FOUNDATION ANALYSIS

In accordance with EN1997-1:2004 + A1:2013 incorporating corrigendum February 2009 and the UK National Annex incorporating corrigendum No.1

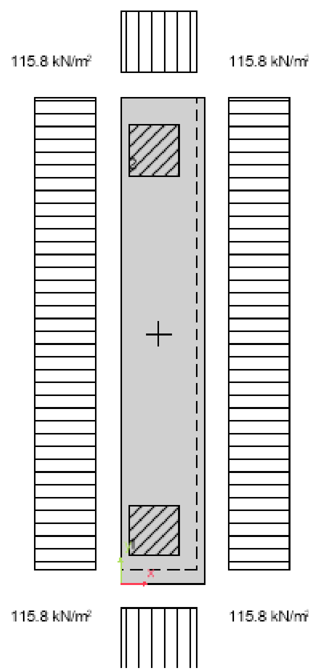
Tedds calculation version 3.3.05

Summary table

Description	Unit	Allowable	Actual	Utilisation	Result
Sliding	kN	58.3	13.4	0.229	Pass
Base pressure	kN/m^2	551.4	115.8	0.210	Pass
Description	**Unit**	**Provided**	**Required**	**Utilisation**	**Result**
Reinforcement x-direction	mm^2	4624	1275	0.276	Pass
Reinforcement y-dir, top	mm^2	1005	340	0.339	Pass
		Allowable	Actual	Utilisation	
Description	**Unit**	**Allowable**	**Actual**	**Utilisation**	**Result**
Punching shear	N/mm^2	0.832	0.271	0.326	Pass

Pad foundation details

Length of foundation	L_x = **500** mm
Width of foundation	L_y = **2900** mm
Foundation area	$A = L_x \times L_y$ = **1.450** m^2
Depth of foundation	h = **500** mm
Depth of soil over foundation	h_{soil} = **0** mm
Level of water	h_{water} = **0** mm
Density of water	γ_{water} = **9.8** kN/m^3
Density of concrete	γ_{conc} = **25.0** kN/m^3



Column no.1 details

Length of column l_{x1} = **300** mm

Width of column l_{y1} = **300** mm

position in x-direction x_1 = **200** mm

position in y-direction y_1 = **317** mm

Column no.2 details

Length of column l_{x2} = **300** mm

Width of column l_{y2} = **300** mm

position in x-direction x_2 = **200** mm

position in y-direction y_2 = **2583** mm

Soil properties

Density of soil γ_{soil} = **18.0** kN/m^3

Characteristic cohesion c'_k = **20** kN/m^2

Characteristic effective shear resistance angle ϕ'_k = **33** deg

Characteristic friction angle δ_k = **25** deg

Foundation loads

Self weight $F_{swt} = h \times \gamma_{conc}$ = **12.5** kN/m^2

Column no.1 loads

Permanent axial load F_{Gz1} = **55.0** kN

Variable axial load F_{Qz1} = **5.0** kN

Wind horizontal load in x-direction F_{Wx1} = **2.5** kN

Wind horizontal load in y-direction F_{Wy1} = **4.5** kN

Snow axial load F_{Sz1} = **9.0** kN

Column no.2 loads

Permanent axial load F_{Gz2} = **55.0** kN

Variable axial load F_{Qz2} = **5.0** kN

Wind horizontal load in x-direction F_{Wx2} = **2.5** kN

Wind horizontal load in y-direction F_{Wy2} = **4.5** kN

Snow axial load F_{Sz2} = **9.0** kN

Design approach 1

Partial factors on actions - Combination1

Partial factor set A1

Permanent unfavourable action - Table A.3 γ_G = **1.35**

Permanent favourable action - Table A.3 γ_{Gf} = **1.00**

Variable unfavourable action - Table A.3 γ_Q = **1.50**

Variable favourable action - Table A.3 γ_{Qf} = **0.00**

Partial factors for soil parameters - Combination1

Soil factor set M1

Angle of shearing resistance - Table A.4 $\gamma_{\phi'}$ = **1.00**

Effective cohesion - Table A.4 $\gamma_{c'}$ = **1.00**

Weight density - Table A.4 γ_γ = **1.00**

Partial factors for spread foundations - Combination1

Resistance factor set R1

Bearing - Table A.5 $\gamma_{R.v}$ = **1.00**

Sliding - Table A.5 $\gamma_{R.h}$ = **1.00**

Bearing resistance (Section 6.5.2)

Forces on foundation

Force in x-direction $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2})$ = **7.5** kN

Force in y-direction $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2})$ = **13.5** kN

Force in z-direction $F_{dz} = \gamma_G \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} + F_{Sz2})$ = **197.0** kN

Moments on foundation

Moment in x-direction $M_{dx} = \gamma_G \times (A \times F_{swt} \times L_x / 2 + F_{Gz1} \times x_1 + F_{Gz2} \times x_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times x_1 + F_{Qz2} \times x_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times x_1 + F_{Sz2} \times x_2) + (\gamma_Q \times (F_{Wx1} + F_{Wx2})) \times h$ = **44.4** kNm

Moment in y-direction $M_{dy} = \gamma_G \times (A \times F_{swt} \times L_y / 2 + F_{Gz1} \times y_1 + F_{Gz2} \times y_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times y_1 + F_{Qz2} \times y_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times y_1 + F_{Sz2} \times y_2) + (\gamma_Q \times (F_{Wy1} + F_{Wy2})) \times h$ = **292.4** kNm

Eccentricity of base reaction

Eccentricity of base reaction in x-direction $e_x = M_{dx} / F_{dz} - L_x / 2$ = **-25** mm

Eccentricity of base reaction in y-direction $e_y = M_{dy} / F_{dz} - L_y / 2$ = **34** mm

Effective area of base

Effective length $L'_x = L_x + 2 \times e_x$ = **450** mm

Effective width $L'_y = L_y - 2 \times e_y$ = **2831** mm

Effective area $A' = L'_x \times L'_y = \mathbf{1.276}\ m^2$

Pad base pressure

Design base pressure $f_{dz} = F_{dz} / A' = \mathbf{154.4}\ kN/m^2$

Ultimate bearing capacity under drained conditions (Annex D.4)

Design angle of shearing resistance $\phi'_d = atan(tan(\phi'_k) / \gamma_{\phi'}) = \mathbf{33.000}$ deg

Design effective cohesion $c'_d = c'_k / \gamma_{c'} = \mathbf{20.000}\ kN/m^2$

Effective overburden pressure $q = (h + h_{soil}) \times \gamma_{soil} - h_{water} \times \gamma_{water} = \mathbf{9.000}\ kN/m^2$

Design effective overburden pressure $q' = q / \gamma_\gamma = \mathbf{9.000}\ kN/m^2$

Bearing resistance factors $N_q = Exp(\pi \times tan(\phi'_d)) \times (tan(45\ deg + \phi'_d / 2))^2 = \mathbf{26.092}$

$N_c = (N_q - 1) \times cot(\phi'_d) = \mathbf{38.638}$

$N_\gamma = 2 \times (N_q - 1) \times tan(\phi'_d) = \mathbf{32.590}$

Foundation shape factors $s_q = 1 + (L'_x / L'_y) \times sin(\phi'_d) = \mathbf{1.087}$

$s_\gamma = 1 - 0.3 \times (L'_x / L'_y) = \mathbf{0.952}$

$s_c = (s_q \times N_q - 1) / (N_q - 1) = \mathbf{1.090}$

Load inclination factors $H = [F_{dx}^2 + F_{dy}^2]^{0.5} = \mathbf{15.4}$ kN

$m_y = [2 + (L'_y / L'_x)] / [1 + (L'_y / L'_x)] = \mathbf{1.137}$

$m_x = [2 + (L'_x / L'_y)] / [1 + (L'_x / L'_y)] = \mathbf{1.863}$

$m = m_x \times cos(atan(F_{dy} / F_{dx}))^2 + m_y \times sin(atan(F_{dy} / F_{dx}))^2 = \mathbf{1.308}$

$i_q = [1 - H / (F_{dz} + A' \times c'_d \times cot(\phi'_d))]^m = \mathbf{0.915}$

$i_\gamma = [1 - H / (F_{dz} + A' \times c'_d \times cot(\phi'_d))]^{m+1} = \mathbf{0.856}$

$i_c = i_q - (1 - i_q) / (N_c \times tan(\phi'_d)) = \mathbf{0.912}$

Ultimate bearing capacity $n_f = c'_d \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{soil} \times L'_x \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{1109.5}\ kN/m^2$

PASS - Ultimate bearing capacity exceeds design base pressure

Sliding resistance (Section 6.5.3)

Forces on foundation

Force in x-direction $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2}) = \mathbf{7.5}$ kN

Force in y-direction $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2}) = \mathbf{13.5}$ kN

Force in z-direction $F_{dz} = \gamma_{Gf} \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_{Qf} \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_{Qf} \times \psi_{S0} \times (F_{Sz1} + F_{Sz2}) = \mathbf{128.1}$ kN

Sliding resistance verification (Section 6.5.3)

Horizontal force on foundation $H = [F_{dx}^2 + F_{dy}^2]^{0.5} = \mathbf{15.4}$ kN

Angle to horizontal force $\theta_H = \mathbf{60.945}$ deg

Design friction angle $\delta_d = atan(tan(\delta_k) / \gamma_{\phi'}) = \mathbf{25}$ deg

Passive pressure coefficient $K_p = (1 + sin(\phi'_d)) / (1 - sin(\phi'_d)) = \mathbf{3.392}$

Design soil density $\gamma_{soil}' = \gamma_{soil} / \gamma_\gamma = \mathbf{18}\ kN/m^3$

Passive soil resistance $F_p = \gamma_{Gf} \times K_p \times cos(\delta_d) \times \gamma_{soil}' \times (L_y \times cos(\theta_H) + L_x \times sin(\theta_H)) \times h \times (h + 2 \times h_{soil}) / 2 = \mathbf{12.8}$ kN

Sliding resistance (exp.6.3a) $R_{H.d} = F_{dz} \times tan(\delta_d) + F_p = \mathbf{72.5}$ kN

$H / R_{H.d} = \mathbf{0.213}$

PASS - Foundation is not subject to failure by sliding

Design approach 1

Partial factors on actions - Combination2

Partial factor set A2

Permanent unfavourable action - Table A.3 γ_G = **1.00**

Permanent favourable action - Table A.3 γ_{Gf} = **1.00**

Variable unfavourable action - Table A.3 γ_Q = **1.30**

Variable favourable action - Table A.3 γ_{Qf} = **0.00**

Partial factors for soil parameters - Combination2

Soil factor set M2

Angle of shearing resistance - Table A.4 $\gamma_{\phi'}$ = **1.25**

Effective cohesion - Table A.4 $\gamma_{c'}$ = **1.25**

Weight density - Table A.4 γ_γ = **1.00**

Partial factors for spread foundations - Combination2

Resistance factor set R1

Bearing - Table A.5 $\gamma_{R.v}$ = **1.00**

Sliding - Table A.5 $\gamma_{R.h}$ = **1.00**

Bearing resistance (Section 6.5.2)

Forces on foundation

Force in x-direction $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2})$ = **6.5** kN

Force in y-direction $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2})$ = **11.7** kN

Force in z-direction $F_{dz} = \gamma_G \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} + F_{Sz2})$ = **148.9** kN

Moments on foundation

Moment in x-direction $M_{dx} = \gamma_G \times (A \times F_{swt} \times L_x / 2 + F_{Gz1} \times x_1 + F_{Gz2} \times x_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times x_1 + F_{Qz2} \times x_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times x_1 + F_{Sz2} \times x_2) + (\gamma_Q \times (F_{Wx1} + F_{Wx2})) \times h$ = **33.9** kNm

Moment in y-direction $M_{dy} = \gamma_G \times (A \times F_{swt} \times L_y / 2 + F_{Gz1} \times y_1 + F_{Gz2} \times y_2) + \gamma_Q \times \psi_{Q0} \times (F_{Qz1} \times y_1 + F_{Qz2} \times y_2) + \gamma_Q \times \psi_{S0} \times (F_{Sz1} \times y_1 + F_{Sz2} \times y_2) + (\gamma_Q \times (F_{Wy1} + F_{Wy2})) \times h$ = **221.8** kNm

Eccentricity of base reaction

Eccentricity of base reaction in x-direction $e_x = M_{dx} / F_{dz} - L_x / 2$ = **-22** mm

Eccentricity of base reaction in y-direction $e_y = M_{dy} / F_{dz} - L_y / 2$ = **39** mm

Effective area of base

Effective length $L'_x = L_x + 2 \times e_x$ = **456** mm

Effective width $L'_y = L_y - 2 \times e_y$ = **2821** mm

Effective area $A' = L'_x \times L'_y$ = **1.286** m^2

Pad base pressure

Design base pressure $f_{dz} = F_{dz} / A'$ = **115.8** kN/m^2

Ultimate bearing capacity under drained conditions (Annex D.4)

Design angle of shearing resistance $\phi'_d = atan(tan(\phi'_k) / \gamma_{\phi'})$ = **27.453** deg

Design effective cohesion $c'_d = c'_k / \gamma_{c'}$ = **16.000** kN/m^2

Effective overburden pressure $q = (h + h_{soil}) \times \gamma_{soil} - h_{water} \times \gamma_{water} = \mathbf{9.000}$ kN/m^2

Design effective overburden pressure $q' = q / \gamma_\gamma = \mathbf{9.000}$ kN/m^2

Bearing resistance factors $N_q = Exp(\pi \times \tan(\phi'_d)) \times (\tan(45 \text{ deg} + \phi'_d / 2))^2 = \mathbf{13.865}$

$N_c = (N_q - 1) \times \cot(\phi'_d) = \mathbf{24.763}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_d) = \mathbf{13.367}$

Foundation shape factors $s_q = 1 + (L'_x / L'_y) \times \sin(\phi'_d) = \mathbf{1.074}$

$s_\gamma = 1 - 0.3 \times (L'_x / L'_y) = \mathbf{0.952}$

$s_c = (s_q \times N_q - 1) / (N_q - 1) = \mathbf{1.080}$

Load inclination factors $H = [F_{dx}^2 + F_{dy}^2]^{0.5} = \mathbf{13.4}$ kN

$m_y = [2 + (L'_y / L'_x)] / [1 + (L'_y / L'_x)] = \mathbf{1.139}$

$m_x = [2 + (L'_x / L'_y)] / [1 + (L'_x / L'_y)] = \mathbf{1.861}$

$m = m_x \times \cos(\text{atan}(F_{dy} / F_{dx}))^2 + m_y \times \sin(\text{atan}(F_{dy} / F_{dx}))^2 = \mathbf{1.309}$

$i_q = [1 - H / (F_{dz} + A' \times c'_d \times \cot(\phi'_d))]^m = \mathbf{0.908}$

$i_\gamma = [1 - H / (F_{dz} + A' \times c'_d \times \cot(\phi'_d))]^{m+1} = \mathbf{0.844}$

$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_d)) = \mathbf{0.901}$

Ultimate bearing capacity $n_f = c'_d \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{soil} \times L'_x \times N_\gamma \times s_\gamma \times i_\gamma =$ **551.4** kN/m^2

PASS - Ultimate bearing capacity exceeds design base pressure

Sliding resistance (Section 6.5.3)

Forces on foundation

Force in x-direction $F_{dx} = \gamma_Q \times (F_{Wx1} + F_{Wx2}) = \mathbf{6.5}$ kN

Force in y-direction $F_{dy} = \gamma_Q \times (F_{Wy1} + F_{Wy2}) = \mathbf{11.7}$ kN

Force in z-direction $F_{dz} = \gamma_{Gf} \times (A \times F_{swt} + F_{Gz1} + F_{Gz2}) + \gamma_{Qf} \times \psi_{Q0} \times (F_{Qz1} + F_{Qz2}) + \gamma_{Qf} \times \psi_{S0} \times (F_{Sz1} + F_{Sz2}) = \mathbf{128.1}$ kN

Sliding resistance verification (Section 6.5.3)

Horizontal force on foundation $H = [F_{dx}^2 + F_{dy}^2]^{0.5} = \mathbf{13.4}$ kN

Angle to horizontal force $\theta_H = \mathbf{60.945}$ deg

Design friction angle $\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) = \mathbf{20.458}$ deg

Passive pressure coefficient $K_p = (1 + \sin(\phi'_d)) / (1 - \sin(\phi'_d)) = \mathbf{2.711}$

Design soil density $\gamma_{soil}' = \gamma_{soil} / \gamma_\gamma = \mathbf{18}$ kN/m^3

Passive soil resistance $F_p = \gamma_{Gf} \times K_p \times \cos(\delta_d) \times \gamma_{soil}' \times (L_y \times \cos(\theta_H) + L_x \times \sin(\theta_H)) \times h \times (h + 2 \times h_{soil}) / 2 = \mathbf{10.5}$ kN

Sliding resistance (exp.6.3a) $R_{H.d} = F_{dz} \times \tan(\delta_d) + F_p = \mathbf{58.3}$ kN

$H / R_{H.d} = \mathbf{0.229}$

PASS - Foundation is not subject to failure by sliding

FOUNDATION DESIGN

In accordance with EN1992-1-1:2004 + A1:2014 incorporating corrigenda January 2008, November 2010 and January 2014 and the UK National Annex incorporating National Amendment No.1 and No.2

Tedds calculation version 3.3.05

Concrete details (Table 3.1 - Strength and deformation characteristics for concrete)

Concrete strength class C30/37

Characteristic compressive cylinder strength $f_{ck} = \mathbf{30}$ N/mm^2

Characteristic compressive cube strength $f_{ck,cube}$ = **37** N/mm^2

Mean value of compressive cylinder strength $f_{cm} = f_{ck} + 8$ N/mm^2 = **38** N/mm^2

Mean value of axial tensile strength $f_{ctm} = 0.3$ N/mm$^2 \times (f_{ck}/ 1$ N/mm$^2)^{2/3}$ = **2.9** N/mm^2

5% fractile of axial tensile strength $f_{ctk,0.05} = 0.7 \times f_{ctm}$ = **2.0** N/mm^2

Secant modulus of elasticity of concrete $E_{cm} = 22$ kN/mm$^2 \times [f_{cm}/10$ N/mm$^2]^{0.3}$ = **32837** N/mm^2

Partial factor for concrete (Table 2.1N) γ_C = **1.50**

Compressive strength coefficient (cl.3.1.6(1)) α_{cc} = **0.85**

Design compressive concrete strength (exp.3.15) $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C$ = **17.0** N/mm^2

Tens.strength coeff.for plain concrete (cl.12.3.1(1)) $\alpha_{ct,pl}$ = **0.80**

Des.tens.strength for plain concrete (exp.12.1) $f_{ctd,pl} = \alpha_{ct,pl} \times f_{ctk,0.05} / \gamma_C$ = **1.1** N/mm^2

Maximum aggregate size h_{agg} = **20** mm

Ultimate strain - Table 3.1 ε_{cu2} = **0.0035**

Shortening strain - Table 3.1 ε_{cu3} = **0.0035**

Effective compression zone height factor λ = **0.80**

Effective strength factor η = **1.00**

Bending coefficient k_1 K_1 = **0.40**

Bending coefficient k_2 $K_2 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2})$ =**1.00**

Bending coefficient k_3 K_3 =**0.40**

Bending coefficient k_4 $K_4 =1.00 \times (0.6 + 0.0014/\varepsilon_{cu2})$ = **1.00**

Reinforcement details

Characteristic yield strength of reinforcement f_{yk} = **500** N/mm^2

Modulus of elasticity of reinforcement E_s = **210000** N/mm^2

Partial factor for reinforcing steel (Table 2.1N) γ_S = **1.15**

Design yield strength of reinforcement $f_{yd} = f_{yk} / \gamma_S$ = **435** N/mm^2

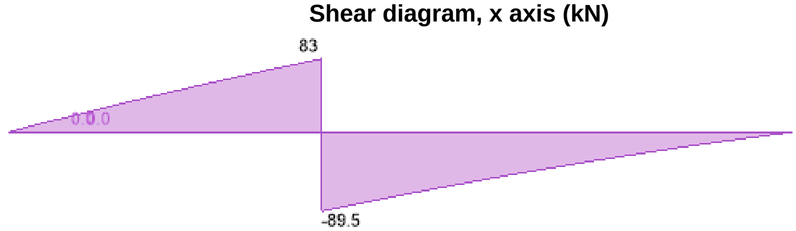
Nominal cover to top of foundation c_{nom_t} = **40** mm

Nominal cover to bottom of foundation c_{nom_b} = **40** mm

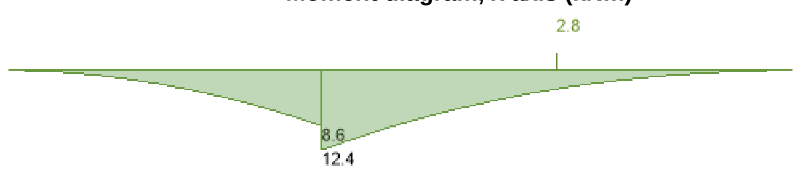
Nominal cover to side of foundation c_{nom_s} = **40** mm

Nominal cover to top reinforcement c_{nom_t} = **40** mm

Shear diagram, x axis (kN)



Moment diagram, x axis (kNm)



Rectangular section in flexure (Section 6.1)

Design bending moment $M_{Ed.x.max}$ = **2.8** kNm

Depth to tension reinforcement $d = h - c_{nom\_b} - \phi_{y.bot} - \phi_{x.bot} / 2$ = **292** mm

$K = M_{Ed.x.max} / (L_y \times d^2 \times f_{ck})$ = **0.000**

$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **277** mm

Depth of neutral axis $x = 2.5 \times (d - z)$ = **37** mm

Area of tension reinforcement required $A_{sx.bot.req} = M_{Ed.x.max} / (f_{yd} \times z)$ = **23** mm²

Tension reinforcement provided 16 ϕ bars @ 125 c/c bottom

Area of tension reinforcement provided $A_{sx.bot.prov}$ = **4624** mm²

Minimum area of reinforcement (exp.9.1N) $A_{s.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times L_y \times d$ = **1275** mm²

Maximum area of reinforcement (cl.9.2.1.1(3)) $A_{s.max} = 0.04 \times L_y \times d$ = **33872** mm²

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control (Section 7.3)

Limiting crack width w_{max} = **0.3** mm

Variable load factor (EN1990 – Table A1.1) ψ_2 = **0.3**

Serviceability bending moment $M_{sls.x.max}$ = **1.5** kNm

Tensile stress in reinforcement $\sigma_s = M_{sls.x.max} / (A_{sx.bot.prov} \times z)$ = **1.2** N/mm²

Load duration factor k_t = **0.4**

Effective depth of concrete in tension $h_{c.ef} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **155** mm

Effective area of concrete in tension $A_{c.eff} = h_{c.ef} \times L_y$ = **448050** mm²

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm}$ = **2.9** N/mm²

Reinforcement ratio $\rho_{p.eff} = A_{sx.bot.prov} / A_{c.eff}$ = **0.010**

Modular ratio $\alpha_e = E_s / E_{cm}$ = **6.395**

Bond property coefficient k_1 = **0.8**

Strain distribution coefficient k_2 = **0.5**

$k_3 = 3.4$ =**3.4**

k_4 = **0.425**

Maximum crack spacing (exp.7.11) $s_{r.max} = k_3 \times (c_{nom\_b} + \phi_{y.bot}) + k_1 \times k_2 \times k_4 \times \phi_{x.bot} / \rho_{p.eff}$ = **944** mm

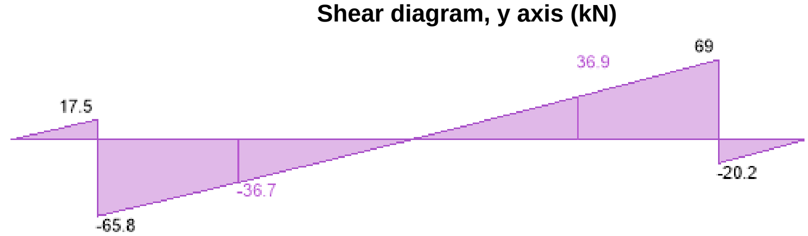
Maximum crack width (exp.7.8) $w_k = s_{r.max} \times \max([\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff})] / E_s,$

$0.6 \times \sigma_s / E_s)$ = **0.003** mm

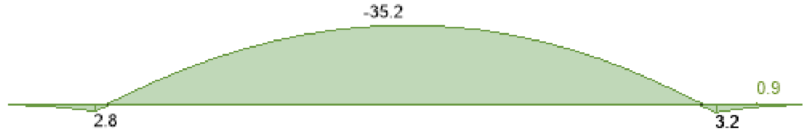
PASS - Maximum crack width is less than limiting crack width

Library item: Crack width output

Shear diagram, y axis (kN)



Moment diagram, y axis (kNm)



Rectangular section in flexure (Section 6.1)

Design bending moment: $abs(M_{Ed.y.min})$ = **35.2** kNm

Depth to tension reinforcement: $d = h - c_{nom\_t} - \phi_{y.top} / 2$ = **452** mm

$K = abs(M_{Ed.y.min}) / (L_x \times d^2 \times f_{ck})$ = **0.011**

$K' = (2 \times \eta \times \alpha_{cc}/\gamma_C)\times(1 - \lambda \times (\delta - K_1)/(2 \times K_2))\times(\lambda \times (\delta - K_1)/(2 \times K_2))$

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm: $z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_C))^{0.5}, 0.95) \times d$ = **429** mm

Depth of neutral axis: $x = 2.5 \times (d - z)$ = **57** mm

Area of tension reinforcement required: $A_{sy.top.req} = abs(M_{Ed.y.min}) / (f_{yd} \times z)$ = **189** mm^2

Tension reinforcement provided: 16 ϕ bars @ 100 c/c top

Area of tension reinforcement provided: $A_{sy.top.prov}$ = **1005** mm^2

Minimum area of reinforcement (exp.9.1N): $A_{s.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times L_x \times d$ = **340** mm^2

Maximum area of reinforcement (cl.9.2.1.1(3)): $A_{s.max} = 0.04 \times L_x \times d$ = **9040** mm^2

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control (Section 7.3)

Limiting crack width: w_{max} = **0.3** mm

Variable load factor (EN1990 – Table A1.1): ψ_2 = **0.3**

Serviceability bending moment: $abs(M_{sls.y.min})$ = **23.4** kNm

Tensile stress in reinforcement: $\sigma_s = abs(M_{sls.y.min}) / (A_{sy.top.prov} \times z)$ = **54.3** N/mm^2

Load duration factor: k_t = **0.4**

Effective depth of concrete in tension: $h_{c.ef} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **120** mm

Effective area of concrete in tension: $A_{c.eff} = h_{c.ef} \times L_x$ = **60000** mm^2

Mean value of concrete tensile strength: $f_{ct.eff} = f_{ctm}$ = **2.9** N/mm^2

Reinforcement ratio: $\rho_{p.eff} = A_{sy.top.prov} / A_{c.eff}$ = **0.017**

Modular ratio: $\alpha_e = E_s / E_{cm}$ = **6.395**

Bond property coefficient: k_1 = **0.8**

Strain distribution coefficient: k_2 = **0.5**

k_3 = 3.4 =**3.4**

k_4 = **0.425**

Maximum crack spacing (exp.7.11): $s_{r.max} = k_3 \times c_{nom\_t} + k_1 \times k_2 \times k_4 \times \phi_{y.top} / \rho_{p.eff}$ = **298** mm

Maximum crack width (exp.7.8): $w_k = s_{r.max} \times \max([\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff})] / E_s,$ $0.6 \times \sigma_s / E_s)$ = **0.046** mm

PASS - Maximum crack width is less than limiting crack width

Library item: Crack width output

Rectangular section in shear (Section 6.2)

Design shear force: $V_{Ed.y.max}$ = **36.9** kN

$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$

$k = \min(1 + \sqrt{(200\ mm / d)}, 2) = \mathbf{1.741}$

Longitudinal reinforcement ratio $\rho_l = \min(A_{sy.bot.prov} / (L_x \times d), 0.02) = \mathbf{0.020}$

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.440}\ N/mm^2$

Design shear resistance (exp.6.2a & 6.2b) $V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\ N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times L_x \times d$

$V_{Rd.c} = \mathbf{148.9}\ kN$

PASS - Design shear resistance exceeds design shear force

Punching shear (Section 6.4)

Strength reduction factor (exp 6.6N) $v = 0.6 \times [1 - f_{ck} / 250\ N/mm^2] = \mathbf{0.528}$

Average depth to reinforcement $d = \mathbf{372}\ mm$

Maximum punching shear resistance (cl.6.4.5(3)) $v_{Rd.max} = 0.5 \times v \times f_{cd} = \mathbf{4.488}\ N/mm^2$

$k = \min(1 + \sqrt{(200\ mm / d)}, 2) = \mathbf{1.733}$

Longitudinal reinforcement ratio (cl.6.4.4(1)) $\rho_{lx} = A_{sx.bot.prov} / (L_y \times d) = \mathbf{0.004}$

$\rho_{ly} = A_{sy.bot.prov} / (L_x \times d) = \mathbf{0.432}$

$\rho_l = \min(\sqrt{(\rho_{lx} \times \rho_{ly})}, 0.02) = \mathbf{0.020}$

$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.437}\ N/mm^2$

Design punching shear resistance (exp.6.47) $v_{Rd.c} = \max(C_{Rd.c} \times k \times (100\ N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) = \mathbf{0.814}\ N/mm^2$

Design punching shear resistance at 1d (exp. 6.50) $v_{Rd.c1} = (2 \times d / d) \times v_{Rd.c} = \mathbf{1.628}\ N/mm^2$

Column No.1 - Punching shear perimeter at column face

Punching shear perimeter $u_0 = \mathbf{1200}\ mm$

Area within punching shear perimeter $A_0 = \mathbf{0.090}\ m^2$

Maximum punching shear force $V_{Ed.max} = \mathbf{82.9}\ kN$

Punching shear stress factor (fig 6.21N) $\beta = \mathbf{1.500}$

Maximum punching shear stress (exp 6.38) $v_{Ed.max} = \beta \times V_{Ed.max} / (u_0 \times d) = \mathbf{0.278}\ N/mm^2$

PASS - Maximum punching shear resistance exceeds maximum punching shear stress

Column No.1 - Punching shear perimeter at 1d from column face

Punching shear perimeter $u_1 = \mathbf{505}\ mm$

Area within punching shear perimeter $A_1 = \mathbf{0.418}\ m^2$

Design punching shear force $V_{Ed.1} = \mathbf{48.8}\ kN$

Punching shear stress factor (fig 6.21N) $\beta = \mathbf{1.500}$

Design punching shear stress (exp 6.38) $v_{Ed.1} = \beta \times V_{Ed.1} / (u_1 \times d) = \mathbf{0.390}\ N/mm^2$

PASS - Design punching shear resistance exceeds increased design punching shear stress

Column No.1 - Punching shear perimeter at 2d from column face

Punching shear perimeter $u_2 = \mathbf{501}\ mm$

Area within punching shear perimeter $A_2 = \mathbf{0.605}\ m^2$

Design punching shear force $V_{Ed.2} = \mathbf{26}\ kN$

Punching shear stress factor (fig 6.21N) $\beta = \mathbf{1.500}$

Design punching shear stress (exp 6.38) $v_{Ed.2} = \beta \times V_{Ed.2} / (u_2 \times d) = \mathbf{0.209}\ N/mm^2$

PASS - Design punching shear resistance exceeds design punching shear stress

Column No.2 - Punching shear perimeter at column face

Punching shear perimeter $u_0 = \mathbf{1200}\ mm$

Area within punching shear perimeter A_0 = **0.090** m²

Maximum punching shear force $V_{Ed.max}$ = **82.9** kN

Punching shear stress factor (fig 6.21N) β = **1.500**

Maximum punching shear stress (exp 6.38) $v_{Ed.max} = \beta \times V_{Ed.max} / (u_0 \times d)$ = **0.278** N/mm²

PASS - Maximum punching shear resistance exceeds maximum punching shear stress

Column No.2 - Punching shear perimeter at 1d from column face

Punching shear perimeter u_1 = **505** mm

Area within punching shear perimeter A_1 = **0.418** m²

Design punching shear force $V_{Ed.1}$ = **44** kN

Punching shear stress factor (fig 6.21N) β = **1.500**

Design punching shear stress (exp 6.38) $v_{Ed.1} = \beta \times V_{Ed.1} / (u_1 \times d)$ = **0.352** N/mm²

PASS - Design punching shear resistance exceeds increased design punching shear stress

Column No.2 - Punching shear perimeter at 2d from column face

Punching shear perimeter u_2 = **501** mm

Area within punching shear perimeter A_2 = **0.605** m²

Design punching shear force $V_{Ed.2}$ = **21.3** kN

Punching shear stress factor (fig 6.21N) β = **1.500**

Design punching shear stress (exp 6.38) $v_{Ed.2} = \beta \times V_{Ed.2} / (u_2 \times d)$ = **0.171** N/mm²

PASS - Design punching shear resistance exceeds design punching shear stress