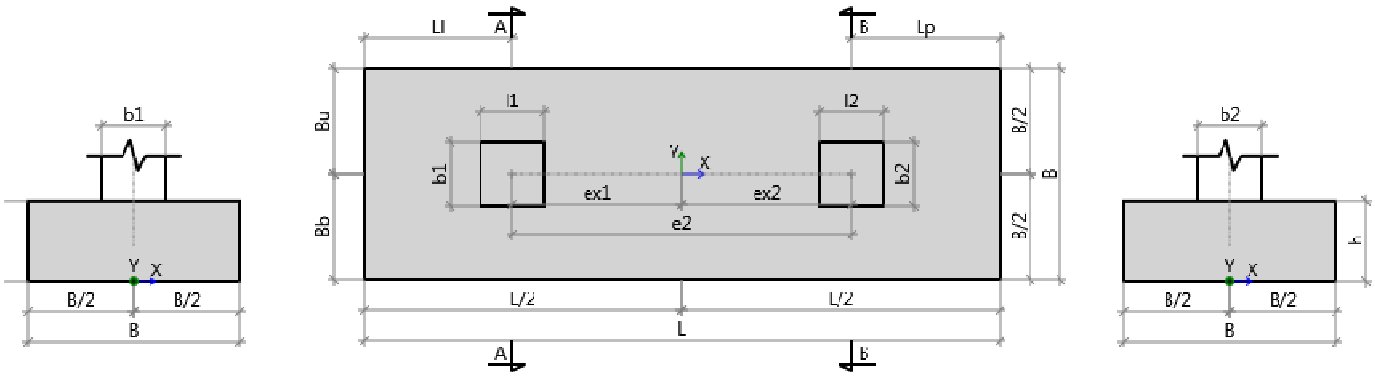
Foundation Pad with Two Columns Analysis & Design According to EC2 1992-1-1-2004 & EC7 with NA=CEN

Calculation according to EUROCODE2 1992-1-1:2004
National annex: CEN

Calculation of foundation: Ultimate Limit State 1

Calculation according to EN 1997-1:2008

Foundation geometry - Pad for two columns



Width of foundation	B	= 2.50 m
Length of foundation	L	= 7.50 m
Height of foundation	H	= 0.95 m
Dimensions of left column	l1	= 0.75 m
	b1	= 0.75 m
Dimensions of right column	l2	= 0.75 m
	b2	= 0.75 m
Column position	e_2	= 4.00 m
	e_{x1}	= -2.00 m
	e_{x2}	= 2.00 m
	e_y	= 0.00 m

Soil input

Nr	Name	Z [m]	H [m]	γ_{soil} [kN/m^3]	γ_s [kN/m^3]	γ_d [kN/m^3]	φ' [deg]	C' [kPa]	C_u [kPa]	M_{Oi} [kPa]	M_i [kPa]
1	poorly graded gravels	-4.90	4.90	20.50	26.00	20.50	0.70	0.00	0.00	19200.00	19200.00
2	clayey sands	-11.00	6.00	11.09	26.80	20.00	0.40	0.00	74.00	36000.00	36000.00
3	silty clays	-14.50	3.50	7.12	26.80	17.00	0.44	25.00	86.00	24000.00	24000.00
4	sand - silt mixtures	-15.50	1.00	12.18	26.50	21.00	0.47	35.00	50.00	22800.00	22800.00

Foundation formation level z_{FL} = -2.50 m
Ground water level z_{WL} = -5.50 m
Foundation cast-in-situ
Depth of unplanned excavation h_{soil} = 1.00 m

Bearing pressure check Critical ULS1 **q_{max} / q_{ult} = 76% Pass**
Sliding check Critical ULS1 **H_{xd} / R_{xres} = 11% Pass**
Sliding check Critical ULS1 **H_{yd} / R_{yres} = 0% Pass**
Uplift check (UPL) Critical SLS1 **$V_{dst,d}$ / $G_{stb,d}$ = 0% Pass**

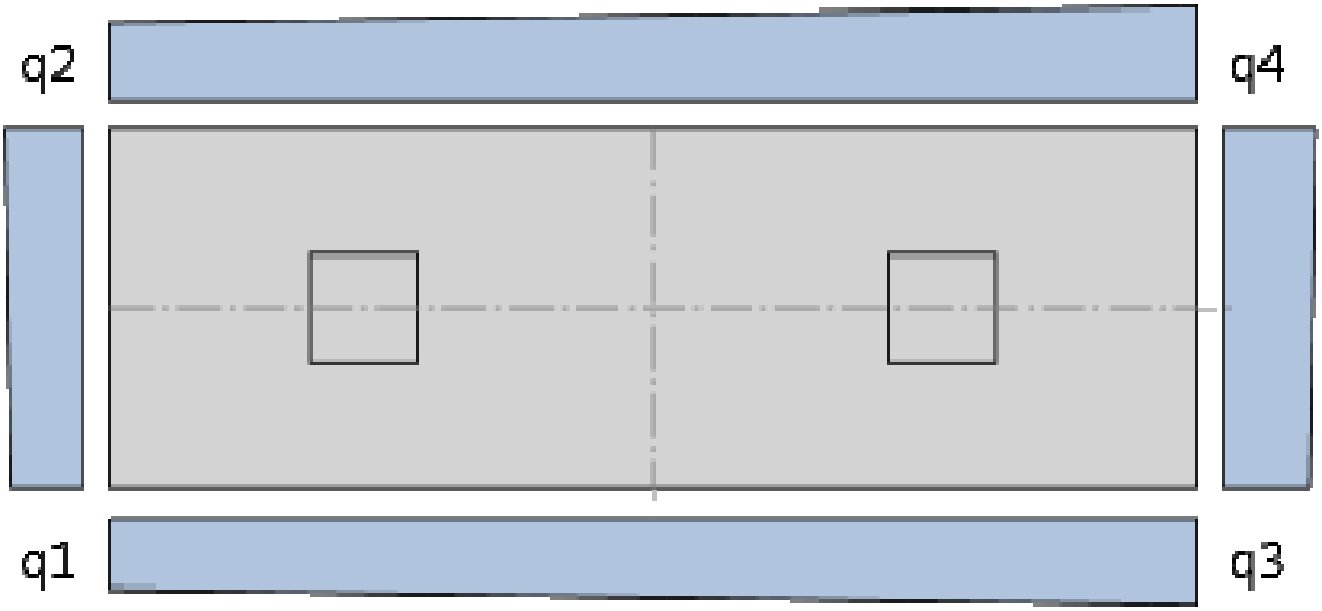
Loads

Design load combinations:

Name	Limit state	V_A [kN]	V_B [kN]	H_{xA} [kN]	H_{xB} [kN]	H_{yA} [kN]	H_{yB} [kN]	M_{xA} [kNm]	M_{xB} [kNm]	M_{yA} [kNm]	M_{yB} [kNm]	q [kPa]
ULS1	ULS	1150.00	1035.00	250.00	75.00	25.00	-35.00	185.00	-105.00	245.00	155.00	15.00

Bearing pressure check

Critical ULS1 **q_{max} / q_{ult} = 76% Pass**



q_1= 192.79 kN/m^2

q_2= 210.84 kN/m^2

q_3= 233.64 kN/m^2

q_4= 251.69 kN/m^2

Maximum pressure q_{max} = 251.69 kN/m^2

Minimum pressure q_{min} = 192.79 kN/m^2

$A = B * L = 18.75$ m^2

$V = V_A + V_B + F = 4167.04$ kN

$e_{Tx}=(V_A * e_{x1} + V_B * e_{x2} + M_{xA} + M_{xB} + (H_{xA} + H_{xB}) * H) / V = 0.11$ m

$e_{Ty}=(V_A * e_y + V_B * e_y + M_{yA} + M_{yB} + (H_{yA} + H_{yB}) * H) / V = 0.02$ m

Base reaction acts within combined middle third of base

$abs(e_{Ty}) / B < 1/3$

$abs(e_{Tx}) / L < 1/3$

$B' = min(B - 2 * abs(e_{Ty}), L - 2 * abs(e_{Tx})) = 6.50$ m

$L' = max(B - 2 * abs(e_{Ty}), L - 2 * abs(e_{Tx})) = 11.06$ m

Bearing pressure for drained conditions

Soil layer - sand - silt mixtures

$N_q = e^{\pi*\tan(\varphi')}*\tan^2(45 + \varphi' / 2) = 13.20$

$N_c = (N_q - 1) * \operatorname{ctg}(\varphi') = 23.94$

$N_y = 2 * (N_q - 1) * \tan(\varphi') = 12.43$

$b_q = b_y = (1 - \alpha * \tan(\varphi'))^2 = 1.00$

$b_c = b_q - (1 - b_q) / (N_c * \tan(\varphi')) = 1.00$

$s_q = 1 + (B' / L') * \sin(\varphi') = 1.27$

$s_y = 1 - 0.3 * (B' / L') = 0.82$

$s_c = (s_q * N_q - 1) / (N_q - 1) = 1.29$

$m_B = [2 + (B' / L')] / [1 + (B' / L')] = 1.63$

$m_L = [2 + (L' / B')] / [1 + (L' / B')] = 1.37$

$\theta = \operatorname{atan}(H_x / H_y) = -1.54$

$m = m_L * \cos^2\theta + m_B * \sin^2\theta = 1.63$

$i_q = [1 - H / (V + A' * c' * \operatorname{ctg}(\varphi'))]^m = 0.99$

$i_c = i_q - (1 - i_q) / (N_c * \tan(\varphi')) = 0.99$

$i_y = [1 - H / (V + A' * c' * \operatorname{ctg}(\varphi'))]^{m+1} = 0.98$

$q' = 51.25$ kPa

Allowable bearing pressure $q_{ultD} = c' * Nc * b_c * s_c * i_c + q' * N_q * b_q * s_q * i_q + 0,5 * \gamma_i' * B' * N_\gamma * b_\gamma * s_\gamma * i_\gamma = 2599.17$ kN/m^2

Allowable bearing pressure $q_{ult} = q_{ultD} / \gamma_{R,v} = 331.87$ kN/m^2

Sliding check

Critical ULS1 **H_{xd} / R_{xres} = 11% Pass**

Total horizontal load $H_{xd} = H_{xA} + H_{xB} + R_{xa} = 325.00$ kN

Minimum vertical load $V_{G,min} = [V_{GA} + V_{GB} + A * (q_{Gsur} + q_{swt} + q_{soil})] * \gamma_{FG.pos} = 3226.09$ kN

Bearing pressure for drained conditions $R_{dD} = V_{G,min} * \tan(\delta_k) / \gamma_{R,h} = 2707.01$ kN

$K_p = (1 + \sin(\varphi')) / (1 - \sin(\varphi')) = 4.60$

Passive resistance of soil $R_{px,d} = 265.16$ kN

Total resistance to sliding $R_{xres} = \min(R_{dD}, R_{dUD}) + R_{xp,d} + R_{d.add} = 2972.17$ kN

Critical ULS1 **H_{yd} / R_{yres} = 0% Pass**

Total horizontal load $H_{yd} = H_{yA} + H_{yB} + R_{ya} = -10.00$ kN

Minimum vertical load $V_{G,min} = [V_{GA} + V_{GB} + A * (q_{Gsur} + q_{swt} + q_{soil})] * \gamma_{FG.pos} = 3226.09$ kN

Bearing pressure for drained conditions $R_{dD} = V_{G,min} * \tan(\delta_k) / \gamma_{R,h} = 2707.01$ kN

$K_p = (1 + \sin(\varphi')) / (1 - \sin(\varphi')) = 4.60$

Passive resistance of soil	$R_{py,d}$ = 795.47 kN
Total resistance to sliding	$R_{yres} = \min(R_{dD}, R_{dUD}) + R_{yp,d} + R_{d.add}$ = 3502.48 kN

Uplift check (UPL)

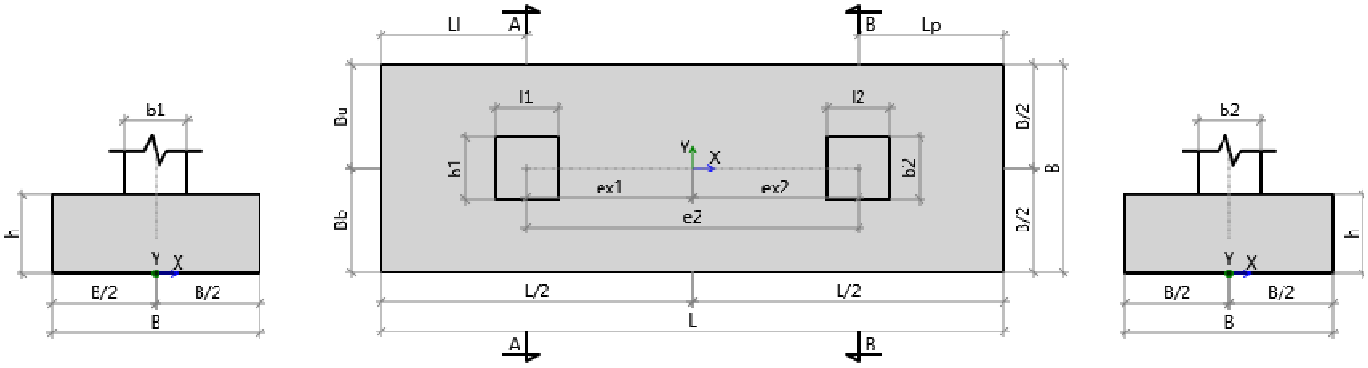
Critical SLS1 **$V_{dst,d} / G_{stb,d}$ = 0% Pass**

Stabilizing vertical actions	$G_{stb,d} = V_{G,min} * \gamma_{Gstb}$ = 936.98 kN
Destabilizing permanent and variable vetical actions	$V_{dst,d} = \max(-V + \gamma_w * \min(h_{FL} - h_{WL}, 0) * A; \gamma_w * \max(h_{FL} - h_{WL}, 0) * A)$ = 0.00 kN

Calculation of foundation: Servicebility Limit State 1

Calculation according to EN 1997-1:2008

Foundation geometry - Pad for two columns



Width of foundation	B	= 2.50 m
Length of foundation	L	= 7.50 m
Height of foundation	H	= 0.95 m
Dimensions of left column	l1	= 0.75 m
	b1	= 0.75 m
Dimensions of right column	l2	= 0.75 m
	b2	= 0.75 m
Column position	e_2	= 4.00 m
	e_{x1}	= -2.00 m

e_{x2} = 2.00 m

e_y = 0.00 m

Soil input

Nr	Name	Z [m]	H [m]	γ_{soil} [kN/m^3]	γ_s [kN/m^3]	γ_d [kN/m^3]	φ' [deg]	C' [kPa]	C_u [kPa]	M_{Oi} [kPa]	M_i [kPa]
1	poorly graded gravels	-4.90	4.90	20.50	26.00	20.50	0.70	0.00	0.00	19200.00	19200.00
2	clayey sands	-11.00	6.10	11.09	26.80	20.00	0.40	0.00	74.00	36000.00	36000.00
3	silty clays	-14.50	3.50	7.12	26.80	17.00	0.44	25.00	86.00	24000.00	24000.00
4	sand - silt mixtures	-15.50	1.00	12.18	26.50	21.00	0.47	35.00	50.00	22800.00	22800.00

Foundation formation level z_{FL} = -2.50 m

Ground water level z_{WL} = -5.50 m

Foundation cast-in-situ

Depth of unplanned excavation h_{soil} = 1.00 m

Settlement check Critical SLS1 **s / s_{allow} = 73% Pass**

Differental settlement check Critical SLS1 **$s_{max} - s_{min} / s_{diff}$ = 4% Pass**

Loads

Design load combinations:

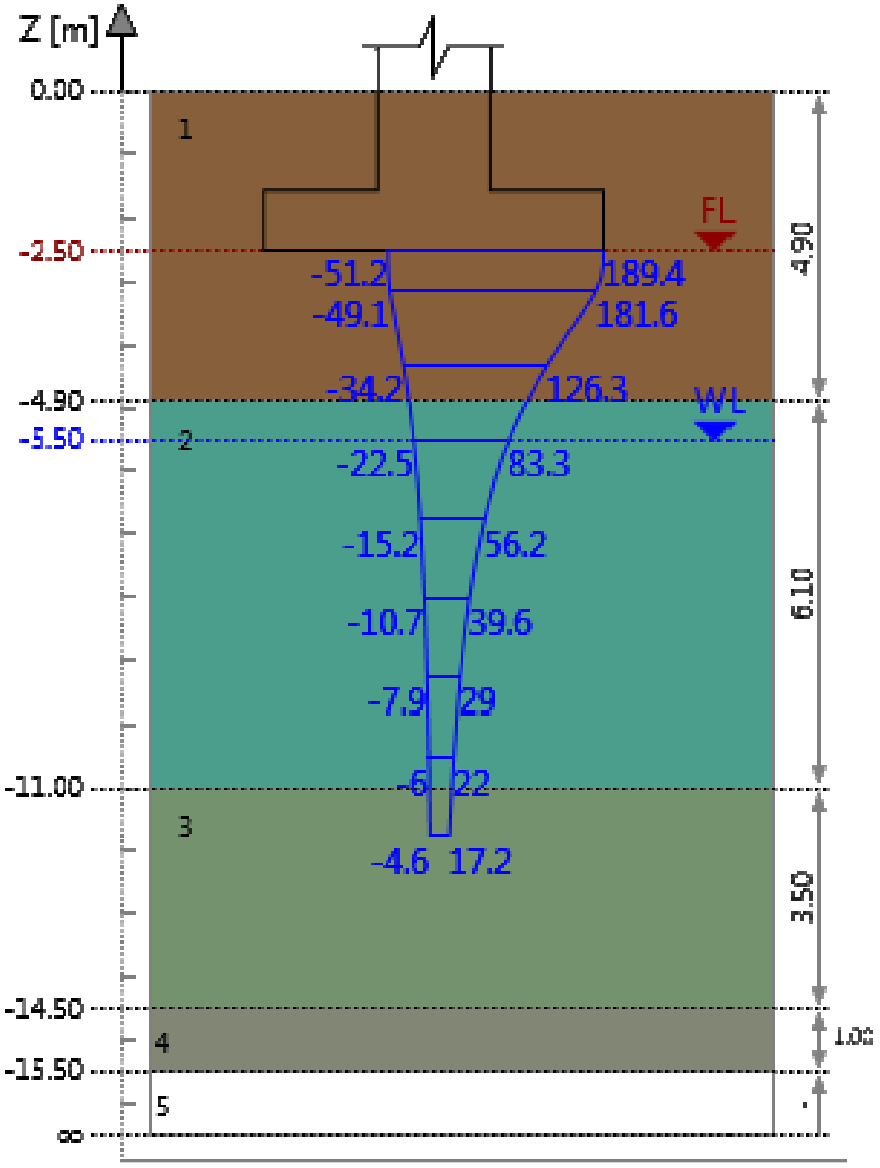
Name	Limit state	V_A [kN]	V_B [kN]	H_{xA} [kN]	H_{xB} [kN]	H_{yA} [kN]	H_{yB} [kN]	M_{xA} [kNm]	M_{xB} [kNm]	M_{yA} [kNm]	M_{yB} [kNm]	q [kPa]
SLS1	SLS	1050.00	1035.00	150.00	25.00	10.00	-15.00	85.00	-85.00	145.00	105.00	15.00

Settlement check

Critical SLS1 **s / s_{allow} = 73% Pass**

No	Z [m]	H [m]	σ_{zp} [kN/m^2]	σ'_{zp} [kN/m^2]	σ_{zq} [kN/m^2]	σ_{zsi} [kN/m^2]	σ_{zdi} [kN/m^2]	s_i [mm]
1	-2.50	0.00	51.25	-51.25	240.66	-51.25	189.41	0.00
2	-3.13	1.25	64.06	-49.14	230.75	-49.14	181.61	15.02

3	-4.33	1.15	88.66	-34.18	160.49	-34.18	126.31	9.61
4	-5.53	1.25	112.87	-22.53	105.78	-22.53	83.25	3.67
5	-6.78	1.25	133.87	-15.21	71.40	-15.21	56.20	2.48
6	-8.03	1.25	154.87	-10.72	50.34	-10.72	39.62	1.75
7	-9.28	1.25	175.87	-7.86	36.89	-7.86	29.04	1.28
8	-10.53	1.25	196.87	-5.96	27.97	-5.96	22.01	1.46
9	-11.78	1.25	217.87	-4.65	21.82	-4.65	17.17	1.20



Intermediate settlement	$s_0 = \Sigma(\sigma_{zdi} * h_i / M_{Oi}) = 28.70$ mm
Consolidation settlement	$s_1 = \Sigma(\lambda * \sigma_{zsi} * h_i / M_i) = 7.77$ mm
Total settlement	$s = s_0 + s_1 = 36.47$ mm
Allowable settlement	$s_{allow} = 50.00$ mm

Differental settlement check

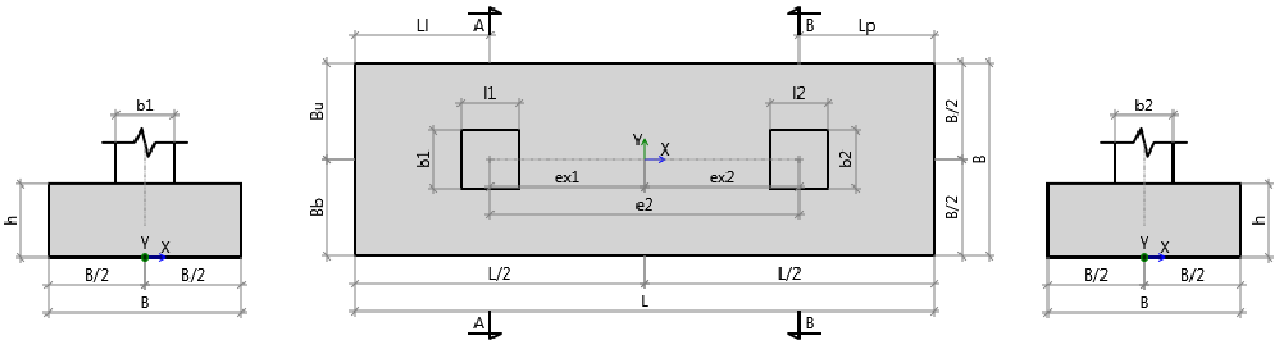
Critical SLS1 $s_{max} - s_{min} / s_{diff}$ **= 4% Pass**

Total maximum settlement	$s_{max} = 13.63$ mm
Total minimum settlementt	$s_{min} = 11.83$ mm
Allowable differential settlement	$s_{diff} = 50.00$ mm

Calculation of foundation: Reinforcement 1

Calculation according to EN 1997-1:2008

Foundation geometry - Pad for two columns



Width of foundation	B	= 2.50 m
Length of foundation	L	= 7.50 m
Height of foundation	H	= 0.95 m
Dimensions of left column	l1	= 0.75 m

	b1	= 0.75 m
Dimensions of right column	l2	= 0.75 m
	b2	= 0.75 m
Column position	e_2	= 4.00 m
	e_{x1}	= -2.00 m
	e_{x2}	= 2.00 m
	e_y	= 0.00 m

Soil input

Nr	Name	Z [m]	H [m]	γ_{soil} [kN/m^3]	γ_s [kN/m^3]	γ_d [kN/m^3]	φ' [deg]	C' [kPa]	C_u [kPa]	M_{Oi} [kPa]	M_i [kPa]
1	poorly graded gravels	-4.90	4.90	20.50	26.00	20.50	0.70	0.00	0.00	19200.00	19200.00
2	clayey sands	-11.00	6.10	11.09	26.80	20.00	0.40	0.00	74.00	36000.00	36000.00
3	silty clays	-14.50	3.50	7.12	26.80	17.00	0.44	25.00	86.00	24000.00	24000.00
4	sand - silt mixtures	-15.50	1.00	12.18	26.50	21.00	0.47	35.00	50.00	22800.00	22800.00

Foundation formation level	z_{FL} = -2.50 m
Ground water level	z_{WL} = -5.50 m
Foundation	cast-in-situ
Depth of unplanned excavation	h_{soil} = 1.00 m

Bending in direction x - Bottom reinforcement	Critical SLS1	$A_{s.xreq}$ / $A_{s.xprov}$ = 7% Pass
Bending in direction x - Top reinforcement	Critical ULS1	$A_{s.xreq}$ / $A_{s.xprov}$ = 8% Pass
Bending in direction y - Bottom reinforcement	Critical ULS1	$A_{s.yreq}$ / $A_{s.yprov}$ = 9% Pass
Bending in direction y - Top reinforcement	Critical ULS1	$A_{s.yreq}$ / $A_{s.yprov}$ = 9% Pass
Punching shear check	Critical ULS1	V_{Ed} / $V_{Rd.c}$ = 30% & $V_{Ed'}$ / $V_{Rd.c\ max}$ = 18% Pass
Punching shear check	Critical SLS1	V_{Ed} / $V_{Rd.c}$ = 27% & $V_{Ed'}$ / $V_{Rd.c\ max}$ = 16% Pass

Loads

Design load combinations:

Name	Limit state	V_A [kN]	V_B [kN]	H_{xA} [kN]	H_{xB} [kN]	H_{yA} [kN]	H_{yB} [kN]	M_{xA} [kNm]	M_{xB} [kNm]	M_{yA} [kNm]	M_{yB} [kNm]	q [kPa]
ULS1	ULS	1150.00	1035.00	250.00	75.00	25.00	-35.00	185.00	-105.00	245.00	155.00	15.00

Foundation properties

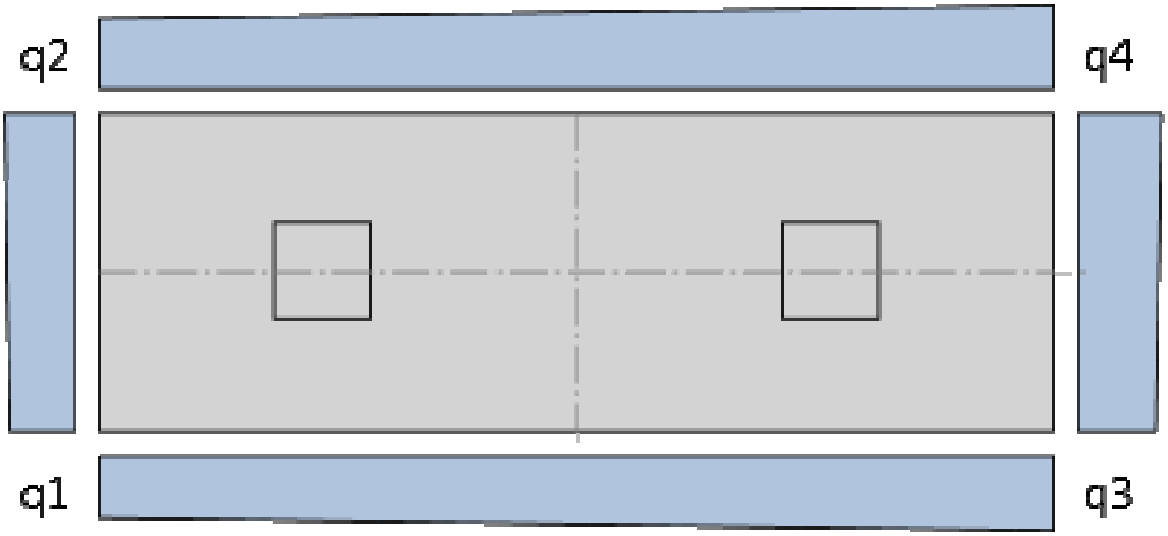
d_{1x} = 0.099 m
d_{2x} = 0.099 m

Concrete C30/37

f_{ck} = 30.00 MPa
γ_c = 1.50
f_{cd} = 20.00 MPa

Steel B 500 A

f_{yk} = 500.00 MPa
γ_s = 1.15
f_{yd} = 434.78 MPa



minimum reinforcement ratio	ρ_{min}	= 0.12 %
maximum reinforcement ratio	ρ_{max}	= 4.00 %
Reinforcement ratio	ρ	= 0.03 %

Bending in direction x - Bottom reinforcement

SLS1 **$A_{s.xreq}$ / $A_{s.xprov}$ = 7% Pass**

Design bending moment in direction x	M_y	= 423.97 kNm
Theoretical area of reinforcement in direction x	$A_{s.xreq}$	= 13.04 cm^2/m
Provided area of reinforcement in direction x	$A_{s.xprov}$	= 180.96 cm^2/m

Bending in direction x - Top reinforcement

ULS1 **$A_{s.xreq}$ < $A_{s.xprov}$ = 8% Pass**

Design negative bending moment in direction x	M_{yneg}	= -394.85 kNm
Theoretical area of reinforcement for negative moment	$A_{s.xneg.req}$	= 13.54 cm^2/m
Provided area of reinforcement for negative moment	$A_{s.xneg.prov}$	= 180.96 cm^2/m

Bending in direction y - Bottom reinforcement

ULS1 **$A_{s.yreg}$ / $A_{s.yprov}$ = 9% Pass**

Design bending moment in direction y	M_x	= 634.31 kNm
Theoretical area of reinforcement in direction y	$A_{s.yreg}$	= 16.11 cm^2/m
Provided area of reinforcement in direction y	$A_{s.yprov}$	= 180.96 cm^2/m

Bending in direction y - Top reinforcement

ULS1 **$A_{s.yreg}$ / $A_{s.yprov}$ = 9% Pass**

Design bending moment in direction y	M_x	= 634.31 kNm
Theoretical area of reinforcement in direction y	$A_{s.yneg.req}$	= 14.73 cm^2/m
Provided area of reinforcement in direction y	$A_{s.yneg.prov}$	= 180.96 cm^2/m

Punching shear check

SLS1 **V_{Ed} \ $V_{Rd.c}$ = 27% & $V_{Ed'}$ \ $V_{Rd.c\ max}$ = 16% Pass**

β = 1.97

$u_1 = \min(4 * \pi * d + 2 * l_1 + 2 * b_1, 2 * (B + L)) = 13.39$ m

$u_0 = 2 * l_1 + 2 * b_1 = 3.00$ m

Net applied force

$V_{Ed} = \beta * V_{Ed,red} / (u_1 * d) = 186.47$ kN

$V_{Ed'} = \beta * V_{Ed,red} / (u_0 * d) = 832.42$ kN

$C_{Rd.c} = 0.18 / \gamma_c = 0.12$

$k = \min(1 + \text{sqrt}(200 / d), 2) = 1.49$

$\rho_L = \min(\text{sqrt}(\rho_x * \rho_y), 2) = 2.00$ %

$V_{min} = 0.035 * k^{3/2} * f_{ck}^{1/2} = 285.98$ kN

Punching shear capacity at control perimeter at distance 2*d from column edge

$V_{Rd.c} = \min(C_{Rd.c} * k * (100 * \rho_L * f_{ck})^{1/3}, V_{min}) * 2 * d / a = 700.81$ kN

$v = 0.6 * (1 - f_{ck} / 250\ \text{MPa}) = 0.53$

Maximum punching shear capacity column perimeter

$V_{Rd.c\ max} = 0.5 * v * f_{cd} = 5280.00$ kN

Punching shear check

SLS1

$V_{Ed} \setminus V_{Rd.c} = 27\%$ & $V_{Ed'} \setminus V_{Rd.c\ max} = 16\%$ Pass

$\beta = 1.97$

$u_1 = \min(4 * \pi * d + 2 * l_1 + 2 * b_1, 2 * (B + L)) = 13.39$ m

$u_0 = 2 * l_1 + 2 * b_1 = 3.00$ m

Net applied force

$V_{Ed} = \beta * V_{Ed,red} / (u_1 * d) = 186.47$ kN

$V_{Ed'} = \beta * V_{Ed,red} / (u_0 * d) = 832.42$ kN

$C_{Rd.c} = 0.18 / \gamma_c = 0.12$

$k = \min(1 + \text{sqrt}(200 / d), 2) = 1.49$

$\rho_L = \min(\text{sqrt}(\rho_x * \rho_y), 2) = 2.00$ %

$V_{min} = 0.035 * k^{3/2} * f_{ck}^{1/2} = 285.98$ kN

Punching shear capacity at control perimeter at distance 2*d from column edge

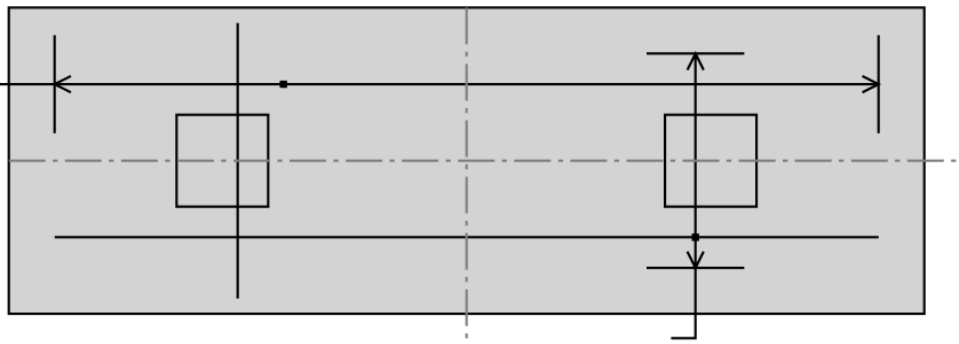
$V_{Rd.c} = \min(C_{Rd.c} * k * (100 * \rho_L * f_{ck})^{1/3}, V_{min}) * 2 * d / a = 700.81$ kN

$v = 0.6 * (1 - f_{ck} / 250\ \text{MPa}) = 0.53$

Maximum punching shear capacity column perimeter

$V_{Rd.c\ max} = 0.5 * v * f_{cd} = 5280.00$ kN

Top ø 48 @ 100mm (74x)
Bottom ø 48 @ 100mm (74x)



Top ø 48 @ 100mm (24x)
Bottom ø 48 @ 100mm (24x)

GEODOMISI Ltd. - Dr. Costas Sachpazis
Civil & Geotechnical Engineering Consulting Company for Structural Engineering, Soil Mechanics, Rock Mechanics, Foundation Engineering & Retaining Structures.
Tel.: (+30) 210 5238127, 210 5711263 - Fax.:+30 210 5711461 - Mobile: (+30) 6936425722 & (+44) 7585939944,
www.geodomisi.com - costas@sachpazis.info