

15 SEP 2021

Redds calculation version 2.0.11

RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 Incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Retaining wall details

Stem type;
Stem height;
Stem thickness;
Angle to rear face of stem;
Stem density;
Toe length;
Heel length;
Base thickness;
Key position;
Key depth;
Key thickness;
Base density;
Height of retained soil;
Angle of soil surface;
Depth of cover;
Depth of excavation;

Cantilever
 $h_{stem} = 3500 \text{ mm}$
 $t_{stem} = 300 \text{ mm}$
 $\alpha = 90 \text{ deg}$
 $\gamma_{stem} = 25 \text{ kN/m}^3$
 $h_{toe} = 400 \text{ mm}$
 $h_{heel} = 1600 \text{ mm}$
 $t_{base} = 400 \text{ mm}$
 $p_{key} = 1950 \text{ mm}$
 $d_{key} = 500 \text{ mm}$
 $t_{key} = 350 \text{ mm}$
 $\gamma_{base} = 25 \text{ kN/m}^3$
 $h_{ret} = 2700 \text{ mm}$
 $\beta = 0 \text{ deg}$
 $d_{cover} = 500 \text{ mm}$
 $d_{exc} = 200 \text{ mm}$

Retained soil properties

Soil type;
Moist density;
Saturated density;
Characteristic effective shear resistance angle;
Characteristic wall friction angle;

Medium dense well graded sand and gravel
 $\gamma_{mr} = 20 \text{ kN/m}^3$
 $\gamma_{sr} = 22.3 \text{ kN/m}^3$
 $\phi'_{r,k} = 30 \text{ deg}$
 $\delta_{r,k} = 15 \text{ deg}$

Base soil properties

Soil type;
Soil density;
Characteristic cohesion;
Characteristic effective shear resistance angle;
Characteristic wall friction angle;
Characteristic base friction angle;

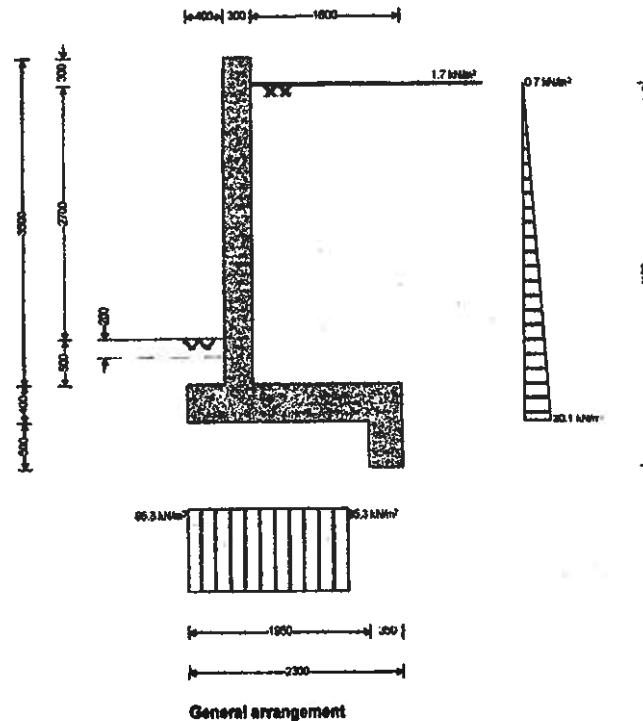
Stiff or hard glacial sandy clay
 $\gamma_b = 21 \text{ kN/m}^3$
 $c'_{b,k} = 0 \text{ kN/m}^2$
 $\phi'_{b,k} = 26 \text{ deg}$
 $\delta_{b,k} = 13 \text{ deg}$
 $\delta_{bb,k} = 17.3 \text{ deg}$

Loading details

Permanent surcharge load;
Variable surcharge load;

Surcharge_G = 1 kN/m^2
Surcharge_Q = 0.5 kN/m^2

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Calculate retaining wall geometry

Base length;

Base height;

Moist soil height;

Length of surcharge load;

- Distance to vertical component;

Effective height of wall;

- Distance to horizontal component;

- Distance to horizontal component above key;

Area of wall stem;

- Distance to vertical component;

Area of wall base;

- Distance to vertical component;

Area of moist soil;

- Distance to vertical component;

- Distance to horizontal component;

- Distance to horizontal component above key;

Area of base soil;

- Distance to vertical component;

$$l_{\text{base}} = l_{\text{hoe}} + l_{\text{stem}} + l_{\text{heel}} = 2300 \text{ mm}$$

$$h_{\text{base}} = l_{\text{base}} + d_{\text{key}} = 900 \text{ mm}$$

$$h_{\text{moist}} = h_{\text{soil}} = 3200 \text{ mm}$$

$$l_{\text{sur}} = l_{\text{heel}} = 1800 \text{ mm}$$

$$x_{\text{sur}_v} = l_{\text{base}} - l_{\text{heel}} / 2 = 1500 \text{ mm}$$

$$h_{\text{eff}} = h_{\text{base}} + d_{\text{cover}} + h_{\text{ret}} = 4100 \text{ mm}$$

$$x_{\text{sur}_h} = h_{\text{eff}} / 2 - d_{\text{key}} = 1550 \text{ mm}$$

$$x_{\text{sur}_{h_s}} = (h_{\text{eff}} - d_{\text{key}}) / 2 = 1800 \text{ mm}$$

$$A_{\text{stem}} = h_{\text{stem}} \times l_{\text{stem}} = 1.05 \text{ m}^2$$

$$x_{\text{stem}} = l_{\text{hoe}} + l_{\text{stem}} / 2 = 550 \text{ mm}$$

$$A_{\text{base}} = l_{\text{base}} \times l_{\text{base}} + d_{\text{key}} \times l_{\text{key}} = 1.095 \text{ m}^2$$

$$x_{\text{base}} = (l_{\text{base}}^2 \times l_{\text{base}} / 2 + d_{\text{key}} \times l_{\text{key}} \times (d_{\text{key}} + l_{\text{key}} / 2)) / A_{\text{base}} = 1306 \text{ mm}$$

$$A_{\text{moist}} = h_{\text{moist}} \times l_{\text{heel}} = 5.12 \text{ m}^2$$

$$x_{\text{moist}_v} = l_{\text{base}} - (h_{\text{moist}} \times l_{\text{heel}}^2 / 2) / A_{\text{moist}} = 1500 \text{ mm}$$

$$x_{\text{moist}_h} = h_{\text{eff}} / 3 - d_{\text{key}} = 867 \text{ mm}$$

$$x_{\text{moist}_{h_s}} = (h_{\text{eff}} - d_{\text{key}}) / 3 = 1200 \text{ mm}$$

$$A_{\text{base}} = d_{\text{cover}} \times l_{\text{hoe}} = 0.2 \text{ m}^2$$

$$x_{\text{base}_v} = l_{\text{base}} - (d_{\text{cover}} \times l_{\text{hoe}} \times (l_{\text{base}} - l_{\text{hoe}} / 2)) / A_{\text{base}} = 200 \text{ mm}$$

- Distance to horizontal component;
- Area of excavated base soil;
- Distance to vertical component;
- Distance to horizontal component;

$$x_{pass_h} = (d_{cover} + h_{base}) / 3 - d_{key} = -33 \text{ mm}$$

$$A_{exc} = h_{pass} \times h_{oe} = 0.12 \text{ m}^2$$

$$x_{exc_v} = h_{base} - (h_{pass} \times h_{oe} \times (h_{base} - h_{oe} / 2)) / A_{exc} = 200 \text{ mm}$$

$$x_{exc_h} = (h_{pass} + h_{base}) / 3 - d_{key} = -100 \text{ mm}$$

Design approach 1

Partial factors on actions - Table A.3 - Combination 1

Partial factor set;	A1
Permanent unfavourable action;	$\gamma_G = 1.35$
Permanent favourable action;	$\gamma_{Gr} = 1.00$
Variable unfavourable action;	$\gamma_Q = 1.50$
Variable favourable action;	$\gamma_{Qr} = 0.00$

Partial factors for soil parameters – Table A.4 - Combination 1

Soil parameter set;	M1
Angle of shearing resistance;	$\gamma_\psi = 1.00$
Effective cohesion;	$\gamma_c = 1.00$
Weight density;	$\gamma_r = 1.00$

Library item; Partial factors output

Retained soil properties

Design moist density;	$\gamma_{mr}' = \gamma_{mr} / \gamma_r = 20 \text{ kN/m}^3$
Design saturated density;	$\gamma_w' = \gamma_w / \gamma_r = 22.3 \text{ kN/m}^3$
Design effective shear resistance angle;	$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_\psi) = 30 \text{ deg}$
Design wall friction angle;	$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_\psi) = 15 \text{ deg}$

Base soil properties

Design soil density;	$\gamma_b' = \gamma_b / \gamma_r = 21 \text{ kN/m}^3$
Design effective shear resistance angle;	$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_\psi) = 26 \text{ deg}$
Design wall friction angle;	$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_\psi) = 13 \text{ deg}$
Design base friction angle;	$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_\psi) = 17.3 \text{ deg}$
Design effective cohesion;	$c'_{b,d} = c'_{b,k} / \gamma_c = 0 \text{ kN/m}^2$

Using Rankine theory

Active pressure coefficient;	$K_A = (1 - \sin(\phi'_{r,d})) / (1 + \sin(\phi'_{r,d})) = 0.333$
Passive pressure coefficient;	$K_P = (1 + \sin(\phi'_{b,d})) / (1 - \sin(\phi'_{b,d})) = 2.561$

Sliding check

Vertical forces on wall

Wall stem;	$F_{stem} = \gamma_{Gr} \times A_{stem} \times \gamma_{stem} = 26.3 \text{ kN/m}$
Wall base;	$F_{base} = \gamma_{Gr} \times A_{base} \times \gamma_{base} = 27.4 \text{ kN/m}$
Moist retained soil;	$F_{moist_v} = \gamma_{Gr} \times A_{moist} \times \gamma_{mr}' = 102.4 \text{ kN/m}$
Base soil;	$F_{exc_v} = \gamma_{Gr} \times A_{exc} \times \gamma_b' = 2.6 \text{ kN/m}$
Total;	$F_{total_v} = F_{stem} + F_{base} + F_{moist_v} + F_{exc_v} = 158.5 \text{ kN/m}$

Horizontal forces on wall

Surcharge load;	$F_{sur_h} = K_A \times (\gamma_G \times \text{Surcharge}_G + \gamma_Q \times \text{Surcharge}_Q) \times h_{sur} = 2.9 \text{ kN/m}$
Moist retained soil;	$F_{moist_h} = \gamma_G \times K_A \times \gamma_{mr}' \times h_{sur}^2 / 2 = 75.6 \text{ kN/m}$
Total;	$F_{total_h} = F_{sur_h} + F_{moist_h} = 78.5 \text{ kN/m}$

Check stability against sliding

Base soil resistance;

Base friction;

Resistance to sliding;

Factor of safety;

$$F_{exc_h} = \gamma_G \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = 38.7 \text{ kN/m}$$

$$F_{friction} = F_{total_v} \times \tan(\delta_{obs,d}) = 49.4 \text{ kN/m}$$

$$F_{rest} = F_{exc_h} + F_{friction} = 88.1 \text{ kN/m}$$

$$FoS_{sl} = F_{rest} / F_{total_h} = 1.122$$

PASS - Resistance to sliding is greater than sliding force**Overturning check****Vertical forces on wall**

Wall stem;

Wall base;

Moist retained soil;

Base soil;

Total;

$$F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = 26.3 \text{ kN/m}$$

$$F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = 27.4 \text{ kN/m}$$

$$F_{moist_v} = \gamma_G \times A_{moist} \times \gamma_{mv}' = 102.4 \text{ kN/m}$$

$$F_{exc_v} = \gamma_G \times A_{exc} \times \gamma_b' = 2.5 \text{ kN/m}$$

$$F_{total_v} = F_{stem} + F_{base} + F_{moist_v} + F_{exc_v} = 158.5 \text{ kN/m}$$

Horizontal forces on wall

Surcharge load;

Moist retained soil;

Base soil;

Total;

$$F_{sur_h} = K_A \times (\gamma_G \times \text{Surcharge}_G + \gamma_G \times \text{Surcharge}_Q) \times (h_{eff} - d_{key}) = 2.5 \text{ kN/m}$$

$$F_{moist_h} = \gamma_G \times K_A \times \gamma_{mv}' \times (h_{eff} - d_{key})^2 / 2 = 58.3 \text{ kN/m}$$

$$F_{exc_h} = -\gamma_G \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = -38.7 \text{ kN/m}$$

$$F_{total_h} = F_{sur_h} + F_{moist_h} + F_{exc_h} = 22.1 \text{ kN/m}$$

Overturning moments on wall

Surcharge load;

Moist retained soil;

Base soil;

Total;

$$M_{sur_OT} = F_{sur_h} \times X_{sur_h,s} = 4.5 \text{ kNm/m}$$

$$M_{moist_OT} = F_{moist_h} \times X_{moist_h,s} = 70 \text{ kNm/m}$$

$$M_{exc_OT} = F_{exc_h} \times X_{exc_h} = 3.9 \text{ kNm/m}$$

$$M_{total_OT} = M_{sur_OT} + M_{moist_OT} + M_{exc_OT} = 78.4 \text{ kNm/m}$$

Restoring moments on wall

Wall stem;

Wall base;

Moist retained soil;

Base soil;

Total;

$$M_{stem_R} = F_{stem} \times X_{stem} = 14.4 \text{ kNm/m}$$

$$M_{base_R} = F_{base} \times X_{base} = 35.7 \text{ kNm/m}$$

$$M_{moist_R} = F_{moist_v} \times X_{moist_v} = 153.8 \text{ kNm/m}$$

$$M_{exc_R} = F_{exc_v} \times X_{exc_v} = 0.5 \text{ kNm/m}$$

$$M_{total_R} = M_{stem_R} + M_{base_R} + M_{moist_R} + M_{exc_R} = 204.3 \text{ kNm/m}$$

Check stability against overturning

Factor of safety;

$$FoS_{ot} = M_{total_R} / M_{total_OT} = 2.606$$

PASS - Maximum restoring moment is greater than overturning moment**Bearing pressure check****Vertical forces on wall**

Wall stem;

Wall base;

Surcharge load;

Moist retained soil;

Base soil;

Total;

$$F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = 35.4 \text{ kN/m}$$

$$F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = 37 \text{ kN/m}$$

$$F_{sur_v} = (\gamma_G \times \text{Surcharge}_G + \gamma_G \times \text{Surcharge}_Q) \times h_{base} = 3.4 \text{ kN/m}$$

$$F_{moist_v} = \gamma_G \times A_{moist} \times \gamma_{mv}' = 138.2 \text{ kN/m}$$

$$F_{pass_v} = \gamma_G \times A_{pass} \times \gamma_b' = 5.7 \text{ kN/m}$$

$$F_{total_v} = F_{stem} + F_{base} + F_{sur_v} + F_{moist_v} + F_{pass_v} = 219.7 \text{ kN/m}$$

Variable favourable action;

$$\gamma_{\alpha} = 0.00$$

Partial factors for soil parameters – Table A.4 - Combination 2

M2

$$\gamma_{\psi} = 1.25$$

$$\gamma_{\sigma} = 1.25$$

$$\gamma_{\gamma} = 1.00$$

Library item; Partial factors output

Retained soil properties

Design moist density;

$$\gamma_{mr}' = \gamma_{mr} / \gamma_{\gamma} = 20 \text{ kN/m}^3$$

Design saturated density;

$$\gamma_{\sigma}' = \gamma_{\sigma} / \gamma_{\gamma} = 22.3 \text{ kN/m}^3$$

Design effective shear resistance angle;

$$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\psi}) = 24.8 \text{ deg}$$

Design wall friction angle;

$$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\psi}) = 12.1 \text{ deg}$$

Base soil properties

Design soil density;

$$\gamma_b' = \gamma_b / \gamma_{\gamma} = 21 \text{ kN/m}^3$$

Design effective shear resistance angle;

$$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\psi}) = 21.3 \text{ deg}$$

Design wall friction angle;

$$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\psi}) = 10.5 \text{ deg}$$

Design base friction angle;

$$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\psi}) = 14 \text{ deg}$$

Design effective cohesion;

$$c'_{b,d} = c'_{b,k} / \gamma_{\sigma} = 0 \text{ kN/m}^2$$

Using Rankine theory

Active pressure coefficient;

$$K_A = (1 - \sin(\phi'_{r,d})) / (1 + \sin(\phi'_{r,d})) = 0.409$$

Passive pressure coefficient;

$$K_P = (1 + \sin(\phi'_{b,d})) / (1 - \sin(\phi'_{b,d})) = 2.142$$

Sliding check

Vertical forces on wall

Wall stem;

$$F_{stem} = \gamma_{\sigma} \times A_{stem} \times \gamma_{stem} = 26.3 \text{ kN/m}$$

Wall base;

$$F_{base} = \gamma_{\sigma} \times A_{base} \times \gamma_{base} = 27.4 \text{ kN/m}$$

Moist retained soil;

$$F_{moist,v} = \gamma_{\sigma} \times A_{moist} \times \gamma_{mr}' = 102.4 \text{ kN/m}$$

Base soil;

$$F_{exo,v} = \gamma_{\sigma} \times A_{exo} \times \gamma_b' = 2.5 \text{ kN/m}$$

Total;

$$F_{total,v} = F_{stem} + F_{base} + F_{moist,v} + F_{exo,v} = 158.5 \text{ kN/m}$$

Horizontal forces on wall

Surcharge load;

$$F_{sur,h} = K_A \times (\gamma_{\sigma} \times \text{Surcharge}_G + \gamma_{\sigma} \times \text{Surcharge}_Q) \times h_{eff} = 2.8 \text{ kN/m}$$

Moist retained soil;

$$F_{moist,h} = \gamma_{\sigma} \times K_A \times \gamma_{mr}' \times h_{eff}^2 / 2 = 68.8 \text{ kN/m}$$

Total;

$$F_{total,h} = F_{sur,h} + F_{moist,h} = 71.5 \text{ kN/m}$$

Check stability against sliding

Base soil resistance;

$$F_{exo,h} = \gamma_{\sigma} \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = 32.4 \text{ kN/m}$$

Base friction;

$$F_{friction} = F_{total,v} \times \tan(\delta_{bb,d}) = 39.5 \text{ kN/m}$$

Resistance to sliding;

$$F_{rest} = F_{exo,h} + F_{friction} = 71.9 \text{ kN/m}$$

Factor of safety;

$$FoS_{sl} = F_{rest} / F_{total,h} = 1.005$$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem;

$$F_{stem} = \gamma_{\sigma} \times A_{stem} \times \gamma_{stem} = 26.3 \text{ kN/m}$$

Wall base;

$$F_{base} = \gamma_{\sigma} \times A_{base} \times \gamma_{base} = 27.4 \text{ kN/m}$$

Horizontal forces on wall

Surcharge load;

$$F_{sur,h} = K_A \times (\gamma_G \times \text{Surcharge}_G + \gamma_Q \times \text{Surcharge}_Q) \times (h_{eff} - d_{key}) = 2.5 \text{ kN/m}$$

Moist retained soil;

$$F_{moist,h} = \gamma_G \times K_A \times \gamma_{mr}' \times (h_{eff} - d_{key})^2 / 2 = 58.3 \text{ kN/m}$$

Base soil;

$$F_{pass,h} = -\gamma_{Gr} \times K_P \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2 = -52.7 \text{ kN/m}$$

Total;

$$F_{total,h} = \max(F_{sur,h} + F_{moist,h} + F_{pass,h} - F_{total,v} \times \tan(\delta_{bb,d}), 0 \text{ kN/m}) = 0 \text{ kN/m}$$

Moments on wall

Wall stem;

$$M_{stem} = F_{stem} \times X_{stem} = 19.5 \text{ kNm/m}$$

Wall base;

$$M_{base} = F_{base} \times X_{base} = 48.3 \text{ kNm/m}$$

Surcharge load;

$$M_{sur} = F_{sur,v} \times X_{sur,v} - F_{sur,h} \times X_{sur,h,s} = 0.5 \text{ kNm/m}$$

Moist retained soil;

$$M_{moist} = F_{moist,v} \times X_{moist,v} - F_{moist,h} \times X_{moist,h,s} = 137.4 \text{ kNm/m}$$

Base soil;

$$M_{pass} = F_{pass,v} \times X_{pass,v} - F_{pass,h} \times X_{pass,h} = -0.6 \text{ kNm/m}$$

Total;

$$M_{total} = M_{stem} + M_{base} + M_{sur} + M_{moist} + M_{pass} = 205 \text{ kNm/m}$$

Check bearing pressure

Distance to reaction;

$$\bar{x} = M_{total} / F_{total,v} = 933 \text{ mm}$$

Eccentricity of reaction;

$$e = \bar{x} - l_{base} / 2 = -217 \text{ mm}$$

Loaded length of base;

$$l_{load} = 2 \times \bar{x} = 1867 \text{ mm}$$

Bearing pressure at toe;

$$q_{toe} = F_{total,v} / l_{load} = 117.7 \text{ kN/m}^2$$

Bearing pressure at heel;

$$q_{heel} = 0 \text{ kN/m}^2$$

Effective overburden pressure;

$$q = (l_{base} + d_{cover}) \times \gamma_b' = 18.9 \text{ kN/m}^2$$

Design effective overburden pressure;

$$q' = q / \gamma_f = 18.9 \text{ kN/m}^2$$

Bearing resistance factors;

$$N_q = \text{Exp}(\pi \times \tan(\phi'_{b,d})) \times (\tan(45 \text{ deg} + \phi'_{b,d} / 2))^2 = 11.854$$

$$N_c = (N_q - 1) \times \cot(\phi'_{b,d}) = 22.254$$

$$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b,d}) = 10.588$$

Foundation shape factors;

$$s_q = 1$$

$$s_\gamma = 1$$

$$s_c = 1$$

Load inclination factors;

$$H = F_{sur,h} + F_{moist,h} + F_{pass,h} = 8.1 \text{ kN/m}$$

$$V = F_{total,v} = 219.7 \text{ kN/m}$$

$$m = 2$$

$$i_q = [1 - H / (V + l_{load} \times c'_{b,d} \times \cot(\phi'_{b,d}))]^m = 0.927$$

$$i_\gamma = [1 - H / (V + l_{load} \times c'_{b,d} \times \cot(\phi'_{b,d}))]^{(m+1)} = 0.893$$

$$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b,d})) = 0.921$$

Net ultimate bearing capacity

$$r_f = c'_{b,d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_b' \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma = 393.1 \text{ kN/m}^2$$

Factor of safety;

$$FoS_{bp} = r_f / \max(q_{toe}, q_{heel}) = 3.34$$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure**Design approach 1****Partial factors on actions - Table A.3 - Combination 2**

Partial factor set;

A2

Permanent unfavourable action;

$$\gamma_G = 1.00$$

Permanent favourable action;

$$\gamma_{Gr} = 1.00$$

Variable unfavourable action;

$$\gamma_Q = 1.30$$

Surcharge load;
Moist retained soil;
Base soil;
Total;

$$M_{sur} = F_{sur_v} \times X_{sur_v} - F_{sur_h} \times X_{sur_h_s} = -0.4 \text{ kNm/m}$$

$$M_{moist} = F_{moist_v} \times X_{moist_v} - F_{moist_h} \times X_{moist_h_s} = 90 \text{ kNm/m}$$

$$M_{pass} = F_{pass_v} \times X_{pass_v} - F_{pass_h} \times X_{pass_h} = -0.6 \text{ kNm/m}$$

$$M_{total} = M_{stem} + M_{base} + M_{sur} + M_{moist} + M_{pass} = 139.1 \text{ kNm/m}$$

Check bearing pressure

Distance to reaction;
Eccentricity of reaction;
Loaded length of base;
Bearing pressure at toe;
Bearing pressure at heel;
Effective overburden pressure;
Design effective overburden pressure;
Bearing resistance factors;

$$\bar{x} = M_{total} / F_{total_v} = 854 \text{ mm}$$

$$e = \bar{x} - l_{base} / 2 = -296 \text{ mm}$$

$$l_{load} = 2 \times \bar{x} = 1708 \text{ mm}$$

$$q_{toe} = F_{total_v} / l_{load} = 95.3 \text{ kN/m}^2$$

$$q_{heel} = 0 \text{ kN/m}^2$$

$$q = (l_{base} + d_{cover}) \times \gamma_b' = 18.9 \text{ kN/m}^2$$

$$q' = q / \gamma_r = 18.9 \text{ kN/m}^2$$

$$N_q = \text{Exp}(\pi \times \tan(\phi'_{b,d})) \times (\tan(45 \text{ deg} + \phi'_{b,d} / 2))^2 = 7.298$$

$$N_c = (N_q - 1) \times \cot(\phi'_{b,d}) = 16.141$$

$$N_r = 2 \times (N_q - 1) \times \tan(\phi'_{b,d}) = 4.915$$

Foundation shape factors;

$$s_q = 1$$

$$s_r = 1$$

$$s_c = 1$$

Load inclination factors;

$$H = F_{sur_h} + F_{moist_h} + F_{pass_h} = 11.4 \text{ kN/m}$$

$$V = F_{total_v} = 162.9 \text{ kN/m}$$

$$m = 2$$

$$i_q = [1 - H / (V + l_{load} \times c'_{b,d} \times \cot(\phi'_{b,d}))]^m = 0.865$$

$$i_r = [1 - H / (V + l_{load} \times c'_{b,d} \times \cot(\phi'_{b,d}))]^{(m+1)} = 0.805$$

$$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b,d})) = 0.844$$

Net ultimate bearing capacity

$$n_f = c'_{b,d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_b' \times l_{load} \times N_r \times s_r \times i_r = 190.3 \text{ kN/m}^2$$

Factor of safety;

$$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = 1.996$$

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 Incorporating Corrigendum dated January 2008 and the UK National Annex Incorporating National Amendment No.1

Tedds calculation version 2.9.11

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

Concrete strength class;
Characteristic compressive cylinder strength;
Characteristic compressive cube strength;
Mean value of compressive cylinder strength;
Mean value of axial tensile strength;
5% fractile of axial tensile strength;
Secant modulus of elasticity of concrete;
Partial factor for concrete - Table 2.1N;
Compressive strength coefficient - cl.3.1.6(1);
Design compressive concrete strength - exp.3.15;
Maximum aggregate size;

$$C30/37$$

$$f_{ck} = 30 \text{ N/mm}^2$$

$$f_{ck,cube} = 37 \text{ N/mm}^2$$

$$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = 38 \text{ N/mm}^2$$

$$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = 2.9 \text{ N/mm}^2$$

$$f_{ctk,0.05} = 0.7 \times f_{ctm} = 2.0 \text{ N/mm}^2$$

$$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = 32837 \text{ N/mm}^2$$

$$\gamma_c = 1.50$$

$$\alpha_{cc} = 0.85$$

$$f_{ed} = \alpha_{cc} \times f_{ck} / \gamma_c = 17.0 \text{ N/mm}^2$$

$$h_{agg} = 20 \text{ mm}$$

Moist retained soil;
Base soil;
Total;

$$F_{moist_v} = \gamma_G \times A_{moist} \times \gamma_{mr}' = 102.4 \text{ kN/m}$$

$$F_{exc_v} = \gamma_G \times A_{exc} \times \gamma_b' = 2.5 \text{ kN/m}$$

$$F_{total_v} = F_{stem} + F_{base} + F_{moist_v} + F_{exc_v} = 158.5 \text{ kN/m}$$

Horizontal forces on wall
Surcharge load;

$$F_{sur_h} = K_A \times (\gamma_G \times \text{Surcharge}_a + \gamma_a \times \text{Surcharge}_a) \times (h_{eff} - d_{key}) = 2.4 \text{ kN/m}$$

Moist retained soil;
Base soil;
Total;

$$F_{moist_h} = \gamma_G \times K_A \times \gamma_{mr}' \times (h_{eff} - d_{key})^2 / 2 = 53 \text{ kN/m}$$

$$F_{exc_h} = -\gamma_G \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = -32.4 \text{ kN/m}$$

$$F_{total_h} = F_{sur_h} + F_{moist_h} + F_{exc_h} = 23.1 \text{ kN/m}$$

Overturning moments on wall

Surcharge load;
Moist retained soil;
Base soil;
Total;

$$M_{sur_OT} = F_{sur_h} \times X_{sur_h_a} = 4.4 \text{ kNm/m}$$

$$M_{moist_OT} = F_{moist_h} \times X_{moist_h_a} = 63.6 \text{ kNm/m}$$

$$M_{exc_OT} = F_{exc_h} \times X_{exc_h} = 3.2 \text{ kNm/m}$$

$$M_{total_OT} = M_{sur_OT} + M_{moist_OT} + M_{exc_OT} = 71.2 \text{ kNm/m}$$

Restoring moments on wall

Wall stem;
Wall base;
Moist retained soil;
Base soil;
Total;

$$M_{stem_R} = F_{stem} \times X_{stem} = 14.4 \text{ kNm/m}$$

$$M_{base_R} = F_{base} \times X_{base} = 35.7 \text{ kNm/m}$$

$$M_{moist_R} = F_{moist_v} \times X_{moist_v} = 153.6 \text{ kNm/m}$$

$$M_{exc_R} = F_{exc_v} \times X_{exc_v} = 0.5 \text{ kNm/m}$$

$$M_{total_R} = M_{stem_R} + M_{base_R} + M_{moist_R} + M_{exc_R} = 204.3 \text{ kNm/m}$$

Check stability against overturning
Factor of safety;

$$FoS_{OT} = M_{total_R} / M_{total_OT} = 2.868$$

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem;
Wall base;
Surcharge load;

$$F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = 26.3 \text{ kN/m}$$

$$F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = 27.4 \text{ kN/m}$$

$$F_{sur_v} = (\gamma_G \times \text{Surcharge}_a + \gamma_a \times \text{Surcharge}_a) \times h_{heel} = 2.6 \text{ kN/m}$$

Moist retained soil;
Base soil;
Total;

$$F_{moist_v} = \gamma_G \times A_{moist} \times \gamma_{mr}' = 102.4 \text{ kN/m}$$

$$F_{pass_v} = \gamma_G \times A_{pass} \times \gamma_b' = 4.2 \text{ kN/m}$$

$$F_{total_v} = F_{stem} + F_{base} + F_{sur_v} + F_{moist_v} + F_{pass_v} = 162.9 \text{ kN/m}$$

Horizontal forces on wall

Surcharge load;

$$F_{sur_h} = K_A \times (\gamma_G \times \text{Surcharge}_a + \gamma_a \times \text{Surcharge}_a) \times (h_{eff} - d_{key}) = 2.4 \text{ kN/m}$$

Moist retained soil;
Base soil;
Total;

$$F_{moist_h} = \gamma_G \times K_A \times \gamma_{mr}' \times (h_{eff} - d_{key})^2 / 2 = 53 \text{ kN/m}$$

$$F_{pass_h} = -\gamma_G \times K_P \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2 = -44.1 \text{ kN/m}$$

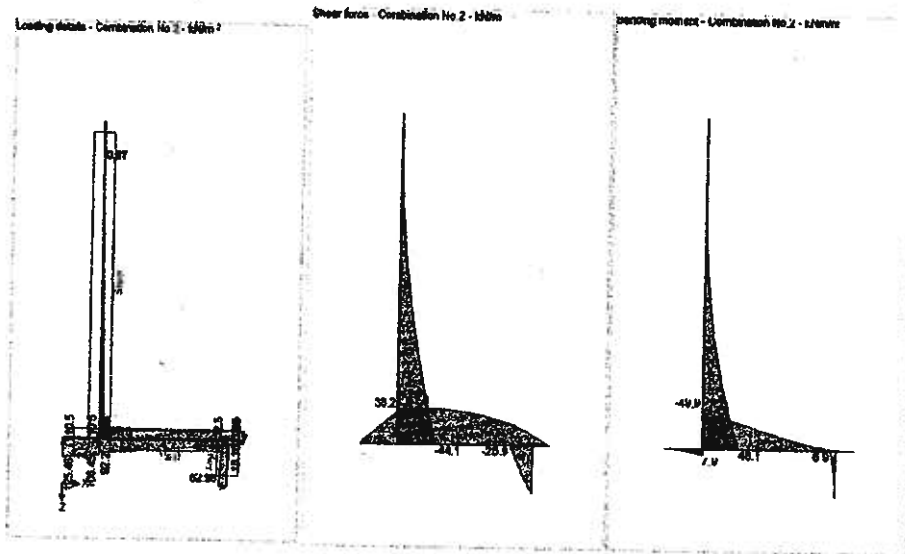
$$F_{total_h} = \max(F_{sur_h} + F_{moist_h} + F_{pass_h} - F_{total_v} \times \tan(\delta_{ob.d}), 0 \text{ kN/m}) = 0 \text{ kN/m}$$

Moments on wall

Wall stem;
Wall base;

$$M_{stem} = F_{stem} \times X_{stem} = 14.4 \text{ kNm/m}$$

$$M_{base} = F_{base} \times X_{base} = 35.7 \text{ kNm/m}$$



Check stem design at base of stem

Depth of section;

$$h = 300 \text{ mm}$$

Rectangular section in flexure - Section 6.1

Design bending moment combination 1;

$$M = 52.7 \text{ kNm/m}$$

Depth to tension reinforcement;

$$d = h - c_{\text{eff}} - \phi_{\text{sr}} / 2 = 242 \text{ mm}$$

$$K = M / (d^2 \times f_{\text{ck}}) = 0.030$$

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

$\times K_2)$

$$K' = 0.207$$

$K' > K$ - No compression reinforcement is required

$$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{\text{eff}} \gamma_c))^{0.5}, 0.95) \times d =$$

Lever arm;

$$x = 2.5 \times (d - z) = 30 \text{ mm}$$

230 mm

$$A_{\text{sr, req}} = M / (f_{\text{yd}} \times z) = 528 \text{ mm}^2/\text{m}$$

Depth of neutral axis;

$$16 \text{ dia. bars @ } 150 \text{ c/c}$$

Area of tension reinforcement required;

$$A_{\text{sr, prov}} = \pi \times \phi_{\text{sr}}^2 / (4 \times s_{\text{sr}}) = 1340 \text{ mm}^2/\text{m}$$

Tension reinforcement provided;

$$A_{\text{sr, min}} = \max(0.26 \times f_{\text{ctm}} / f_{\text{yk}}, 0.0013) \times d = 384 \text{ mm}^2/\text{m}$$

Area of tension reinforcement provided;

$$A_{\text{sr, max}} = 0.04 \times h = 12000 \text{ mm}^2/\text{m}$$

Minimum area of reinforcement - exp.9.1N;

$$\max(A_{\text{sr, req}}, A_{\text{sr, min}}) / A_{\text{sr, prov}} = 0.394$$

Maximum area of reinforcement - cl.8.2.1.1(3);

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

Library Item: Rectangular single output

Deflection control - Section 7.4

Reference reinforcement ratio;

$$\rho_0 = \sqrt{f_{\text{ck}} / 1 \text{ N/mm}^2} / 1000 = 0.005$$

Required tension reinforcement ratio;

$$\rho = A_{\text{sr, req}} / d = 0.002$$

Required compression reinforcement ratio;

$$\rho' = A_{\text{sr, 2, req}} / d_2 = 0.000$$

Structural system factor - Table 7.4N;

$$K_b = 0.4$$

Reinforcement factor - exp.7.17;

$$K_s = \min(500 \text{ N/mm}^2 / (f_{\text{yk}} \times A_{\text{sr, req}} / A_{\text{sr, prov}}), 1.5) = 1.5$$

Ultimate strain - Table 3.1;

$$\epsilon_{cu2} = 0.0035$$

Shortening strain - Table 3.1;

$$\epsilon_{cu3} = 0.0035$$

Effective compression zone height factor;

$$\lambda = 0.80$$

Effective strength factor;

$$\eta = 1.00$$

Bending coefficient k_1 ;

$$K_1 = 0.40$$

Bending coefficient k_2 ;

$$K_2 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$$

Bending coefficient k_3 ;

$$K_3 = 0.40$$

Bending coefficient k_4 ;

$$K_4 = 1.00 \times (0.6 + 0.0014/\epsilon_{cu2}) = 1.00$$

Reinforcement details

Characteristic yield strength of reinforcement;

$$f_{yk} = 500 \text{ N/mm}^2$$

Modulus of elasticity of reinforcement;

$$E_s = 200000 \text{ N/mm}^2$$

Partial factor for reinforcing steel - Table 2.1N;

$$\gamma_s = 1.15$$

Design yield strength of reinforcement;

$$f_{yd} = f_{yk} / \gamma_s = 435 \text{ N/mm}^2$$

Cover to reinforcement

Front face of stem;

$$c_{ef} = 40 \text{ mm}$$

Rear face of stem;

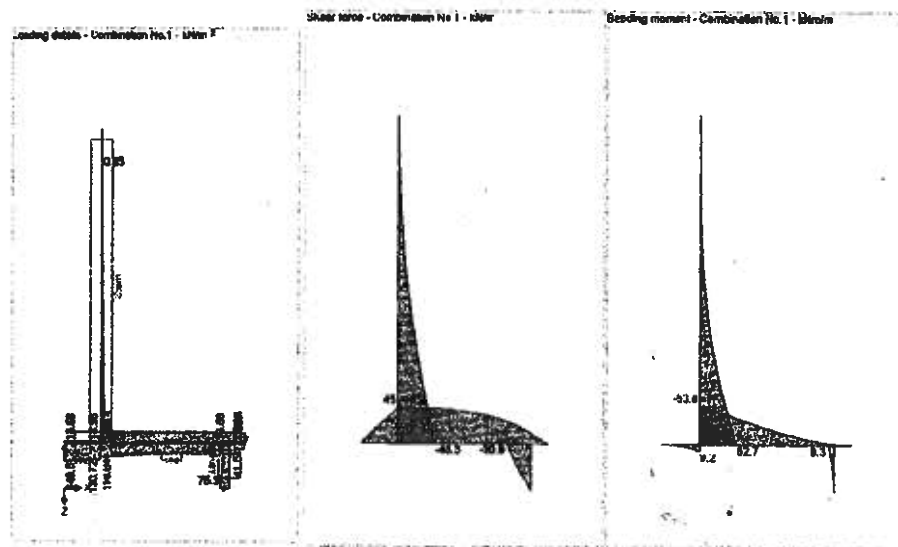
$$c_{er} = 50 \text{ mm}$$

Top face of base;

$$c_{ot} = 50 \text{ mm}$$

Bottom face of base;

$$c_{ob} = 75 \text{ mm}$$



Limiting span to depth ratio - exp.7.16.a;

$$\min(K_b \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b) = 16$$

Actual span to depth ratio;

$$l_{\text{stem}} / d = 14.5$$

PASS - Span to depth ratio is less than deflection control limit

Crack control - Section 7.3

Limiting crack width;

$$w_{\text{max}} = 0.3 \text{ mm}$$

Variable load factor - EN1990 - Table A1.1;

$$\psi_2 = 0.6$$

Serviceability bending moment;

$$M_{\text{slb}} = 38.6 \text{ kNm/m}$$

Tensile stress in reinforcement;

$$\sigma_s = M_{\text{slb}} / (A_{\text{sr,prov}} \times z) = 125.3 \text{ N/mm}^2$$

Load duration;

Long term

Load duration factor;

$$k_1 = 0.4$$

Effective area of concrete in tension;

$$A_{c,\text{eff}} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,\text{eff}} = 89917 \text{ mm}^2/\text{m}$$

Mean value of concrete tensile strength;

$$f_{ct,\text{eff}} = f_{ctm} = 2.9 \text{ N/mm}^2$$

Reinforcement ratio;

$$\rho_{p,\text{eff}} = A_{\text{sr,prov}} / A_{c,\text{eff}} = 0.015$$

Modular ratio;

$$\alpha_s = E_s / E_{cm} = 6.091$$

Bond property coefficient;

$$k_1 = 0.8$$

Strain distribution coefficient;

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

Maximum crack spacing - exp.7.11;

$$s_{r,\text{max}} = k_3 \times c_{er} + k_1 \times k_2 \times k_4 \times \phi_{er} / \rho_{p,\text{eff}} = 352 \text{ mm}$$

Maximum crack width - exp.7.8;

$$w_k = s_{r,\text{max}} \times \max(\sigma_s - k_4 \times (f_{ct,\text{eff}} / \rho_{p,\text{eff}}) \times (1 + \alpha_s \times \rho_{p,\text{eff}}), 0.6 \times \sigma_s) / E_s$$

$$w_k = 0.133 \text{ mm}$$

$$w_k / w_{\text{max}} = 0.442$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force;

$$V = 48.3 \text{ kN/m}$$

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

$$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.909$$

Longitudinal reinforcement ratio;

$$\rho_1 = \min(A_{\text{sr,prov}} / d, 0.02) = 0.008$$

$$v_{\text{min}} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.506 \text{ N/mm}^2$$

Design shear resistance - exp.6.2a & 6.2b;

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_1 \times f_{ck})^{1/3}, v_{\text{min}}) \times d$$

$$V_{Rd,c} = 141.5 \text{ kN/m}$$

$$V / V_{Rd,c} = 0.342$$

PASS - Design shear resistance exceeds design shear force

Horizontal reinforcement parallel to face of stem - Section 9.6

Minimum area of reinforcement - cl.9.6.3(1);

$$A_{s,\text{req}} = \max(0.25 \times A_{\text{sr,prov}}, 0.001 \times l_{\text{stem}}) = 335 \text{ mm}^2/\text{m}$$

Maximum spacing of reinforcement - cl.9.6.3(2);

$$s_{s,\text{max}} = 400 \text{ mm}$$

Transverse reinforcement provided;

$$10 \text{ dia.bars @ } 200 \text{ c/c}$$

Area of transverse reinforcement provided;

$$A_{s,\text{prov}} = \pi \times \phi_{s,\text{bar}}^2 / (4 \times s_{s,\text{bar}}) = 393 \text{ mm}^2/\text{m}$$

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

Check base design at toe

Depth of section;

$$h = 400 \text{ mm}$$

Longitudinal reinforcement ratio;

$$\rho_l = \min(A_{s,prov} / d, 0.02) = 0.002$$

Design shear resistance - exp.6.2a & 6.2b;

$$V_{min} = 0.035 N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} = 0.460 N/mm^2$$

$$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, V_{min}) \times d$$

$$V_{Rd,c} = 146.7 kN/m$$

$$V / V_{Rd,c} = 0.307$$

PASS - Design shear resistance exceeds design shear force

Check base design at heel

Depth of section;

$$h = 400 \text{ mm}$$

Rectangular section in flexure - Section 6.1

Design bending moment combination 1;

$$M = 53.8 kNm/m$$

Depth to tension reinforcement;

$$d = h - C_{bt} - \phi_{bt} / 2 = 342 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.015$$

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

$\times K_2))$

$$K' = 0.207$$

$K' > K$ - No compression reinforcement is required

$$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{oe} / \gamma_c))^{0.5}, 0.95) \times d =$$

Lever arm;

325 mm

$$x = 2.5 \times (d - z) = 43 \text{ mm}$$

Depth of neutral axis;

$$A_{s,req} = M / (f_{yd} \times z) = 381 \text{ mm}^2/m$$

Area of tension reinforcement required;

16 dia.bars @ 150 c/c

Tension reinforcement provided;

$$A_{s,prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) = 1340 \text{ mm}^2/m$$

Area of tension reinforcement provided;

$$A_{s,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 515 \text{ mm}^2/m$$

Minimum area of reinforcement - exp.9.1N;

$$A_{s,max} = 0.04 \times h = 16000 \text{ mm}^2/m$$

Maximum area of reinforcement - cl.9.2.1.1(3);

$$\max(A_{s,req}, A_{s,min}) / A_{s,prov} = 0.384$$

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

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width;

$$w_{max} = 0.3 \text{ mm}$$

Variable load factor - EN1990 - Table A1.1;

$$\psi_2 = 0.6$$

Serviceability bending moment;

$$M_{sle} = 28.1 kNm/m$$

Tensile stress in reinforcement;

$$\sigma_s = M_{sle} / (A_{s,prov} \times z) = 84.5 N/mm^2$$

Load duration;

Long term

Load duration factor;

$$k_t = 0.4$$

Effective area of concrete in tension;

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

Mean value of concrete tensile strength;

$$A_{c,eff} = 119083 \text{ mm}^2/m$$

Reinforcement ratio;

$$f_{ct,eff} = f_{ctm} = 2.9 N/mm^2$$

Modular ratio;

$$\rho_{p,eff} = A_{s,prov} / A_{c,eff} = 0.011$$

Bond property coefficient;

$$\alpha_o = E_s / E_{cm} = 6.081$$

Strain distribution coefficient;

$$k_1 = 0.8$$

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

Maximum crack spacing - exp.7.11;

$$s_{r,max} = k_3 \times C_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = 412 \text{ mm}$$

Rectangular section in flexure - Section 6.1

Design bending moment combination 1;

Depth to tension reinforcement;

$\times K_2$)

Lever arm;

303 mm

Depth of neutral axis;

Area of tension reinforcement required;

Tension reinforcement provided;

Area of tension reinforcement provided;

Minimum area of reinforcement - exp.9.1N;

Maximum area of reinforcement - cl.9.2.1.1(3);

$$M = 0.2 \text{ kNm/m}$$

$$d = h - c_{bb} - \phi_{bb} / 2 = 319 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.003$$

$$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (6 - K_1) / (2 \times K_2)) \times (\lambda \times (6 - K_1) / (2$$

$$K' = 0.207$$

$K' > K$ - No compression reinforcement is required

$$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{1.5}, 0.95) \times d =$$

$$x = 2.5 \times (d - z) = 40 \text{ mm}$$

$$A_{bb,req} = M / (f_{yd} \times z) = 70 \text{ mm}^2/\text{m}$$

$$12 \text{ dia.bars @ } 200 \text{ c/c}$$

$$A_{bb,prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = 565 \text{ mm}^2/\text{m}$$

$$A_{bb,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 480 \text{ mm}^2/\text{m}$$

$$A_{bb,max} = 0.04 \times h = 16000 \text{ mm}^2/\text{m}$$

$$\max(A_{bb,req}, A_{bb,min}) / A_{bb,prov} = 0.85$$

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

Library Item: Rectangular single output

Crack control - Section 7.3

Limiting crack width;

Variable load factor - EN1990 - Table A1.1;

Serviceability bending moment;

Tensile stress in reinforcement;

Load duration;

Load duration factor;

Effective area of concrete in tension;

Mean value of concrete tensile strength;

Reinforcement ratio;

Modular ratio;

Bond property coefficient;

Strain distribution coefficient;

Maximum crack spacing - exp.7.11;

Maximum crack width - exp.7.8;

$$w_{max} = 0.3 \text{ mm}$$

$$\psi_2 = 0.6$$

$$M_{sbb} = 5.7 \text{ kNm/m}$$

$$\sigma_s = M_{sbb} / (A_{bb,prov} \times z) = 33 \text{ N/mm}^2$$

Long term

$$k_1 = 0.4$$

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$$

$$A_{c,eff} = 120042 \text{ mm}^2/\text{m}$$

$$f_{ct,eff} = f_{ctm} = 2.9 \text{ N/mm}^2$$

$$\rho_{p,eff} = A_{bb,prov} / A_{c,eff} = 0.005$$

$$\alpha_e = E_s / E_{cm} = 6.091$$

$$k_1 = 0.8$$

$$k_2 = 0.5$$

$$k_3 = 3.4$$

$$k_4 = 0.425$$

$$s_{r,max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p,eff} = 688 \text{ mm}$$

$$w_k = s_{r,max} \times \max(\sigma_s - k_1 \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$$

$$w_k = 0.068 \text{ mm}$$

$$w_k / w_{max} = 0.227$$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force;

$$V = 45 \text{ kN/m}$$

$$C_{rd,c} = 0.18 / \gamma_c = 0.120$$

$$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.792$$

