1 Combination 2: {A2 "+" M2 "+" R1}

Design Approach 2: {A1 "+" M1 "+" R2}

Design Approach 3: {A1 "+" M2 "+" R3} EN-1997-1 Annex A

	Partial factors		
A1	Permanent, unfavourable actions	$\gamma_{G,unfav}$	1,35
	Permanent, favourable actions	$\gamma_{G,fav}$	1
	Variable, unfavourable actions	$\gamma_{Q,unfav}$	1,5
	Variable, favourable actions	$\gamma_{Q,fav}$	0
M1	Angle of effective shear resistance	γ_φ	1
	Effective cohesion	γ_c	1
	Undrained shear strength	γ_{cu}	1
	Unconfined strength	γ_{qu}	1
	Weight density	γ_γ	1
R1	Bearing resistance	$\gamma_{R,v}$	1
	Sliding resistance	$\gamma_{R,h}$	1
	Earth forces	$\gamma_{R,e}$	1

6.2.1. Design value of loads at the top of the footing - Nodal support internal forces

Load case: **[ST1+ST2+1,1*1*ST5+1,1*1*ST6] {1,5*ST4}** (A1(b))

Nodal support 1

$F_x = 45$ kN

$F_y = 10$ kN

$F_z = -770$ kN

$M_x = -19{,}5$ kNm

$M_y = 177$ kNm

$V = -F_z = -(-770) = 770$ kN

6.2.2. Design value of loads at the top of the blind concrete

$H_{dx} = F_x = 45$ kN

$H_{dy} = F_y = 10$ kN

$V_d = V + (G_{f,k} + G_{bf,k}) \cdot \gamma_{G,fav} = 770 + (27{,}591 + 8{,}8731) \cdot 1 = 806{,}46$ kN

Eccentricity of the vertical load (V_d) relative to the center of the footing

$$e_x = \frac{V \cdot e_{0x} + M_y + F_x \cdot h + (G_{f,k} \cdot e_{fx} + G_{bf,k} \cdot e_{bfx}) \cdot \gamma_{G,fav}}{V_d} = \frac{770 \cdot 0 + 177 + 45 \cdot 0{,}5 + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{806{,}46} = 0{,}247 \text{ m}$$

$$e_y = \frac{V \cdot e_{0y} - M_x + F_y \cdot h + (G_{f,k} \cdot e_{fy} + G_{bf,k} \cdot e_{bfy}) \cdot \gamma_{G,fav}}{V_d} = \frac{770 \cdot 0 - (-19{,}5) + 10 \cdot 0{,}5 + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{806{,}46} = 0{,}03 \text{ m}$$

Effective width of the footing:

$B' = b_x - |e_x| \cdot 2 = 1{,}5 - |0{,}247| \cdot 2 = 1{,}006$ m

Effective length of the footing:

$L' = b_y - |e_y| \cdot 2 = 1{,}5 - |0{,}03| \cdot 2 = 1{,}44$ m

Effective area of the footing:

$A' = B' \cdot L' = 1{,}006 \cdot 1{,}44 = 1{,}4486$ m²

Coefficient of friction between the footing and the blind concrete: $\mu_{cc} = 0{,}7$

Partial factor for friction between elements: $\gamma_\mu = 1$

Sliding resistance:

$$R_{d,Hb} = V_d \cdot \frac{\mu_{cc}}{\gamma_\mu} = 806{,}46 \cdot \frac{0{,}7}{1} = 564{,}52 \text{ kN}$$

Sliding ultilization: $\Lambda_{R,h,b} = \left| \frac{H_d}{R_{d,Hb}} \right| = \left| \frac{41{,}231_d}{564{,}52} \right| = 0{,}082 \le \Lambda_{R,h,b,lim} = 1{,}000$ passed!

7. Structural investigation of the footing

7.1. Reinforcement design

$d_x = h - u_{B,x} = 0{,}5 - 0{,}04 = 0{,}46$ m

$d_y = h - u_{B,y} = 0{,}5 - 0{,}06 = 0{,}44$ m

Longitudinal rebars

	X	Y
Top	∅ 20 mm ($A_\varnothing = 3{,}14$ cm²)	∅ 20 mm ($A_\varnothing = 3{,}14$ cm²)
Bottom	∅ 20 mm ($A_\varnothing = 3{,}14$ cm²)	∅ 20 mm ($A_\varnothing = 3{,}14$ cm²)

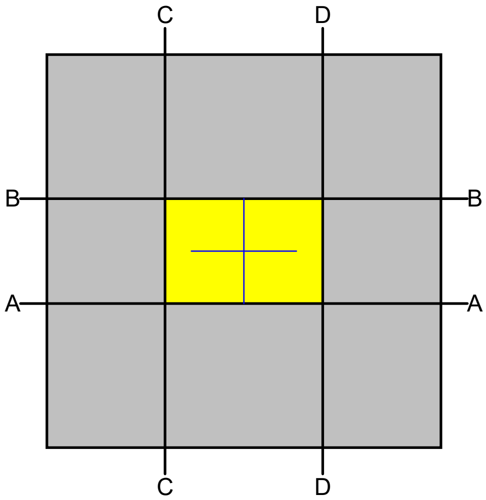
7.2. Design of reinforcement for bending moment

Factor, defining the effective height of the compression zone:

λ = 0,8 EN-1992-1-1 3.1.7 (3.19)

Factor, defining the effective strength:

η = 1 EN-1992-1-1 3.1.7 (3.21)



Moments in investigated cross-sections:

	Investigated cross-section	m_d $[kNm/m]$	Load case
1.	A-A	87,457	[1,35*ST1+1,35*ST2+0,9*ST5+0,9*ST6] {0,7*1,5*ST3}
2.	B-B	**108,41**	[1,35*ST1+1,35*ST2+0,9*ST5+0,9*ST6] {0,7*1,5*ST3}
3.	C-C	16,107	[1,35*ST1+1,35*ST2+0,9*ST5+0,9*ST6] {0,7*1,5*ST3}
4.	D-D	**72,572**	[1,35*ST1+1,35*ST2+0,9*ST5+0,9*ST6] {0,7*1,5*ST3}

f_{ck} = 16 MPa γ_c = 1,500 $$f_{cd} = \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_s} = 1 \cdot \frac{16}{1,150} = 10,667 \text{ MPa}$$

f_{yk} = 500 MPa γ_s = 1,150 $$f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{500}{1,150} = 434,78 \text{ MPa}$$

$$\xi_0 = \frac{\varepsilon_{cu1}}{\varepsilon_{cu1} - \frac{f_{yd}}{E_s}} \cdot \lambda = \frac{(-3,500)}{(-3,500) - \frac{434783}{2 \cdot 10^8}} \cdot 0,8 = 0,49349$$

7.2.1. Design of longitudinal reinforcement for M_y bending moment

7.2.1.1. Investigation at the edge of the supported element - cross-section C-C and D-D

Tension reinforcement in x direction

$m_d = Max(m_{dC-C}\ ;\ m_{dD-D}) = Max(16{,}107\ ;\ 72{,}572) = 72{,}572$ kNm/m

$m_d = 72{,}572$ kNm/m

$d = h - u_{Bx} = 0{,}5 - 0{,}04 = 0{,}46$ m

$d_2 = u_{Tx} = 0{,}04$ m

$x_{c0} = d \cdot \xi_0 = 0{,}46 \cdot 0{,}49349 = 0{,}227$ m

$$x_c = d - \sqrt{d^2 - \frac{2 \cdot m_d}{\eta \cdot f_{cd}}} = 0{,}46 - \sqrt{0{,}46^2 - \frac{2 \cdot 72{,}572}{1 \cdot 10667}} = 0{,}015036 \text{ m} \le \quad x_{c0} = 0{,}227 \text{ m}$$

Tension reinforcement area:

$$a_{s1,c} = \frac{x_c \cdot b_w \cdot \eta \cdot f_{cd}}{f_{yd}} = \frac{0{,}015036 \cdot 1 \cdot 1 \cdot 10667}{434783} = 0{,}00036889 \text{ m²/m} = 369 \text{ mm²/m}$$

Minimum reinforcement

$$\rho_{l,min} = 0{,}26 \cdot \frac{f_{ctm}}{f_{yk}} \ge 0{,}0013 = 0{,}26 \cdot \frac{1{,}9049}{500} \ge 0{,}0013 = 0{,}0013$$ EN-1992-1-1 9.2.1.1 (1)

Minimum longitudinal tension reinforcement:

$a_{s,min} = \rho_{l,min} \cdot d = 0{,}0013 \cdot 0{,}46 = 0{,}000598$ m²/m = 598 mm²/m

$a_{s1} = Max(a_{s1,c}\ ;\ a_{s,min}) = Max(369\ ;\ 598) = 598$ mm²/m = 0,000598 m²/m

$$A_{\varnothing} = \frac{\varnothing_{Bx}^{\ 2}}{4} \cdot \pi = \frac{20^2}{4} \cdot 3{,}1416 = 3{,}14 \text{ cm²} = 0{,}00031416 \text{ m²}$$

$s_{max,slabs} = \text{Min}\ (2 \cdot h = 2 \cdot 0{,}5 = 1\ ;\ 0{,}25) = 0{,}25$ m EN-1992-1-1 9.3.1.1 (3)

$$s = \text{Min}\ \left(\frac{A_{\varnothing}}{a_{s1}} = \frac{0{,}00031416}{0{,}000598} = 0{,}52535\ ;\ s_{max,slabs} = 0{,}25\right) = 0{,}25 \text{ m} = 250 \text{ mm}$$

Longitudinal rebars:

$$a_{s,prov} = \frac{A_{\varnothing}}{s} = \frac{0{,}00031416}{0{,}25} = 0{,}0012566 \text{ m²/m} = 1257 \text{ mm²/m} \quad (\varnothing\, 20 \text{ mm}/250 \text{ mm})$$

7.2.2. Design of longitudinal reinforcement for M_x bending moment

7.2.2.1. Investigation at the edge of the supported element - cross-section A-A and B-B

Tension reinforcement in y direction

$m_d = Max(m_{dA-A}\ ;\ m_{dB-B}) = Max(87{,}457\ ;\ 108{,}41) = 108{,}41$ kNm/m

$m_d = 108{,}41$ kNm/m

$d = h - u_{By} = 0{,}5 - 0{,}06 = 0{,}44$ m

$d_2 = u_{Ty} = 0{,}06$ m

$x_{c0} = d \cdot \xi_0 = 0{,}44 \cdot 0{,}49349 = 0{,}21713$ m

$$x_c = d - \sqrt{d^2 - \frac{2 \cdot m_d}{\eta \cdot f_{cd}}} = 0{,}44 - \sqrt{0{,}44^2 - \frac{2 \cdot 108{,}41}{1 \cdot 10667}} = 0{,}023739 \text{ m} \le \quad x_{c0} = 0{,}21713 \text{ m}$$

Tension reinforcement area:

$$a_{s1,c} = \frac{x_c \cdot b_w \cdot \eta \cdot f_{cd}}{f_{yd}} = \frac{0{,}023739 \cdot 1 \cdot 1 \cdot 10667}{434783} = 582 \text{ mm}^2/\text{m}$$

Minimum reinforcement

$$\rho_{l,min} = 0{,}26 \cdot \frac{f_{ctm}}{f_{yk}} \geq 0{,}0013 = 0{,}26 \cdot \frac{1{,}9049}{500} \geq 0{,}0013 = 0{,}0013 \qquad \text{EN-1992-1-1 9.2.1.1 (1)}$$

Minimum longitudinal tension reinforcement:

$$a_{s,min} = \rho_{l,min} \cdot d = 0{,}0013 \cdot 0{,}44 = 572 \text{ mm}^2/\text{m}$$

$$a_{s1} = Max(a_{s1,c}\ ;\ a_{s,min}) = Max(582\ ;\ 572) = 0{,}0005824 \text{ m}^2/\text{m}$$

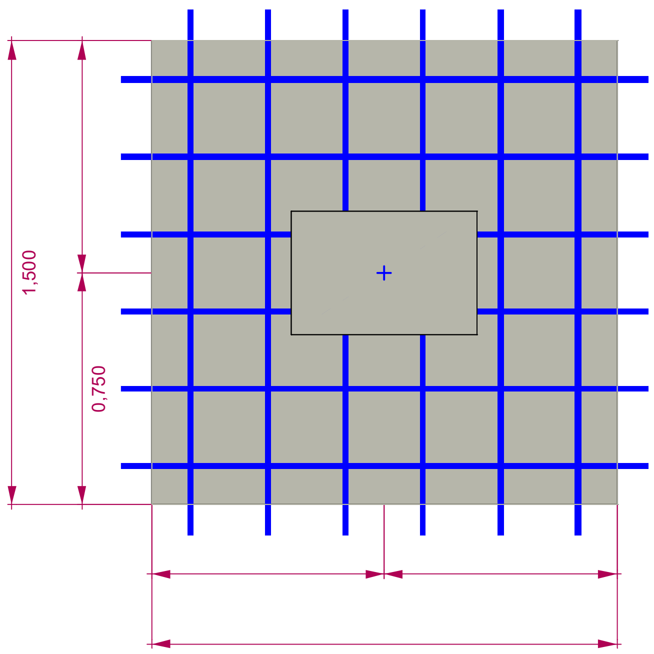
$$A_{\varnothing} = \frac{\varnothing_{By}^{\ 2}}{4} \cdot \pi = \frac{20^2}{4} \cdot 3{,}1416 = 3{,}14 \text{ cm}^2 = 0{,}00031416 \text{ m}^2$$

$$s_{max,slabs} = \text{Min}(\ 2 \cdot h = 2 \cdot 0{,}5 = 1\ ;\ 0{,}25) = 0{,}25 \text{ m} \qquad \text{EN-1992-1-1 9.3.1.1 (3)}$$

$$s = \text{Min}(\ \frac{A_{\varnothing}}{a_{s1}} = \frac{0{,}00031416}{0{,}0005824} = 0{,}53943\ ;\ s_{max,slabs} = 0{,}25) = 0{,}25 \text{ m} = 250 \text{ mm}$$

Longitudinal rebars:

$$a_{s,prov} = \frac{A_{\varnothing}}{s} = \frac{0{,}00031416}{0{,}25} = 1257 \text{ mm}^2/\text{m} \qquad (\varnothing\, 20 \text{ mm}/250 \text{ mm})$$



7.3. Punching - Punching reinforcement

Plate thickness

h = 0,5 m

Effective thickness:

$$d=\frac{d_x+d_y}{2}=\frac{0{,}46+0{,}44}{2}=0{,}45\text{ m}$$

Radial spacing of first perimeter of shear reinforcement from the convex perimeter of the column a_1 = 0,2 m

Radial spacing of perimeters of shear reinforcement s_r = 0,3 m

Bonded tension steel ratios in x and y direction:

$$\rho_{lx}=\frac{A_{s,ax}}{d_x}=\frac{0{,}0012566}{0{,}46}=0{,}0027318$$

$$\rho_{ly}=\frac{A_{s,ay}}{d_y}=\frac{0{,}0012566}{0{,}44}=0{,}002856$$

$$\rho_l=\sqrt{\rho_{lx}\cdot\rho_{ly}}\le 0{,}02=\sqrt{0{,}0027318\cdot 0{,}002856}\le 0{,}02=0{,}0027932$$

$$k=1+\sqrt{\frac{200}{d}}\le 2=1+\sqrt{\frac{200}{450}}\le 2=1{,}6667$$

where d is measured in mm

$$v=0{,}6\cdot\left[1-\frac{f_{ck}}{250}\right]=0{,}6\cdot\left[1-\frac{16}{250}\right]=0{,}5616$$

$$v_{min}=0{,}035\cdot k^{\frac{3}{2}}\cdot\sqrt{f_{ck}}=0{,}035\cdot 1{,}6667^{\frac{3}{2}}\cdot\sqrt{16}=0{,}30123$$

where f_{ck} is measured in N / mm^2

α_{cc} = 1 EN-1992-1-1 2.4.8 (2)

Design situation:Persistent and transient

γ_c = 1,5

γ_s = 1,15

$$f_{cd}=\alpha_{cc}\cdot\frac{f_{ck}}{\gamma_c}=1\cdot\frac{16}{1{,}5}=10{,}667\text{ MPa }=\text{ 10667 KPa}$$

The design value of the maximum punching shear resistance along the column perimeter:

$$v_{Rd,max}=0{,}4\cdot v\cdot f_{cd}=0{,}4\cdot 0{,}5616\cdot 10667=2396{,}2\text{ KPa}$$

$$C_{Rd,c}=\frac{C_{Rk,c}}{\gamma_c}=\frac{??C_{Rk,c}}{1{,}5}=0{,}12$$

The design value of punching shear resistance of the slab without punching shear reinforcement:

$$v_{Rd,c}=C_{Rd,c}\cdot k\cdot(100\cdot\rho_l\cdot f_{ck})^{\frac{1}{3}}=0{,}12\cdot 1{,}6667\cdot(100\cdot 0{,}0027932\cdot 16)^{\frac{1}{3}}=329{,}44\text{ KPa}$$

where f_{ck} is measured in N / mm^2

Critical load combination

7.3.1. Design value of loads at the top of the footing - Nodal support internal forces

Load case: **[1,35*ST1+1,35*ST2+0,9*ST5+0,9*ST6] {0,7*1,5*ST3}** (A1(a))

Nodal support 1

$F_x = 31{,}5 \text{ kN}$

$F_y = 13{,}5 \text{ kN}$

$F_z = -1275 \text{ kN}$

$M_x = -29{,}25 \text{ kNm}$

$M_y = 139{,}5 \text{ kNm}$

$V = -F_z = -(-1275) = 1275 \text{ kN}$

7.3.2. Design value of loads at the base of footing

$H_{dx} = F_x = 31{,}5 \text{ kN}$

$H_{dy} = F_y = 13{,}5 \text{ kN}$

$V_d = V + (G_{f,k} + G_{b,k} + G_{bf,k}) \cdot \gamma_{G,fav} = 1275 + (27{,}591 + 4{,}8559 + 8{,}8731) \cdot 1 = 1316{,}3 \text{ kN}$

Eccentricity of the vertical load (V_d) relative to the center of the footing

$$e_x = \frac{V \cdot e_{0x} + M_y + F_x \cdot (h_b + h) + (G_{f,k} \cdot e_{fx} + G_{bf,k} \cdot e_{bfx}) \cdot \gamma_{G,fav}}{V_d} =$$

$$= \frac{1275 \cdot 0 + 139{,}5 + 31{,}5 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{1316{,}3} = 0{,}12 \text{ m}$$

$$e_y = \frac{V \cdot e_{0y} - M_x + F_y \cdot (h_b + h) + (G_{f,k} \cdot e_{fy} + G_{bf,k} \cdot e_{bfy}) \cdot \gamma_{G,fav}}{V_d} =$$

$$= \frac{1275 \cdot 0 - (-29{,}25) + 13{,}5 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{1316{,}3} = 0{,}028 \text{ m}$$

Effective width of the footing:

$B' = b_x - |e_x| \cdot 2 = 1{,}5 - |0{,}12| \cdot 2 = 1{,}26 \text{ m}$

Effective length of the footing:

$L' = b_y - |e_y| \cdot 2 = 1{,}5 - |0{,}028| \cdot 2 = 1{,}444 \text{ m}$

Effective area of the footing:

$A' = B' \cdot L' = 1{,}26 \cdot 1{,}444 = 1{,}8194 \text{ m}^2$

$$q_{E,d} = \frac{V_d}{A'} = \frac{1316{,}3}{1{,}8194} = 723{,}48 \text{ KPa}$$

$H_B = 31{,}5 \text{ kN}$

$H_L = 13{,}5 \text{ kN}$

$V_{Ed} = -F_z = -(-1275) = 1275 \text{ kN } (\downarrow)$

Checking the maximum punching shear resistance along the column perimeter

Length of the perimeter of the load area

$u_0 = 2 \text{ m}$

$$\beta = \left[1 + \sqrt{\left(k_x \cdot \frac{M_{Edx} \cdot u_0}{V_{Ed} \cdot W_x}\right)^2 + \left(k_y \cdot \frac{M_{Edy} \cdot u_0}{V_{Ed} \cdot W_y}\right)^2}\right] = \left[1 + \sqrt{\left(0{,}5 \cdot \frac{(-29{,}25) \cdot 2}{1275 \cdot 0{,}32}\right)^2 + \left(0{,}65 \cdot \frac{139{,}5 \cdot 2}{1275 \cdot 0{,}42}\right)^2}\right] = 1{,}3462$$

$$v_{Ed,0} = \frac{\beta \cdot V_{Ed}}{u_0 \cdot d} = \frac{1{,}3462 \cdot 1275}{2 \cdot 0{,}45} = 1907{,}1 \text{ KPa}$$

$$\frac{v_{Ed,0}}{v_{Rd,max}} = \frac{1907,1}{2396,2} = 0,79588 \ < \ 1 \text{passed}$$

7.3.3. Verifying punching resistance of column bases at control perimeters within the 2d periphery of the column

	a $[m]$	A_{cont} $[m^2]$	A_{sr} $[m^2]$	ΔV_{Ed} $[kN]$	$V_{Ed,red}$ $[kN]$	u_i $[m]$	$\frac{2\cdot d}{a}$	v_{Ed} $[KPa]$	v_{Rd} $[KPa]$	$\frac{v_{Ed}}{v_{Rd}}$	✔ ✗
1.	0,045	0,33635	0,33635	238,49	1036,5 (↓)	2,2827	20	1383,6	6588,7	0,20999	✔
2.	0,09	0,44541	0,44541	315,82	959,18 (↓)	2,5653	10	1126,7	3294,4	0,34202	✔
3.	0,135	0,56718	0,56718	402,16	872,84 (↓)	2,848	6,6667	920,91	2196,2	0,41931	✔
4.	0,18	0,70166	0,70166	497,51	777,49 (↓)	3,1306	5	750,39	1647,2	0,45556	✔
5.	0,225	0,84884	0,84124	596,48	678,52 (↓)	3,4133	4	608,83	1317,7	0,46202	✔
6.	0,27	1,0087	0,97089	688,41	586,59 (↓)	3,6959	3,3333	495,3	1098,1	0,45105	✔
7.	0,315	1,1813	1,1053	783,71	491,29 (↓)	3,9786	2,8571	397,59	941,25	0,42241	✔
8.	0,36	1,68	1,4112	1000,6	274,38 (↓)	5,24	2,5	296,52	823,59	0,36003	✔
9.	0,405	1,815	1,5246	1081	193,98 (↓)	5,42	2,2222	259,53	732,08	0,35452	✔
10.	0,45	1,95	1,638	1161,4	113,57 (↓)	5,6	2	224,95	658,87	0,34142	✔

where:

a : The distance between the column periphery and the control perimeter

A_{cont} : Area within the control perimeter considered

A_{sr} : the area of the control perimeter falling inside the effective base area

$$A_{sr} = A' \cap A_{cont}$$

$$\Delta V_{Ed} = A_{sr} \cdot (q_{E,d} - \gamma_{RC} \cdot h \cdot \gamma_G)$$

$$V_{Ed,red} = V_{Ed} - \Delta V_{Ed}$$

$$v_{Ed} = \frac{V_{Ed,red}}{u \cdot d} \cdot \left[1 + \sqrt{\left(k_x \cdot \frac{M_{Edx} \cdot u}{V_{Ed,red} \cdot W_x} \right)^2 + \left(k_y \cdot \frac{M_{Edy} \cdot u}{V_{Ed,red} \cdot W_y} \right)^2} \right]$$

$$v_{Rd} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{\frac{1}{3}} \cdot \frac{2 \cdot d}{a} \geq v_{min} \cdot \frac{2 \cdot d}{a} \ \rightarrow \ v_{Rd} = v_{Rd,c} \cdot \frac{2 \cdot d}{a}$$

The maximum utilization is on control perimeter 5.

$$\frac{v_{Ed}}{v_{Rd}} = \frac{608,83}{1317,7} = 0,46202 \ < \ 1$$ No punching reinforcement is necessary.

on all checked control perimeters $v_{Ed} \leq v_{Rd}$ No punching reinforcement is necessary. passed

8. Settlement evaluation

8.1. Stress-strain method EN-1997-1 Annex F

(Critical) EN-1997-1 Annex A

	Partial factors		
A0	Permanent, unfavourable actions	$\gamma_{G,unfav}$	1
	Permanent, favourable actions	$\gamma_{G,fav}$	1
	Variable, unfavourable actions	$\gamma_{Q,unfav}$	1
	Variable, favourable actions	$\gamma_{Q,fav}$	0
M1	Angle of effective shear resistance	γ_{φ}	1
	Effective cohesion	γ_{c}	1
	Undrained shear strength	γ_{cu}	1
	Unconfined strength	γ_{qu}	1
	Weight density	γ_{γ}	1
R1	Bearing resistance	$\gamma_{R,v}$	1
	Sliding resistance	$\gamma_{R,h}$	1
	Earth forces	$\gamma_{R,e}$	1

EN-1997-12.4.8 (2) Values of partial factors for serviceability limit states should normally be taken as 1.0.

8.2. Design value of loads at the top of the footing - Nodal support internal forces

Load case: **[ST1+ST2+ST5+ST6] {0,3*ST3}** (SLS Quasipermanent)

Nodal support 1

$F_x = 40$ kN

$F_y = 10$ kN

$F_z = -880$ kN

$M_x = -20$ kNm

$M_y = 160$ kNm

$V = -F_z = -(-880) = 880$ kN

8.3. Design value of loads at the base of footing

$H_{dx} = F_x = 40$ kN

$H_{dy} = F_y = 10$ kN

$V_d = V + (G_{f,k} + G_{b,k} + G_{bf,k}) \cdot \gamma_{G,unfav} = 880 + (27{,}591 + 4{,}8559 + 8{,}8731) \cdot 1 = 921{,}32$ kN

Eccentricity of the vertical load (V_d) relative to the center of the footing

$$e_x = \frac{V \cdot e_{0x} + M_y + F_x \cdot (h_b + h) + (G_{f,k} \cdot e_{fx} + G_{bf,k} \cdot e_{bfx}) \cdot \gamma_{G,unfav}}{V_d} =$$

$$= \frac{880 \cdot 0 + 160 + 40 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{921{,}32} = 0{,}2 \text{ m}$$

$$e_y = \frac{V \cdot e_{0y} - M_x + F_y \cdot (h_b + h) + (G_{f,k} \cdot e_{fy} + G_{bf,k} \cdot e_{bfy}) \cdot \gamma_{G,unfav}}{V_d} =$$

$$= \frac{880 \cdot 0 - (-20) + 10 \cdot (0{,}1 + 0{,}5) + (27{,}591 \cdot 0 + 8{,}8731 \cdot 0) \cdot 1}{921{,}32} = 0{,}028 \text{ m}$$

Effective width of the footing:

$$B' = b_x - |e_x| \cdot 2 = 1{,}5 - |0{,}2| \cdot 2 = 1{,}1 \text{ m}$$

Effective length of the footing:

$$L' = b_y - |e_y| \cdot 2 = 1{,}5 - |0{,}028| \cdot 2 = 1{,}444 \text{ m}$$

Effective area of the footing:

$$A' = B' \cdot L' = 1{,}1 \cdot 1{,}444 = 1{,}5884 \text{ m}^2$$

$$q_{E,d} = \frac{V_d}{A'} = \frac{921{,}32}{1{,}5884} = 580{,}03 \text{ KPa}$$

$$H_B = 40 \text{ kN}$$

$$H_L = 10 \text{ kN}$$

The normal stress below the corner of a rectangular loaded area at depth z is:

$$\sigma_z = \frac{p}{2 \cdot \pi} \cdot \left[\text{Arc tg} \left(\frac{b}{z} \cdot \frac{a \cdot (a^2 + b^2) - 2 \cdot a \cdot z \cdot (r - z)}{z \cdot (a^2 + b^2) \cdot (r - z) - z \cdot (r - z)^2} \right) \right] + \left[\frac{b \cdot z}{b^2 + z^2} \cdot \frac{a \cdot (r^2 + z^2)}{(a^2 + z^2) \cdot r} \right]$$

after Steinbrenner

where:

p is the uniformly distributed load at the loaded area

a and b are the length and width of the rectangular loaded area

$r = \sqrt{a^2 + b^2 + z^2}$

Stress under the characteristic point:

$$\sigma_{z,a} = \sigma_{z,I} + \sigma_{z,II} + \sigma_{z,III} + \sigma_{z,IV}$$

	a	b
$\sigma_{z,I}$	$(0{,}5 - 0{,}37) \cdot L' = 0{,}18772$	$(0{,}5 - 0{,}37) \cdot B' = 0{,}143$
$\sigma_{z,II}$	$(0{,}5 + 0{,}37) \cdot L' = 1{,}2563$	$(0{,}5 - 0{,}37) \cdot B' = 0{,}143$
$\sigma_{z,III}$	$(0{,}5 + 0{,}37) \cdot L' = 1{,}2563$	$(0{,}5 + 0{,}37) \cdot B' = 0{,}957$
$\sigma_{z,IV}$	$(0{,}5 + 0{,}37) \cdot B' = 0{,}957$	$(0{,}5 - 0{,}37) \cdot L' = 0{,}18772$

Distance of the characteristic point from the central axes of the loaded area is $0{,}37B'$and $0{,}37L'$.

The effective overburden stress at the foundation base:

$$q' = \gamma_\gamma \cdot \sum \gamma_i \cdot h_i = 1 \cdot \sum \gamma_i \cdot h_i = 17{,}952 \text{ KPa}$$

The effective vertical stress due to the foundation load at the foundation base:

$$q_{E,d} = \frac{V_d}{A'} = \frac{921{,}32}{1{,}5884} = 580{,}03 \text{ KPa}$$

$$p = q_{E,d} - q' = 580{,}03 - 17{,}952 = 562{,}08 \text{ KPa}$$

The effective vertical stress due to the foundation load at the limit depth:

$$\sigma_{D_{lim}} = 21{,}784 \text{ KPa}$$

The effective overburden stress at the limit depth:

$$q_{D_{lim}} = 108{,}92 \text{ KPa}$$

Limit depth:

$$D_{lim} = -5{,}5014 \text{ m}$$

This depth may normally be taken as the depth at which the effective vertical stress due to the foundation load is 20 % of the effective overburden stress. EN-1997-1 6.6.2 (6)

Settlement:

$s = \Sigma s_i = 6{,}506$ mm $< s_{lim} = 50{,}000$ mm passed

Reference soil layer: BST - (Solid, dry, sandy gravel)

Compression modulus of the reference soil layer $E_{s,ref} = 1 \cdot 10^5$ KPa

Reference soil layer density $\rho_{s,ref} = 2100$ kg/m³

i	z_0 $[m]$	h_i $[m]$	$h_{i,eq}$ $[m]$	σ_z $[KPa]$	q' $[KPa]$	σ_z/q' $[\%]$	s_i $[mm]$	Σs_i $[mm]$
0.	0	0	0	0	0	-	0	0
1.	−0,1	0,1	0,078881	0	1,8639	0	0	0
2.	−0,2	0,1	0,078881	0	3,7278	0	0	0
3.	−0,3	0,1	0,078881	0	5,5917	0	0	0
4.	−0,4	0,1	0,1	0	7,6518	0	0	0
5.	−0,5	0,1	0,1	0	9,7119	0	0	0
6.	−0,6	0,1	0,1	0	11,772	0	0	0
7.	−0,7	0,1	0,1	0	13,832	0	0	0
8.	−0,8	0,1	0,1	0	15,892	0	0	0
9.	−0,9	0,1	0,1	562,08	17,952	31	0	0
10.	−1	0,1	0,1	520,11	20,012	26	0,541	0,541
11.	−1,1	0,1	0,1	418,38	22,073	19	0,469	1,010
12.	−1,2	0,1	0,1	339,86	24,133	14	0,379	1,389
13.	−1,3	0,1	0,1	288,1	26,193	11	0,314	1,703
14.	−1,4	0,1	0,1	252,28	28,253	9	0,270	1,974
15.	−1,5	0,1	0,1	225,45	30,313	7	0,239	2,212
16.	−1,6	0,1	0,1	203,92	32,373	6	0,307	2,519
17.	−1,7	0,1	0,088413	187,73	34,335	5	0,280	2,799
18.	−1,8	0,1	0,088413	173,44	36,297	5	0,258	3,057
19.	−1,9	0,1	0,088413	160,61	38,259	4	0,239	3,296
20.	−2	0,1	0,088413	148,99	40,221	4	0,221	3,517
21.	−2,1	0,1	0,088413	138,4	42,183	3	0,205	3,722
22.	−2,2	0,1	0,088413	128,7	44,145	3	0,191	3,913
23.	−2,3	0,1	0,088413	119,82	46,107	3	0,178	4,090
24.	−2,4	0,1	0,088413	111,67	48,069	2	0,165	4,256
25.	−2,5	0,1	0,088413	104,2	50,031	2	0,154	4,410
26.	−2,6	0,1	0,088413	97,327	51,993	2	0,144	4,554
27.	−2,7	0,1	0,088413	91,017	53,955	2	0,135	4,688
28.	−2,8	0,1	0,088413	85,217	55,917	2	0,126	4,814
29.	−2,9	0,1	0,088413	79,882	57,879	1	0,118	4,932
30.	−3	0,1	0,088413	74,972	59,841	1	0,111	5,043
31.	−3,1	0,1	0,088413	70,45	61,803	1	0,104	5,147
32.	−3,2	0,1	0,088413	66,282	63,765	1	0,098	5,244

33.	−3,3	0,1	0,088413	62,436	65,727	1	0,092	5,336
34.	−3,4	0,1	0,088413	58,884	67,689	1	0,087	5,423
35.	−3,5	0,1	0,088413	55,6	69,651	1	0,082	5,505
36.	−3,6	0,1	0,088413	52,56	71,613	1	0,077	5,582
37.	−3,7	0,1	0,088413	49,744	73,575	1	0,073	5,655
38.	−3,8	0,1	0,088413	47,131	75,537	1	0,069	5,724
39.	−3,9	0,1	0,088413	44,705	77,499	1	0,066	5,790
40.	−4	0,1	0,088413	42,449	79,461	1	0,062	5,852
41.	−4,1	0,1	0,088413	40,349	81,423	0	0,059	5,911
42.	−4,2	0,1	0,088413	38,392	83,385	0	0,056	5,967
43.	−4,3	0,1	0,088413	36,566	85,347	0	0,054	6,021
44.	−4,4	0,1	0,088413	34,86	87,309	0	0,051	6,072
45.	−4,5	0,1	0,088413	33,264	89,271	0	0,049	6,121
46.	−4,6	0,1	0,088413	31,771	91,233	0	0,046	6,167
47.	−4,7	0,1	0,088413	30,371	93,195	0	0,044	6,211
48.	−4,8	0,1	0,088413	29,058	95,157	0	0,042	6,254
49.	−4,9	0,1	0,088413	27,824	97,119	0	0,041	6,294
50.	−5	0,1	0,088413	26,664	99,081	0	0,039	6,333
51.	−5,1	0,1	0,088413	25,573	101,04	0	0,037	6,371
52.	−5,2	0,1	0,088413	24,544	103,01	0	0,036	6,407
53.	−5,3	0,1	0,088413	23,575	104,97	0	0,034	6,441
54.	−5,4	0,1	0,088413	22,659	106,93	0	0,033	6,474
55.	−5,5	0,1	0,088413	21,795	108,89	0	0,032	6,506
56.	−5,6	0,1	0,088413	20,977	110,85	0	0,031	6,536
57.	−5,7	0,1	0,088413	20,203	112,82	0	0,029	6,566
58.	−5,8	0,1	0,088413	19,47	114,78	0	0,028	6,594
59.	−5,9	0,1	0,088413	18,775	116,74	0	0,027	6,621
60.	−6	0,1	0,088413	18,115	118,7	0	0,026	6,648

z_0 : Depth

h_i : Thickness of the soil layer

$h_{i,eq}$: Equivalent thickness

$$h_{i,eq} = h_i \cdot \left(\frac{E_{s,i}}{E_{s,ref}} \cdot \frac{\rho_{s,ref}}{\rho_{s,i}} \right)^{\frac{1}{2,5}}$$

where:

$\rho_{s,i}$: Soil layer density

$E_{s,i}$: Compression modulus of the soil layer

$E_{s,ref}$: Compression modulus of the reference soil layer

$\rho_{s,ref}$: Reference soil layer density

σ_z : The effective vertical stress due to the foundation load

q' : The effective overburden stress

s_i : Settlement of the soil layer

Σs_i : Total settlement at the given depth