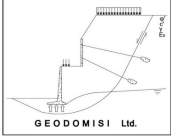
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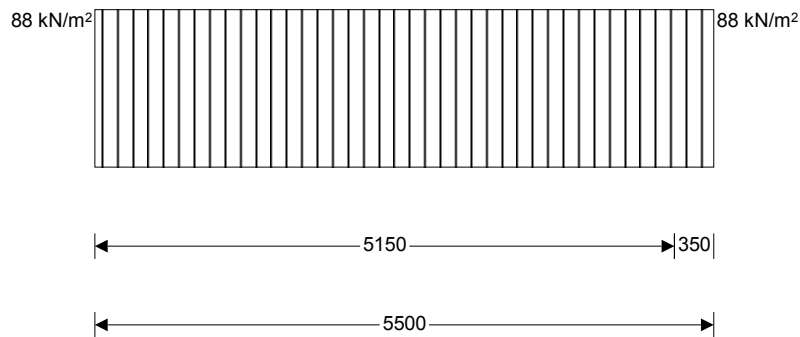
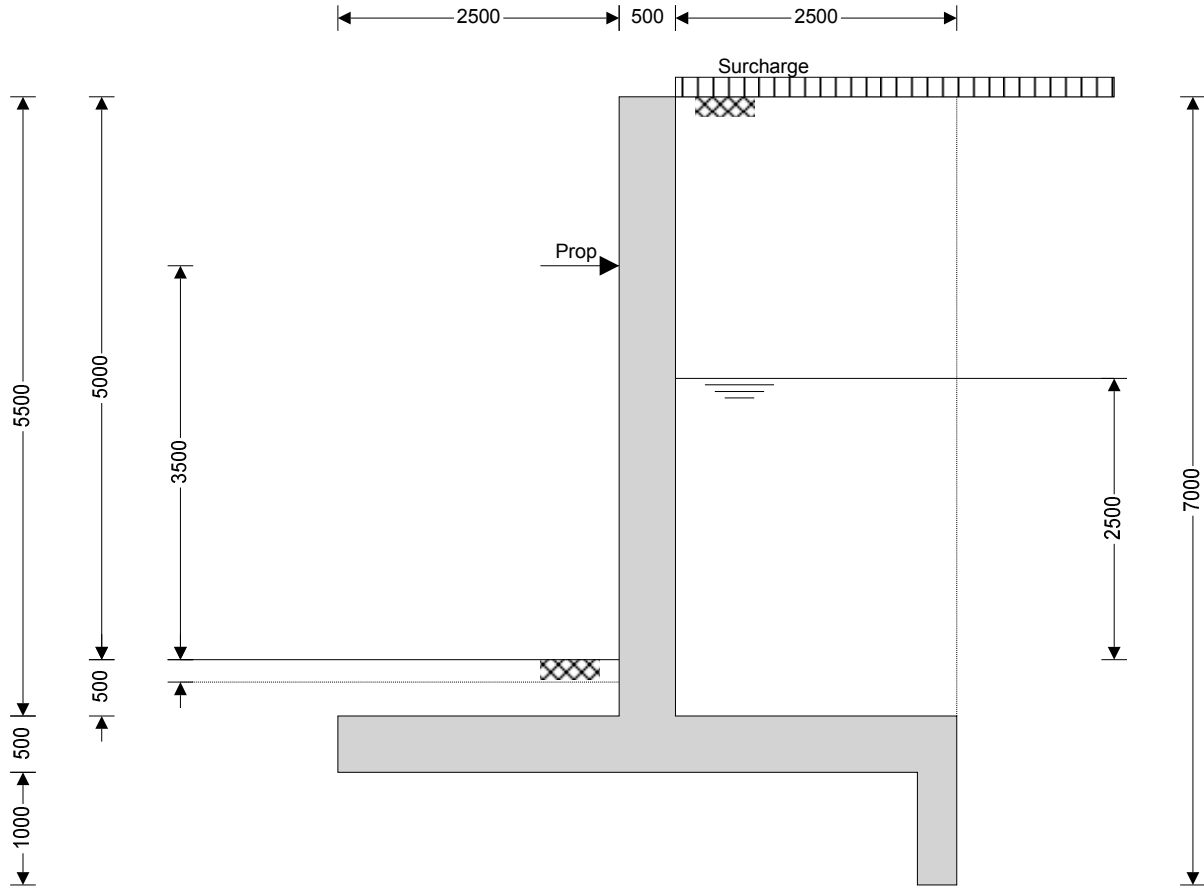
## RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the recommended values

### Retaining wall details

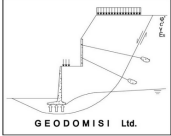
Stem type;	Propped cantilever
Stem height;	$h_{\text{stem}} = 5500$ mm
Prop height;	$h_{\text{prop}} = 4000$ mm
Stem thickness;	$t_{\text{stem}} = 500$ mm
Angle to rear face of stem;	$\alpha = 90$ deg
Stem density;	$\gamma_{\text{stem}} = 25$ kN/m <sup>3</sup>
Toe length;	$l_{\text{toe}} = 2500$ mm
Heel length;	$l_{\text{heel}} = 2500$ mm
Base thickness;	$t_{\text{base}} = 500$ mm
Key position;	$p_{\text{key}} = 5150$ mm
Key depth;	$d_{\text{key}} = 1000$ mm
Key thickness;	$t_{\text{key}} = 350$ mm
Base density;	$\gamma_{\text{base}} = 25$ kN/m <sup>3</sup>
Height of retained soil;	$h_{\text{ret}} = 5000$ mm
Angle of soil surface;	$\beta = 0$ deg
Depth of cover;	$d_{\text{cover}} = 500$ mm
Depth of excavation;	$d_{\text{exc}} = 200$ mm
Height of water;	$h_{\text{water}} = 2500$ mm
Water density;	$\gamma_w = 9.8$ kN/m <sup>3</sup>

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**Retained soil properties**

Soil type;	Soft clay
Moist density;	$\gamma_{mr} = 17 \text{ kN/m}^3$
Saturated density;	$\gamma_{sr} = 17 \text{ kN/m}^3$
Characteristic effective shear resistance angle;	$\phi'_{r,k} = 12 \text{ deg}$
Characteristic wall friction angle;	$\delta_{r,k} = 8 \text{ deg}$

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### Base soil properties

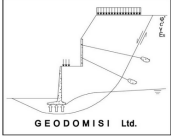
Soil type;	Stiff clay
Moist density;	$\gamma_{mb} = 20 \text{ kN/m}^3$
Characteristic cohesion;	$c'_{b,k} = 25 \text{ kN/m}^2$
Characteristic adhesion;	$a_{b,k} = 20 \text{ kN/m}^2$
Characteristic effective shear resistance angle;	$\phi'_{b,k} = 18 \text{ deg}$
Characteristic wall friction angle;	$\delta_{b,k} = 12 \text{ deg}$
Characteristic base friction angle;	$\delta_{bb,k} = 14 \text{ deg}$

### Loading details

Permanent surcharge load;	Surcharge <sub>G</sub> = <b>12 kN/m<sup>2</sup></b>
Variable surcharge load;	Surcharge <sub>Q</sub> = <b>15 kN/m<sup>2</sup></b>

### Calculate retaining wall geometry

Base length;	$l_{base} = l_{toe} + t_{stem} + l_{heel} = 5500 \text{ mm}$
Base height;	$h_{base} = t_{base} + d_{key} = 1500 \text{ mm}$
Saturated soil height;	$h_{sat} = h_{water} + d_{cover} = 3000 \text{ mm}$
Moist soil height;	$h_{moist} = h_{ret} - h_{water} = 2500 \text{ mm}$
Length of surcharge load;	$l_{sur} = l_{heel} = 2500 \text{ mm}$
- Distance to vertical component;	$x_{sur_v} = l_{base} - l_{heel} / 2 = 4250 \text{ mm}$
Effective height of wall;	$h_{eff} = h_{base} + d_{cover} + h_{ret} = 7000 \text{ mm}$
- Distance to horizontal component;	$x_{sur_h} = h_{eff} / 2 - d_{key} = 2500 \text{ mm}$
Area of wall stem;	$A_{stem} = h_{stem} \times t_{stem} = 2.75 \text{ m}^2$
- Distance to vertical component;	$x_{stem} = l_{toe} + t_{stem} / 2 = 2750 \text{ mm}$
Area of wall base;	$A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key} = 3.1 \text{ m}^2$
- Distance to vertical component;	$x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base} = 3041 \text{ mm}$
Area of saturated soil;	$A_{sat} = h_{sat} \times l_{heel} = 7.5 \text{ m}^2$
- Distance to vertical component;	$x_{sat_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat} = 4250 \text{ mm}$
- Distance to horizontal component;	$x_{sat_h} = (h_{sat} + h_{base}) / 3 - d_{key} = 500 \text{ mm}$
Area of water;	$A_{water} = h_{sat} \times l_{heel} = 7.5 \text{ m}^2$
- Distance to vertical component;	$x_{water_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat} = 4250 \text{ mm}$
- Distance to horizontal component;	$x_{water_h} = (h_{sat} + h_{base}) / 3 - d_{key} = 500 \text{ mm}$
Area of moist soil;	$A_{moist} = h_{moist} \times l_{heel} = 6.25 \text{ m}^2$
- Distance to vertical component;	$x_{moist_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist} = 4250 \text{ mm}$
- Distance to horizontal component;	$x_{moist_h} = (h_{moist} \times (t_{base} + h_{sat} + h_{moist} / 3) / 2 + (h_{sat} + h_{base}) \times ((h_{sat} + h_{base}) / 2 - d_{key})) / (h_{sat} + h_{base} + h_{moist} / 2) = 1920 \text{ mm}$
Area of base soil;	$A_{pass} = d_{cover} \times l_{toe} = 1.25 \text{ m}^2$
- Distance to vertical component;	$x_{pass_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} = 1250 \text{ mm}$
- Distance to horizontal component;	$x_{pass_h} = (d_{cover} + h_{base}) / 3 - d_{key} = -333 \text{ mm}$
Area of excavated base soil;	$A_{exc} = h_{pass} \times l_{toe} = 0.75 \text{ m}^2$
- Distance to vertical component;	$x_{exc_v} = l_{base} - (h_{pass} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{exc} = 1250 \text{ mm}$
- Distance to horizontal component;	$x_{exc_h} = (h_{pass} + h_{base}) / 3 - d_{key} = -400 \text{ mm}$

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

Permanent unfavourable action;	$\gamma_G = 1.35$
Permanent favourable action;	$\gamma_{Gf} = 1.00$
Variable unfavourable action;	$\gamma_Q = 1.50$
Variable favourable action;	$\gamma_{Qf} = 0.00$

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

Angle of shearing resistance;	$\gamma_{\phi'} = 1.00$
Effective cohesion;	$\gamma_{c'} = 1.00$
Weight density;	$\gamma_\gamma = 1.00$

### Retained soil properties

Design effective shear resistance angle;	$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\phi'}) = 12 \text{ deg}$
Design wall friction angle;	$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}) = 8 \text{ deg}$

### Base soil properties

Design effective shear resistance angle;	$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\phi'}) = 18 \text{ deg}$
Design wall friction angle;	$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi'}) = 12 \text{ deg}$
Design base friction angle;	$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = 14 \text{ deg}$
Design effective cohesion;	$c'_{b,d} = c'_{b,k} / \gamma_{c'} = 25 \text{ kN/m}^2$
Design adhesion;	$a_{b,d} = a_{b,k} / \gamma_{c'} = 20 \text{ kN/m}^2$

### Using Coulomb theory

Active pressure coefficient;	$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{[\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))]}]^2) = 0.601$
Passive pressure coefficient;	$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{[\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d}) / (\sin(90 + \delta_{b,d}))]}]^2) = 2.547$

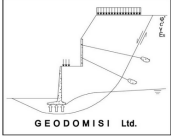
### Bearing pressure check

#### Vertical forces on wall

Wall stem;	$F_{\text{stem}} = \gamma_G \times A_{\text{stem}} \times \gamma_{\text{stem}} = 92.8 \text{ kN/m}$
Wall base;	$F_{\text{base}} = \gamma_G \times A_{\text{base}} \times \gamma_{\text{base}} = 104.6 \text{ kN/m}$
Surcharge load;	$F_{\text{sur}_v} = (\gamma_G \times \text{Surcharge}_G + \gamma_Q \times \text{Surcharge}_Q) \times l_{\text{heel}} = 96.8 \text{ kN/m}$
Saturated retained soil;	$F_{\text{sat}_v} = \gamma_G \times A_{\text{sat}} \times (\gamma_{sr} - \gamma_w) = 72.8 \text{ kN/m}$
Water;	$F_{\text{water}_v} = \gamma_G \times A_{\text{water}} \times \gamma_w = 99.3 \text{ kN/m}$
Moist retained soil;	$F_{\text{moist}_v} = \gamma_G \times A_{\text{moist}} \times \gamma_{mr} = 143.4 \text{ kN/m}$
Base soil;	$F_{\text{pass}_v} = \gamma_G \times A_{\text{pass}} \times \gamma_{mb} = 33.8 \text{ kN/m}$
Total;	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{sat}_v} + F_{\text{moist}_v} + F_{\text{pass}_v} + F_{\text{water}_v} + F_{\text{sur}_v} = 643.5 \text{ kN/m}$

#### Horizontal forces on wall

Surcharge load;	$F_{\text{sur}_h} = K_A \times \cos(\delta_{r,d}) \times (\gamma_G \times \text{Surcharge}_G + \gamma_Q \times \text{Surcharge}_Q) \times h_{\text{eff}} = 161.2 \text{ kN/m}$
Saturated retained soil;	$F_{\text{sat}_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times (\gamma_{sr} - \gamma_w) \times (h_{\text{sat}} + h_{\text{base}})^2 / 2 = 58.5 \text{ kN/m}$
Water;	$F_{\text{water}_h} = \gamma_G \times \gamma_w \times (h_{\text{water}} + d_{\text{cover}} + h_{\text{base}})^2 / 2 = 134.1 \text{ kN/m}$

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Moist retained soil;

$$F_{\text{moist}_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr} \times ((h_{\text{eff}} - h_{\text{sat}} - h_{\text{base}})^2 / 2 + (h_{\text{eff}} - h_{\text{sat}} - h_{\text{base}}) \times (h_{\text{sat}} + h_{\text{base}})) = \mathbf{196.3 \text{ kN/m}}$$

Total;

$$F_{\text{total}_h} = F_{\text{sat}_h} + F_{\text{moist}_h} + F_{\text{water}_h} + F_{\text{sur}_h} = \mathbf{550.1 \text{ kN/m}}$$

### Moments on wall

Wall stem;

$$M_{\text{stem}} = F_{\text{stem}} \times X_{\text{stem}} = \mathbf{255.2 \text{ kNm/m}}$$

Wall base;

$$M_{\text{base}} = F_{\text{base}} \times X_{\text{base}} = \mathbf{318.1 \text{ kNm/m}}$$

Surcharge load;

$$M_{\text{sur}} = F_{\text{sur}_v} \times X_{\text{sur}_v} - F_{\text{sur}_h} \times X_{\text{sur}_h} = \mathbf{8.2 \text{ kNm/m}}$$

Saturated retained soil;

$$M_{\text{sat}} = F_{\text{sat}_v} \times X_{\text{sat}_v} - F_{\text{sat}_h} \times X_{\text{sat}_h} = \mathbf{280.2 \text{ kNm/m}}$$

Water;

$$M_{\text{water}} = F_{\text{water}_v} \times X_{\text{water}_v} - F_{\text{water}_h} \times X_{\text{water}_h} = \mathbf{355.1 \text{ kNm/m}}$$

Moist retained soil;

$$M_{\text{moist}} = F_{\text{moist}_v} \times X_{\text{moist}_v} - F_{\text{moist}_h} \times X_{\text{moist}_h} = \mathbf{232.6 \text{ kNm/m}}$$

Base soil;

$$M_{\text{pass}} = F_{\text{pass}_v} \times X_{\text{pass}_v} = \mathbf{42.2 \text{ kNm/m}}$$

Total;

$$M_{\text{total}} = M_{\text{stem}} + M_{\text{base}} + M_{\text{sat}} + M_{\text{moist}} + M_{\text{pass}} + M_{\text{water}} + M_{\text{sur}} = \mathbf{1491.6 \text{ kNm/m}}$$

### Check bearing pressure

Maximum friction force;

$$F_{\text{friction}_\text{max}} = F_{\text{total}_v} \times \tan(\delta_{bb,d}) = \mathbf{160.4 \text{ kN/m}}$$

Maximum base soil resistance;

$$F_{\text{pass}_h_\text{max}} = \gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_{mb} \times (d_{\text{cover}} + h_{\text{base}})^2 / 2 = \mathbf{99.6 \text{ kN/m}}$$

Base soil resistance;

$$F_{\text{pass}_h} = \min(\max((M_{\text{total}} + F_{\text{total}_h} \times (h_{\text{prop}} + t_{\text{base}}) + F_{\text{friction}_\text{max}} \times (h_{\text{prop}} + t_{\text{base}}) - F_{\text{total}_v} \times l_{\text{base}} / 2) / (x_{\text{pass}_h} - h_{\text{prop}} - t_{\text{base}}), 0 \text{ kN/m}), F_{\text{pass}_h_\text{max}}) = \mathbf{0 \text{ kN/m}}$$

Propping force;

$$F_{\text{prop}_\text{stem}} = \min((F_{\text{total}_v} \times l_{\text{base}} / 2 - M_{\text{total}}) / (h_{\text{prop}} + t_{\text{base}}), F_{\text{total}_h}) = \mathbf{61.8 \text{ kN/m}}$$

Friction force;

$$F_{\text{friction}} = F_{\text{total}_h} - F_{\text{pass}_h} - F_{\text{prop}_\text{stem}} = \mathbf{488.3 \text{ kN/m}}$$

Moment from propping force;

$$M_{\text{prop}} = F_{\text{prop}_\text{stem}} \times (h_{\text{prop}} + t_{\text{base}}) = \mathbf{278.1 \text{ kNm/m}}$$

Distance to reaction;

$$\bar{x} = (M_{\text{total}} + M_{\text{prop}}) / F_{\text{total}_v} = \mathbf{2750 \text{ mm}}$$

Eccentricity of reaction;

$$e = \bar{x} - l_{\text{base}} / 2 = \mathbf{0 \text{ mm}}$$

Loaded length of base;

$$l_{\text{load}} = l_{\text{base}} = \mathbf{5500 \text{ mm}}$$

Bearing pressure at toe;

$$q_{\text{toe}} = F_{\text{total}_v} / l_{\text{base}} = \mathbf{117 \text{ kN/m}^2}$$

Bearing pressure at heel;

$$q_{\text{heel}} = F_{\text{total}_v} / l_{\text{base}} = \mathbf{117 \text{ kN/m}^2}$$

Effective overburden pressure;

$$q = \max((t_{\text{base}} + d_{\text{cover}}) \times \gamma_{mb} - (t_{\text{base}} + d_{\text{cover}} + h_{\text{water}}) \times \gamma_w, 0 \text{ kN/m}^2) = \mathbf{0 \text{ kN/m}^2}$$

Design effective overburden pressure;

$$q' = q / \gamma_\gamma = \mathbf{0 \text{ kN/m}^2}$$

Bearing resistance factors;

$$N_q = \text{Exp}(\pi \times \tan(\phi'_{b,d})) \times (\tan(45 \text{ deg} + \phi'_{b,d} / 2))^2 = \mathbf{5.258}$$

$$N_c = (N_q - 1) \times \cot(\phi'_{b,d}) = \mathbf{13.104}$$

$$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b,d}) = \mathbf{2.767}$$

Foundation shape factors;

$$s_q = 1$$

$$s_\gamma = 1$$

$$s_c = 1$$

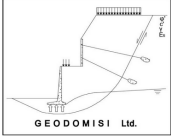
Load inclination factors;

$$H = F_{\text{total}_h} - F_{\text{prop}_\text{stem}} - F_{\text{friction}} = \mathbf{0 \text{ kN/m}}$$

$$V = F_{\text{total}_v} = \mathbf{643.5 \text{ kN/m}}$$

$$m = 2$$

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

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

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

Net ultimate bearing capacity;

$$n_f = c'_{b,d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times I_{load} \times N_{\gamma} \times s_{\gamma} \times i_{\gamma} = 405.1 \text{ kN/m}^2$$

Factor of safety;

$$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = 3.463$$

**PASS - Allowable bearing pressure exceeds maximum applied bearing pressure**

#### Partial factors on actions - Table A.3 - Combination 2

Permanent unfavourable action;  $\gamma_G = 1.00$

Permanent favourable action;  $\gamma_{Gf} = 1.00$

Variable unfavourable action;  $\gamma_Q = 1.30$

Variable favourable action;  $\gamma_{Qf} = 0.00$

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

Angle of shearing resistance;  $\gamma_{\phi'} = 1.25$

Effective cohesion;  $\gamma_{c'} = 1.25$

Weight density;  $\gamma_{\gamma} = 1.00$

#### Retained soil properties

Design effective shear resistance angle;  $\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\phi'}) = 9.7 \text{ deg}$

Design wall friction angle;  $\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}) = 6.4 \text{ deg}$

#### Base soil properties

Design effective shear resistance angle;  $\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\phi'}) = 14.6 \text{ deg}$

Design wall friction angle;  $\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi'}) = 9.7 \text{ deg}$

Design base friction angle;  $\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = 11.3 \text{ deg}$

Design effective cohesion;  $c'_{b,d} = c'_{b,k} / \gamma_{c'} = 20 \text{ kN/m}^2$

Design adhesion;  $a_{b,d} = a_{b,k} / \gamma_{c'} = 16 \text{ kN/m}^2$

#### Using Coulomb theory

Active pressure coefficient;  $K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))}]^2) = 0.661$

Passive pressure coefficient;  $K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{(\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d}) / (\sin(90 + \delta_{b,d}))}]^2) = 2.077$

#### Bearing pressure check

##### Vertical forces on wall

Wall stem;  $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = 68.8 \text{ kN/m}$

Wall base;  $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = 77.5 \text{ kN/m}$

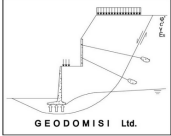
Surcharge load;  $F_{sur_v} = (\gamma_G \times \text{Surcharge}_G + \gamma_Q \times \text{Surcharge}_Q) \times I_{heel} = 78.8 \text{ kN/m}$

Saturated retained soil;  $F_{sat_v} = \gamma_G \times A_{sat} \times (\gamma_{sr} - \gamma_w) = 53.9 \text{ kN/m}$

Water;  $F_{water_v} = \gamma_G \times A_{water} \times \gamma_w = 73.6 \text{ kN/m}$

Moist retained soil;  $F_{moist_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = 106.3 \text{ kN/m}$

Base soil;  $F_{pass_v} = \gamma_G \times A_{pass} \times \gamma_{mb} = 25 \text{ kN/m}$

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Total;  $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{pass\_v} + F_{water\_v} + F_{sur\_v} = \mathbf{483.8}$   
kN/m

### Horizontal forces on wall

Surcharge load;  $F_{sur\_h} = K_A \times \cos(\delta_{r,d}) \times (\gamma_G \times \text{Surcharge}_G + \gamma_Q \times \text{Surcharge}_Q) \times h_{eff} = \mathbf{144.9}$  kN/m

Saturated retained soil;  $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 = \mathbf{47.8}$  kN/m

Water;  $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{99.3}$  kN/m

Moist retained soil;  $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r,d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) = \mathbf{160.6}$  kN/m

Total;  $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h} = \mathbf{452.7}$  kN/m

### Moments on wall

Wall stem;  $M_{stem} = F_{stem} \times x_{stem} = \mathbf{189.1}$  kNm/m

Wall base;  $M_{base} = F_{base} \times x_{base} = \mathbf{235.7}$  kNm/m

Surcharge load;  $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} = \mathbf{-27.6}$  kNm/m

Saturated retained soil;  $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h} = \mathbf{205.3}$  kNm/m

Water;  $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h} = \mathbf{263}$  kNm/m

Moist retained soil;  $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} = \mathbf{143.2}$  kNm/m

Base soil;  $M_{pass} = F_{pass\_v} \times x_{pass\_v} = \mathbf{31.3}$  kNm/m

Total;  $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur} = \mathbf{1039.8}$   
kNm/m

### Check bearing pressure

Maximum friction force;  $F_{friction\_max} = F_{total\_v} \times \tan(\delta_{bb,d}) = \mathbf{96.5}$  kN/m

Maximum base soil resistance;  $F_{pass\_h\_max} = \gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2 = \mathbf{81.9}$  kN/m

Base soil resistance;  $F_{pass\_h} = \min(\max((M_{total} + F_{total\_h} \times (h_{prop} + t_{base}) + F_{friction\_max} \times (h_{prop} + t_{base}) - F_{total\_v} \times l_{base} / 2) / (x_{pass\_h} - h_{prop} - t_{base}), 0 \text{ kN/m}), F_{pass\_h\_max}) = \mathbf{0}$  kN/m

Propping force;  $F_{prop\_stem} = \min((F_{total\_v} \times l_{base} / 2 - M_{total}) / (h_{prop} + t_{base}), F_{total\_h}) = \mathbf{64.6}$   
kN/m

Friction force;  $F_{friction} = F_{total\_h} - F_{pass\_h} - F_{prop\_stem} = \mathbf{388.1}$  kN/m

Moment from propping force;  $M_{prop} = F_{prop\_stem} \times (h_{prop} + t_{base}) = \mathbf{290.5}$  kNm/m

Distance to reaction;  $\bar{x} = (M_{total} + M_{prop}) / F_{total\_v} = \mathbf{2750}$  mm

Eccentricity of reaction;  $e = \bar{x} - l_{base} / 2 = \mathbf{0}$  mm

Loaded length of base;  $l_{load} = l_{base} = \mathbf{5500}$  mm

Bearing pressure at toe;  $q_{toe} = F_{total\_v} / l_{base} = \mathbf{88}$  kN/m<sup>2</sup>

Bearing pressure at heel;  $q_{heel} = F_{total\_v} / l_{base} = \mathbf{88}$  kN/m<sup>2</sup>

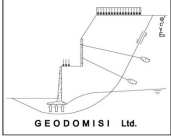
Effective overburden pressure;  $q = \max((t_{base} + d_{cover}) \times \gamma_{mb} - (t_{base} + d_{cover} + h_{water}) \times \gamma_w, 0 \text{ kN/m}^2) = \mathbf{0}$  kN/m<sup>2</sup>

Design effective overburden pressure;  $q' = q / \gamma_\gamma = \mathbf{0}$  kN/m<sup>2</sup>

Bearing resistance factors;  $N_q = \text{Exp}(\pi \times \tan(\phi'_{b,d})) \times (\tan(45 \text{ deg} + \phi'_{b,d} / 2))^2 = \mathbf{3.784}$

$N_c = (N_q - 1) \times \cot(\phi'_{b,d}) = \mathbf{10.711}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b,d}) = \mathbf{1.447}$

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Foundation shape factors;

$$s_q = 1$$

$$s_\gamma = 1$$

$$s_c = 1$$

Load inclination factors;

$$H = F_{\text{total}_h} - F_{\text{prop}_\text{stem}} - F_{\text{friction}} = \mathbf{0 \text{ kN/m}}$$

$$V = F_{\text{total}_v} = \mathbf{483.8 \text{ kN/m}}$$

$$m = 2$$

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

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

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

Net ultimate bearing capacity;

$$n_f = c'_{b,d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times I_{\text{load}} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{254.8 \text{ kN/m}^2}$$

Factor of safety;

$$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{2.897}$$

**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 recommended values

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

Concrete strength class;

C40/50

Characteristic compressive cylinder strength;

$$f_{ck} = \mathbf{40 \text{ N/mm}^2}$$

Characteristic compressive cube strength;

$$f_{ck,cube} = \mathbf{50 \text{ N/mm}^2}$$

Mean value of compressive cylinder strength;

$$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = \mathbf{48 \text{ N/mm}^2}$$

Mean value of axial tensile strength;

$$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = \mathbf{3.5 \text{ N/mm}^2}$$

5% fractile of axial tensile strength;

$$f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.5 \text{ N/mm}^2}$$

Secant modulus of elasticity of concrete;

$$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = \mathbf{35220 \text{ N/mm}^2}$$

Partial factor for concrete - Table 2.1N;

$$\gamma_C = \mathbf{1.50}$$

Compressive strength coefficient - cl.3.1.6(1);

$$\alpha_{cc} = \mathbf{1.00}$$

Design compressive concrete strength - exp.3.15;

$$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = \mathbf{26.7 \text{ N/mm}^2}$$

Maximum aggregate size;

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

### Reinforcement details

Characteristic yield strength of reinforcement;

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

Modulus of elasticity of reinforcement;

$$E_s = \mathbf{210000 \text{ N/mm}^2}$$

Partial factor for reinforcing steel - Table 2.1N;

$$\gamma_S = \mathbf{1.15}$$

Design yield strength of reinforcement;

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

### Cover to reinforcement

Front face of stem;

$$c_{sf} = \mathbf{40 \text{ mm}}$$

Rear face of stem;

$$c_{sr} = \mathbf{50 \text{ mm}}$$

Top face of base;

$$c_{bt} = \mathbf{50 \text{ mm}}$$

Bottom face of base;

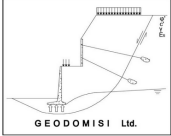
$$c_{bb} = \mathbf{75 \text{ mm}}$$

### Check stem design for maximum moment

Depth of section;

$$h = \mathbf{500 \text{ mm}}$$



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### Rectangular section in flexure - Section 6.1

Design bending moment;

$$M = 104.8 \text{ kNm/m}$$

Depth to tension reinforcement;

$$d = h - c_{sr} - \phi_{sr} / 2 = 442 \text{ mm}$$

$$K = M / (d^2 \times f_{ck}) = 0.013$$

$$K' = 0.196$$

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

Lever arm;

$$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = 420 \text{ mm}$$

Depth of neutral axis;

$$x = 2.5 \times (d - z) = 55 \text{ mm}$$

Area of tension reinforcement required;

$$A_{sr,req} = M / (f_{yd} \times z) = 574 \text{ mm}^2/\text{m}$$

Tension reinforcement provided;

$$16 \text{ dia. bars @ } 200 \text{ c/c}$$

Area of tension reinforcement provided;

$$A_{sr,prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = 1005 \text{ mm}^2/\text{m}$$

Minimum area of reinforcement - exp.9.1N;

$$A_{sr,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 806 \text{ mm}^2/\text{m}$$

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

$$A_{sr,max} = 0.04 \times h = 20000 \text{ mm}^2/\text{m}$$

$$\max(A_{sr,req}, A_{sr,min}) / A_{sr,prov} = 0.802$$

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

### 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;

$$M_{sls} = 71.7 \text{ kNm/m}$$

Tensile stress in reinforcement;

$$\sigma_s = M_{sls} / (A_{sr,prov} \times z) = 169.8 \text{ N/mm}^2$$

Load duration;

Long term

Load duration factor;

$$k_t = 0.4$$

Effective area of concrete in tension;

$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 145000 \text{ mm}^2/\text{m}$$

Mean value of concrete tensile strength;

$$f_{ct,eff} = f_{ctm} = 3.5 \text{ N/mm}^2$$

Reinforcement ratio;

$$\rho_{p,eff} = A_{sr,prov} / A_{c,eff} = 0.007$$

Modular ratio;

$$\alpha_e = E_s / E_{cm} = 5.962$$

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;

$$s_{r,max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p,eff} = 562 \text{ mm}$$

Maximum crack width - exp.7.8;

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

$$w_k = 0.273 \text{ mm}$$

$$w_k / w_{max} = 0.909$$

***PASS - Maximum crack width is less than limiting crack width***

### Rectangular section in shear - Section 6.2

Design shear force;

$$V = 195.7 \text{ kN/m}$$

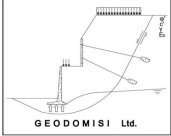
$$C_{Rd,c} = 0.18 / \gamma_C = 0.120$$

$$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.673$$

Longitudinal reinforcement ratio;

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

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.479 \text{ N/mm}^2$$

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

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

$$V_{Rd.c} = \mathbf{211.7 \text{ kN/m}}$$

$$V / V_{Rd.c} = \mathbf{0.924}$$

**PASS - Design shear resistance exceeds design shear force**

### Rectangular section in flexure - Section 6.1

Design bending moment;

$$M = \mathbf{72.6 \text{ kNm/m}}$$

Depth to tension reinforcement;

$$d = h - c_{sf} - \phi_{sx} - \phi_{sf} / 2 = \mathbf{442 \text{ mm}}$$

$$K = M / (d^2 \times f_{ck}) = \mathbf{0.009}$$

$$K' = \mathbf{0.196}$$

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

Lever arm;

$$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{420 \text{ mm}}$$

Depth of neutral axis;

$$x = 2.5 \times (d - z) = \mathbf{55 \text{ mm}}$$

Area of tension reinforcement required;

$$A_{sf.req} = M / (f_{yd} \times z) = \mathbf{398 \text{ mm}^2/m}$$

Tension reinforcement provided;

$$\mathbf{16 \text{ dia. bars @ 225 c/c}}$$

Area of tension reinforcement provided;

$$A_{sf.prov} = \pi \times \phi_{sf}^2 / (4 \times s_{sf}) = \mathbf{894 \text{ mm}^2/m}$$

Minimum area of reinforcement - exp.9.1N;

$$A_{sf.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{806 \text{ mm}^2/m}$$

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

$$A_{sf.max} = 0.04 \times h = \mathbf{20000 \text{ mm}^2/m}$$

$$\max(A_{sf.req}, A_{sf.min}) / A_{sf.prov} = \mathbf{0.902}$$

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

### Crack control - Section 7.3

Limiting crack width;

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

Variable load factor - EN1990 – Table A1.1;

$$\psi_2 = \mathbf{0.6}$$

Serviceability bending moment;

$$M_{sls} = \mathbf{49.5 \text{ kNm/m}}$$

Tensile stress in reinforcement;

$$\sigma_s = M_{sls} / (A_{sf.prov} \times z) = \mathbf{131.8 \text{ N/mm}^2}$$

Load duration;

Long term

Load duration factor;

$$k_t = \mathbf{0.4}$$

Effective area of concrete in tension;

$$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = \mathbf{145000 \text{ mm}^2/m}$$

Mean value of concrete tensile strength;

$$f_{ct.eff} = f_{ctm} = \mathbf{3.5 \text{ N/mm}^2}$$

Reinforcement ratio;

$$\rho_{p.eff} = A_{sf.prov} / A_{c.eff} = \mathbf{0.006}$$

Modular ratio;

$$\alpha_e = E_s / E_{cm} = \mathbf{5.962}$$

Bond property coefficient;

$$k_1 = \mathbf{0.8}$$

Strain distribution coefficient;

$$k_2 = \mathbf{0.5}$$

$$k_3 = \mathbf{3.4}$$

$$k_4 = \mathbf{0.425}$$

Maximum crack spacing - exp.7.11;

$$s_{r.max} = k_3 \times c_{sf} + k_1 \times k_2 \times k_4 \times \phi_{sf} / \rho_{p.eff} = \mathbf{577 \text{ mm}}$$

Maximum crack width - exp.7.8;

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

$$w_k = \mathbf{0.217 \text{ mm}}$$

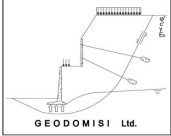
$$w_k / w_{max} = \mathbf{0.725}$$

**PASS - Maximum crack width is less than limiting crack width**

### Rectangular section in shear - Section 6.2

Design shear force;

$$V = \mathbf{195.7 \text{ kN/m}}$$

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

$$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.673}$$

Longitudinal reinforcement ratio;

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

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

$$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.479 \text{ N/mm}^2}$$

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

$$V_{Rd,c} = \mathbf{211.7 \text{ kN/m}}$$

$$V / V_{Rd,c} = \mathbf{0.924}$$

**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);

$$A_{sx,req} = \max(0.25 \times A_{sr,prov}, 0.001 \times t_{stem}) = \mathbf{500 \text{ mm}^2/\text{m}}$$

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

$$s_{sx,max} = \mathbf{400 \text{ mm}}$$

Transverse reinforcement provided;

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

Area of transverse reinforcement provided;

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

**FAIL - Area of reinforcement provided is less than area of reinforcement required**

### Check base design

Depth of section;

$$h = \mathbf{500 \text{ mm}}$$

### Rectangular section in flexure - Section 6.1

Design bending moment at toe;

$$M = \mathbf{270.7 \text{ kNm/m}}$$

Depth to tension reinforcement;

$$d = h - c_{bb} - \phi_{bb} / 2 = \mathbf{415 \text{ mm}}$$

$$K = M / (d^2 \times f_{ck}) = \mathbf{0.039}$$

$$K' = \mathbf{0.196}$$

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

Lever arm;

$$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{394 \text{ mm}}$$

Depth of neutral axis;

$$x = 2.5 \times (d - z) = \mathbf{52 \text{ mm}}$$

Area of tension reinforcement required;

$$A_{bb,req} = M / (f_{yd} \times z) = \mathbf{1579 \text{ mm}^2/\text{m}}$$

Tension reinforcement provided;

$$20 \text{ dia.bars @ } 125 \text{ c/c}$$

Area of tension reinforcement provided;

$$A_{bb,prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = \mathbf{2513 \text{ mm}^2/\text{m}}$$

Minimum area of reinforcement - exp.9.1N;

$$A_{bb,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{757 \text{ mm}^2/\text{m}}$$

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

$$A_{bb,max} = 0.04 \times h = \mathbf{20000 \text{ mm}^2/\text{m}}$$

$$\max(A_{bb,req}, A_{bb,min}) / A_{bb,prov} = \mathbf{0.628}$$

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

### Crack control - Section 7.3

Limiting crack width;

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

Variable load factor - EN1990 – Table A1.1;

$$\psi_2 = \mathbf{0.6}$$

Serviceability bending moment;

$$M_{sls} = \mathbf{189.6 \text{ kNm/m}}$$

Tensile stress in reinforcement;

$$\sigma_s = M_{sls} / (A_{bb,prov} \times z) = \mathbf{191.4 \text{ N/mm}^2}$$

Load duration;

$$\text{Long term}$$

Load duration factor;

$$k_t = \mathbf{0.4}$$

Effective area of concrete in tension;

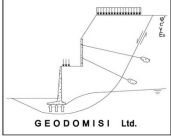
$$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = \mathbf{149375 \text{ mm}^2/\text{m}}$$

Mean value of concrete tensile strength;

$$f_{ct,eff} = f_{ctm} = \mathbf{3.5 \text{ N/mm}^2}$$

Reinforcement ratio;

$$\rho_{p,eff} = A_{bb,prov} / A_{c,eff} = \mathbf{0.017}$$

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Modular ratio;  $\alpha_e = E_s / E_{cm} = \mathbf{5.962}$   
Bond property coefficient;  $k_1 = \mathbf{0.8}$   
Strain distribution coefficient;  $k_2 = \mathbf{0.5}$   
 $k_3 = \mathbf{3.4}$   
 $k_4 = \mathbf{0.425}$   
Maximum crack spacing - exp.7.11;  $s_{r,max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p,eff} = \mathbf{457 \text{ mm}}$   
Maximum crack width - exp.7.8;  $w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$   
 $w_k = \mathbf{0.25 \text{ mm}}$   
 $w_k / w_{max} = \mathbf{0.833}$   
**PASS - Maximum crack width is less than limiting crack width**

### Rectangular section in shear - Section 6.2

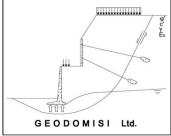
Design shear force;  $V = \mathbf{216.6 \text{ kN/m}}$   
 $C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$   
 $k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.694}$   
Longitudinal reinforcement ratio;  $\rho_l = \min(A_{bb,prov} / d, 0.02) = \mathbf{0.006}$   
 $v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.488 \text{ N/mm}^2}$   
Design shear resistance - exp.6.2a & 6.2b;  $V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$   
 $V_{Rd,c} = \mathbf{244.1 \text{ kN/m}}$   
 $V / V_{Rd,c} = \mathbf{0.887}$   
**PASS - Design shear resistance exceeds design shear force**

### Rectangular section in flexure - Section 6.1

Design bending moment at heel;  $M = \mathbf{170.6 \text{ kNm/m}}$   
Depth to tension reinforcement;  $d = h - c_{bt} - \phi_{bt} / 2 = \mathbf{440 \text{ mm}}$   
 $K = M / (d^2 \times f_{ck}) = \mathbf{0.022}$   
 $K' = \mathbf{0.196}$   
 **$K' > K$  - No compression reinforcement is required**  
Lever arm;  $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{418 \text{ mm}}$   
Depth of neutral axis;  $x = 2.5 \times (d - z) = \mathbf{55 \text{ mm}}$   
Area of tension reinforcement required;  $A_{bt,req} = M / (f_{yd} \times z) = \mathbf{939 \text{ mm}^2/\text{m}}$   
Tension reinforcement provided; **20 dia.bars @ 175 c/c**  
Area of tension reinforcement provided;  $A_{bt,prov} = \pi \times \phi_{bt}^2 / (4 \times S_{bt}) = \mathbf{1795 \text{ mm}^2/\text{m}}$   
Minimum area of reinforcement - exp.9.1N;  $A_{bt,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{803 \text{ mm}^2/\text{m}}$   
Maximum area of reinforcement - cl.9.2.1.1(3);  $A_{bt,max} = 0.04 \times h = \mathbf{20000 \text{ mm}^2/\text{m}}$   
 $\max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = \mathbf{0.523}$   
**PASS - Area of reinforcement provided is greater than area of reinforcement required**

### Crack control - Section 7.3

Limiting crack width;  $w_{max} = \mathbf{0.3 \text{ mm}}$   
Variable load factor - EN1990 – Table A1.1;  $\psi_2 = \mathbf{0.6}$   
Serviceability bending moment;  $M_{sls} = \mathbf{156.3 \text{ kNm/m}}$   
Tensile stress in reinforcement;  $\sigma_s = M_{sls} / (A_{bt,prov} \times z) = \mathbf{208.3 \text{ N/mm}^2}$   
Load duration; **Long term**

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Load duration factor;  $k_t = 0.4$

Effective area of concrete in tension;  $A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 148333 \text{ mm}^2/\text{m}$

Mean value of concrete tensile strength;  $f_{ct,eff} = f_{ctm} = 3.5 \text{ N/mm}^2$

Reinforcement ratio;  $\rho_{p,eff} = A_{bt,prov} / A_{c,eff} = 0.012$

Modular ratio;  $\alpha_e = E_s / E_{cm} = 5.962$

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;  $s_{r,max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = 451 \text{ mm}$

Maximum crack width - exp.7.8;  $W_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$

$W_k = 0.268 \text{ mm}$

$W_k / W_{max} = 0.895$

**PASS - Maximum crack width is less than limiting crack width**

#### Rectangular section in shear - Section 6.2

Design shear force;  $V = 173.8 \text{ kN/m}$

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.674$

Longitudinal reinforcement ratio;  $\rho_l = \min(A_{bt,prov} / d, 0.02) = 0.004$

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.480 \text{ N/mm}^2$

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

$V_{Rd,c} = 224.2 \text{ kN/m}$

$V / V_{Rd,c} = 0.775$

**PASS - Design shear resistance exceeds design shear force**

#### Secondary transverse reinforcement to base - Section 9.3

Minimum area of reinforcement – cl.9.3.1.1(2);  $A_{bx,req} = 0.2 \times A_{bb,prov} = 503 \text{ mm}^2/\text{m}$

Maximum spacing of reinforcement – cl.9.3.1.1(3);  $s_{bx,max} = 450 \text{ mm}$

Transverse reinforcement provided; 12 dia.bars @ 200 c/c

Area of transverse reinforcement provided;  $A_{bx,prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx}) = 565 \text{ mm}^2/\text{m}$

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

#### Check key design

Depth of section;  $h = 350 \text{ mm}$

#### Rectangular section in flexure - Section 6.1

Design bending moment at key;  $M = 17.7 \text{ kNm/m}$

Depth to tension reinforcement;  $d = h - c_{bb} - \phi_k / 2 = 269 \text{ mm}$

$K = M / (d^2 \times f_{ck}) = 0.006$

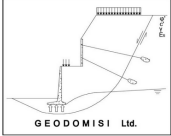
$K' = 0.196$

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

Lever arm;  $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = 256 \text{ mm}$

Depth of neutral axis;  $x = 2.5 \times (d - z) = 34 \text{ mm}$

Area of tension reinforcement required;  $A_{k,req} = M / (f_{yd} \times z) = 160 \text{ mm}^2/\text{m}$

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Tension reinforcement provided; 12 dia.bars @ 200 c/c  
Area of tension reinforcement provided;  $A_{k,prov} = \pi \times \phi_k^2 / (4 \times s_k) = 565 \text{ mm}^2/\text{m}$   
Minimum area of reinforcement - exp.9.1N;  $A_{k,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 491 \text{ mm}^2/\text{m}$   
Maximum area of reinforcement - cl.9.2.1.1(3);  $A_{k,max} = 0.04 \times h = 14000 \text{ mm}^2/\text{m}$   
 $\max(A_{k,req}, A_{k,min}) / A_{k,prov} = 0.868$

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

### Crack control - Section 7.3

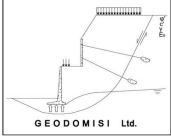
Limiting crack width;  $w_{max} = 0.3 \text{ mm}$   
Variable load factor - EN1990 – Table A1.1;  $\psi_2 = 0.6$   
Serviceability bending moment;  $M_{Sls} = 0 \text{ kNm/m}$   
Tensile stress in reinforcement;  $\sigma_s = M_{Sls} / (A_{k,prov} \times z) = 0 \text{ N/mm}^2$   
Load duration; Long term  
Load duration factor;  $k_t = 0.4$   
Effective area of concrete in tension;  $A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 105458 \text{ mm}^2/\text{m}$   
Mean value of concrete tensile strength;  $f_{ct,eff} = f_{ctm} = 3.5 \text{ N/mm}^2$   
Reinforcement ratio;  $\rho_{p,eff} = A_{k,prov} / A_{c,eff} = 0.005$   
Modular ratio;  $\alpha_e = E_s / E_{cm} = 5.962$   
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;  $s_{r,max} = k_3 \times C_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p,eff} = 635 \text{ mm}$   
Maximum crack width - exp.7.8;  $w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$   
 $w_k = 0 \text{ mm}$   
 $w_k / w_{max} = 0$

**PASS - Maximum crack width is less than limiting crack width**

### Rectangular section in shear - Section 6.2

Design shear force;  $V = 40 \text{ kN/m}$   
 $C_{Rd,c} = 0.18 / \gamma_C = 0.120$   
 $k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.862$   
Longitudinal reinforcement ratio;  $\rho_l = \min(A_{k,prov} / d, 0.02) = 0.002$   
 $v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.563 \text{ N/mm}^2$   
Design shear resistance - exp.6.2a & 6.2b;  $V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$   
 $V_{Rd,c} = 151.3 \text{ kN/m}$   
 $V / V_{Rd,c} = 0.264$

**PASS - Design shear resistance exceeds design shear force**

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