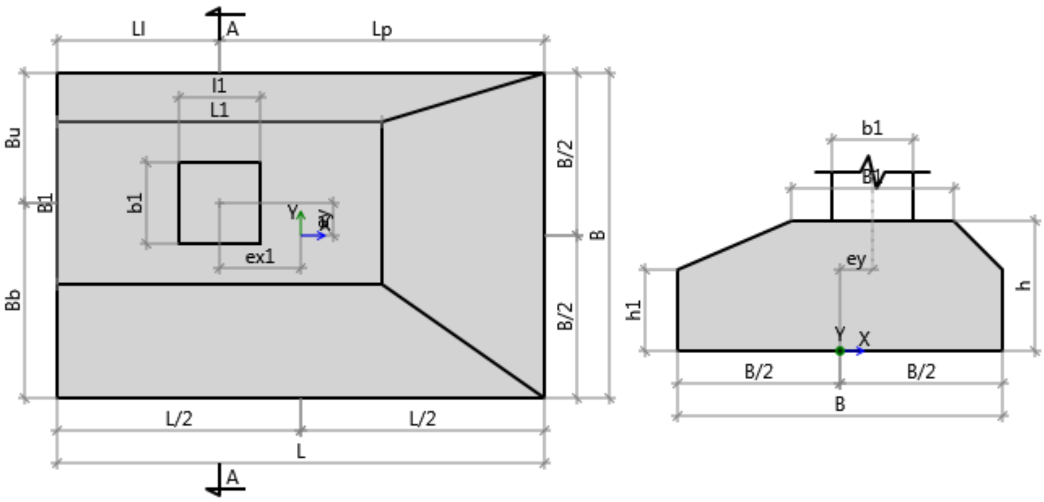
Calculation of foundation: Ultimate Limit State 1

Calculation according to EN 1997-1:2008

Foundation geometry - Trapezoidal pad for one column



Width of foundation	B	= 2.00 m
Length of foundation	L	= 3.00 m
Height of foundation	H	= 0.80 m
Width of top platform	B1	= 1.00 m
Length of top platform	L1	= 2.00 m
Height of step	H1	= 0.50 m
Dimensions of column	l1	= 0.50 m
	b1	= 0.50 m
Column position	e_{x1}	= -0.50 m
	e_y	= 0.20 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	inorganic high plasticy clays	-4.00	4.00	11.66	26.60	20.50	0.33	0.00	100.00	20192.31	20192.31
2	clayey gravels	-7.00	3.00	11.67	26.50	20.50	0.56	0.00	9.50	30000.00	30000.00

Foundation formation level	z_{FL} = -1.00 m
Ground water level	z_{WL} = -3.00 m
Foundation	cast-in-situ

Bearing pressure check	Critical ULS2	**q_{max} / q_{ult} = 100% Pass**
Sliding check	Critical ULS3	**H_{xd} / R_{xres} = 14% Pass**
Sliding check	Critical ULS3	**H_{yd} / R_{yres} = 8% Pass**
Uplift check (UPL)	Critical ULS1	**$V_{dst,d}$ / $G_{stb,d}$ = 0% Pass**

Dimensions after optimization

Width of foundation	B = 5.80 m
Length of foundation	L = 6.80 m
Height of foundation	H = 1.50 m
Width of top foundation	B1 = 1.00 m
Length of top foundation	L1 = 2.00 m
Height of down stepped foundation	h1 = 0.50 m
Height of top stepped foundation	h2 = 1.00 m

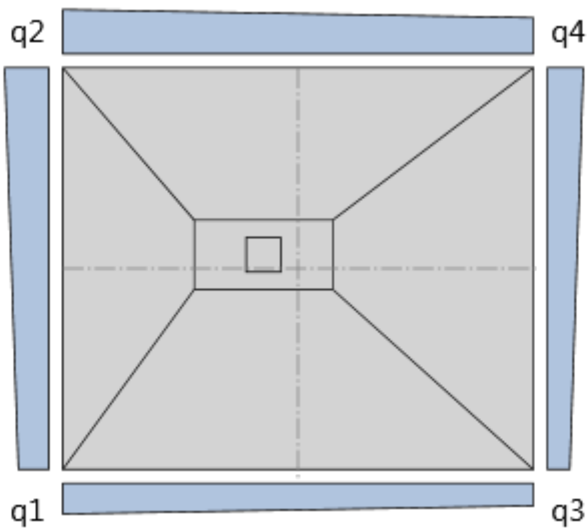
Loads

Design load combinations:

Name	Limit state	V_A [kN]	H_{xA} [kN]	H_{yA} [kN]	M_{xA} [kNm]	M_{yA} [kNm]	q [kPa]
ULS1	ULS	450.00	85.00	50.00	25.00	150.00	3.00
ULS2	ULS	800.00	25.00	25.00	250.00	50.00	3.00
ULS3	ULS	500.00	100.00	55.00	30.00	10.00	5.00

Bearing pressure check

Critical ULS2 **q_{max} / q_{ult} = 100% Pass**



q_1= 52.92 kN/m^2

q_2= 76.39 kN/m^2

q_3= 38.93 kN/m^2

q_4= 62.41 kN/m^2

Maximum pressure q_{max} = 76.39 kN/m^2

Minimum pressure q_{min} = 38.93 kN/m^2

A = B * L = 39.44 m^2

V = V_A + V_B + F = 2274.22 kN

e_{Tx}=(V_A * e_{x1} + V_B * e_{x2} + M_{xA} + M_{xB} + (H_{xA} + H_{xB}) * H) / V = -0.14 m

e_{Ty}=(V_A * e_y + V_B * e_y + M_{yA} + M_{yB} + (H_{yA} + H_{yB}) * H) / V = 0.20 m

Base reaction acts within combined middle third of base

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

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

B = B - 2 * 0.10 m = 5.80 m

L = L - 2 * 0.10 m = 6.80 m

$B' = min(B - 2 * abs(e_{Ty}), L - 2 * abs(e_{Tx})) = 6.39$ m

$L' = max(B - 2 * abs(e_{Ty}), L - 2 * abs(e_{Tx})) = 7.38$ m

Bearing pressure for drained conditions

Soil layer - clayey gravels

$N_q = e^{\pi * tan(\varphi')} * tan^2(45 + \varphi' / 2) = 23.18$

$N_c = (N_q - 1) * ctg(\varphi') = 35.49$

$N_y = 2 * (N_q - 1) * tan(\varphi') = 27.72$

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

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

$s_q = 1 + (B' / L') * sin(\varphi') = 1.46$

$s_y = 1 - 0.3 * (B' / L') = 0.74$

$s_c = (s_q * N_q - 1) / (N_q - 1) = 1.48$

$m_B = [2 + (B' / L')] / [1 + (B' / L')] = 1.54$

$m_L = [2 + (L' / B')] / [1 + (L' / B')] = 1.46$

$\theta = atan(H_x / H_y) = 0.79$

$m = m_L * cos^2\theta + m_B * sin^2\theta = 1.50$

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

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

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

q' = 20.50 kPa

Allowable bearing pressure — $q_{ultD} = c' * Nc * b_c * s_c * i_c + q' * N_q * b_q * s_q * i_q + 0,5 * \gamma_i' * B' * N_y * b_y * s_y * i_y = 2014.38$ kN/m^2

Bearing pressure for undrained conditions

Soil layer - clayey gravels

$b_c = 1 - 2 * \alpha / (\pi + 2) = 1.00$

$s_c = 1 + 0.2 * (B' / L') = 1.17$

$i_c = 1 / 2 * [1 + sqrt(1 - H / (A' * c_u))] = 0.98$

q = 20.50 kPa

$q_{ultUD} = (\pi + 2) * c_u * b_c * s_c * i_c + q = 76.65$ kN/m^2

Allowable bearing pressure — $q_{ult} = min (q_{ultD}, q_{ultUD}) / \gamma_{R,v} = 76.65$ kN/m^2

Sliding check

Critical ULS3 — H_{xd}/ R_{xres} **= 14% Pass**

Total horizontal load	$H_{xd} = H_{xA} + H_{xB} + R_{xa} = 100.00$ kN
Minimum vertical load	$V_{G,min} = [V_{GA} + V_{GB} + A * (q_{Gsur} + q_{swt} + q_{soil})] * \gamma_{FG.pos} = 2059.00$ kN
Bearing pressure for drained conditions	$R_{dD} = V_{G,min} * tan(\delta_k) / \gamma_{R,h} = 708.97$ kN
Bearing pressure for undrained conditions	$R_{dUD} = A' * c_u / \gamma_{R,h} = 4718.70$ kN
Total resistance to sliding	$R_{xres} = min(R_{dD}, R_{dUD}) + R_{xp,d} + R_{d.add} = 708.97$ kN

Critical ULS3 — H_{yd}/ R_{yres} **= 8% Pass**

Total horizontal load	$H_{yd} = H_{yA} + H_{yB} + R_{ya} = 55.00$ kN
Minimum vertical load	$V_{G,min} = [V_{GA} + V_{GB} + A * (q_{Gsur} + q_{swt} + q_{soil})] * \gamma_{FG.pos} = 2059.00$ kN
Bearing pressure for drained conditions	$R_{dD} = V_{G,min} * tan(\delta_k) / \gamma_{R,h} = 708.97$ kN

Bearing pressure for undrained conditions	$R_{dUD} = A' * c_u / \gamma_{R,h} = 4718.70$ kN
Total resistance to sliding	$R_{yres} = \min(R_{dD}, R_{dUD}) + R_{yp,d} + R_{d.add} = 708.97$ kN

Uplift check (UPL)

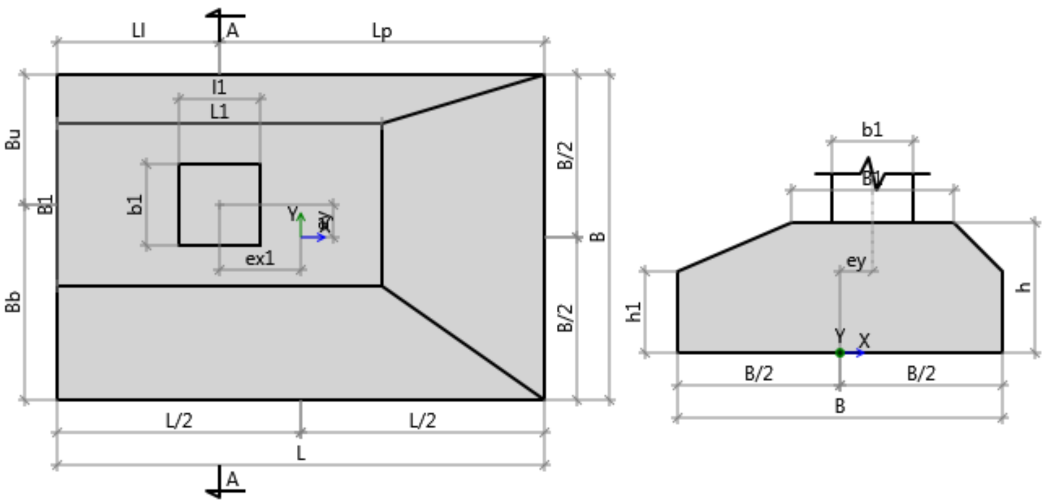
Critical ULS1 **$V_{dst,d}$ / $G_{stb,d}$ = 0% Pass**

Stabilizing vertical actions	$G_{stb,d} = V_{G,min} * \gamma_{Gstb} = 1476.63$ 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: Reinforcement 1

Calculation according to EN 1997-1:2008

Foundation geometry - Trapezoidal pad for one column



Width of foundation	B	= 2.00 m
Length of foundation	L	= 3.00 m
Height of foundation	H	= 0.80 m
Width of top platform	B1	= 1.00 m
Length of top platform	L1	= 2.00 m
Height of step	H1	= 0.50 m
Dimensions of column	l1	= 0.50 m
	b1	= 0.50 m
Column position	e_{x1}	= -0.50 m
	e_y	= 0.20 m

Soil input

Nr	Name	Z [m]	H [m]	γ_{soil} [kN/m³]	γ_s [kN/m³]	γ_d [kN/m³]	φ' [deg]	C' [kPa]	C_u [kPa]	M_{Oi} [kPa]	M_i [kPa]

1	inorganic high plasticy clays	-4.00	4.00	11.66	26.60	20.50	0.33	0.00	100.00	20192.31	20192.31
2	clayey gravels	-7.00	3.00	11.67	26.50	20.50	0.56	0.00	9.50	30000.00	30000.00

Foundation formation level z_{FL} = -1.00 m
Ground water level z_{WL} = -3.00 m
Foundation cast-in-situ

Bending in direction x - Bottom reinforcement Critical ULS3 **$A_{s.xreq}$ / $A_{s.xprov}$ = 47% Pass**
Bending in direction y - Bottom reinforcement Critical ULS3 **$A_{s.yreq}$ / $A_{s.yprov}$ = 49% Pass**
Punching shear check Critical ULS3 **V_{Ed} / $V_{Rd.c}$ = 30% & $V_{Ed'}$ / $V_{Rd.c\ max}$ = 12% Pass**

Dimensions after optimization

Width of foundation B = 4.70 m
Length of foundation L = 5.70 m
Height of foundation H = 1.20 m
Width of top foundation B1 = 1.00 m
Length of top foundation L1 = 2.00 m
Height of down stepped foundation h1 = 0.50 m
Height of top stepped foundation h2 = 0.70 m

Loads

Design load combinations:

Name	Limit state	V_A [kN]	H_{xA} [kN]	H_{yA} [kN]	M_{xA} [kNm]	M_{yA} [kNm]	q [kPa]
ULS1	ULS	450.00	85.00	50.00	25.00	150.00	3.00
ULS2	ULS	800.00	25.00	25.00	250.00	50.00	3.00
ULS3	ULS	500.00	100.00	55.00	30.00	10.00	5.00

Foundation properties

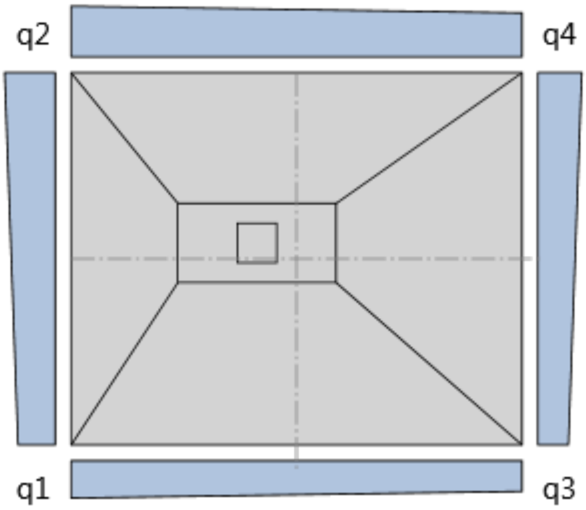
d_{1x} = 0.053 m
d_{2x} = 0.053 m

Concrete C20/25

f_{ck} = 20.00 MPa
γ_c = 1.50
f_{cd} = 13.33 MPa

Steel B 400 B

f_{yk} = 400.00 MPa
γ_s = 1.15
f_{yd} = 347.83 MPa



minimum reinforcement ratio	ρ_{min}	= 0.12 %
maximum reinforcement ratio	ρ_{max}	= 4.00 %
Reinforcement ratio	ρ	= 0.00 %

Bending in direction x - Bottom reinforcement

ULS3 — **$A_{s.xreq}$ / $A_{s.xprov}$ = 47% Pass**

Design bending moment in direction x	M_y	= 132.88 kNm
Theoretical area of reinforcement in direction x	$A_{s.xreq}$	= 3.76 cm^2/m
Provided area of reinforcement in direction x	$A_{s.xprov}$	= 8.04 cm^2/m

Bending in direction y - Bottom reinforcement

ULS3 — **$A_{s.yreg}$ / $A_{s.yprov}$ = 49% Pass**

Design bending moment in direction y	M_x	= 52.73 kNm
Theoretical area of reinforcement in direction y	$A_{s.yreg}$	= 3.91 cm^2/m
Provided area of reinforcement in direction y	$A_{s.yprov}$	= 8.04 cm^2/m

Punching shear check

ULS3 — **V_{Ed} \ $V_{Rd.c}$ = 30% & $V_{Ed'}$ \ $V_{Rd.c\ max}$ = 12% Pass**

$\beta = 1.38$

$u_1 = min(4 * \pi * d + 2 * l_1 + 2 * b_1, 2 * (B + L)) = 12.05$ m

$u_0 = 2 * l_1 + 2 * b_1 = 2.00$ m

Net applied force: $V_{Ed} = \beta * V_{Ed,red} / (u_1 * d) = 71.55$ kN

$V_{Ed'} = \beta * V_{Ed,red} / (u_0 * d) = 431.18$ kN

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

$k = min(1 + sqrt(200 / d), 2) = 1.50$

$\rho_L = min(sqrt(\rho_x * \rho_y), 2) = 0.07$ %

$V_{min} = 0.035 * k^{3/2} * f_{ck}^{1/2} = 234.79$ kN

Punching shear capacity at control perimeter at distance 2*d from column edge	$V_{Rd.c}$ = min($C_{Rd.c}$ * k * (100 * ρ_L * f_{ck})$^{1/3}$, V_{min}) * 2 * d / a = 234.79 kN
	v = 0.6 * (1 - f_{ck} / 250 MPa) = 0.55
Maximum punching shear capacity column perimeter	$V_{Rd.c\ max}$ = 0.5 * v * f_{cd} = 3680.00 kN