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: $h_{\text{stem}} = 5500 \text{ mm}$
- Prop height: $h_{\text{prop}} = 4500 \text{ mm}$
- Stem thickness: $t_{\text{stem}} = 500 \text{ mm}$
- Angle to rear face of stem: $\alpha = 90 \text{ deg}$
- Stem density: $\gamma_{\text{stem}} = 25 \text{ kN/m}^3$
- Toe length: $l_{\text{toe}} = 1000 \text{ mm}$
- Heel length: $l_{\text{heel}} = 3000 \text{ mm}$
- Base thickness: $t_{\text{base}} = 500 \text{ mm}$
- Key position: $p_{\text{key}} = 4150 \text{ mm}$
- Key depth: $d_{\text{key}} = 500 \text{ mm}$
- Key thickness: $t_{\text{key}} = 350 \text{ mm}$
- Base density: $\gamma_{\text{base}} = 25 \text{ kN/m}^3$
- Height of retained soil: $h_{\text{ref}} = 5000 \text{ mm}$
- Angle of soil surface: $\beta = 0 \text{ deg}$
- Depth of cover: $d_{\text{cover}} = 500 \text{ mm}$
- Height of water: $h_{\text{water}} = 150 \text{ mm}$
- Water density: $\gamma_{w} = 9.8 \text{ kN/m}^3$
Retaining wall Analysis & Design (EN1997-1:2004 incorporating Corrigendum dated February 2009)

Retained soil properties

Soil type:
Very loose gravel

Moist density;
\( \gamma_{mr} = 16 \text{ kN/m}^3 \)

Saturated density;
\( \gamma_{sr} = 20 \text{ kN/m}^3 \)
Calculate retaining wall geometry

Base length;
\[ h_{\text{base}} = l_{\text{toe}} + t_{\text{stem}} + h_{\text{heel}} = 4500 \text{ mm} \]

Base height;
\[ h_{\text{base}} = t_{\text{base}} + d_{\text{key}} = 1000 \text{ mm} \]

Saturated soil height;
\[ h_{\text{sat}} = h_{\text{water}} + d_{\text{cover}} = 650 \text{ mm} \]

Moist soil height;
\[ h_{\text{moist}} = h_{\text{ret}} - h_{\text{water}} = 4850 \text{ mm} \]

Length of surcharge load;
\[ l_{\text{sur}} = h_{\text{heel}} = 3000 \text{ mm} \]

Effective height of wall;
\[ h_{\text{eff}} = h_{\text{base}} + d_{\text{cover}} + h_{\text{ret}} = 6500 \text{ mm} \]

Area of wall stem;
\[ A_{\text{stem}} = h_{\text{stem}} \times t_{\text{stem}} = 2.75 \text{ m}^2 \]

Area of wall base;
\[ A_{\text{base}} = h_{\text{base}} \times t_{\text{base}} + d_{\text{key}} \times t_{\text{key}} = 2.425 \text{ m}^2 \]

Area of saturated soil;
\[ A_{\text{sat}} = h_{\text{sat}} \times t_{\text{heel}} = 1.95 \text{ m}^2 \]

Area of water;
\[ A_{\text{water}} = h_{\text{water}} \times t_{\text{heel}} = 1.95 \text{ m}^2 \]

Area of moist soil;
\[ A_{\text{moist}} = h_{\text{moist}} \times t_{\text{heel}} = 14.55 \text{ m}^2 \]

Area of base soil;
\[ A_{\text{pass}} = d_{\text{cover}} \times l_{\text{toe}} = 0.5 \text{ m}^2 \]
- Distance to horizontal component;  
  \[ x_{\text{pass} \_ h} = \frac{(d_{\text{cover}} + h_{\text{base}})}{3} - d_{\text{key}} = 0 \text{ mm} \]
- Distance to vertical component;  
  \[ A_{\text{exc}} = h_{\text{pass}} \times l_{\text{toe}} = 9.5 \text{ m}^2 \]
- Distance to horizontal component;  
  \[ x_{\text{exc} \_ h} = h_{\text{pass}} + h_{\text{base}} / 3 - d_{\text{key}} = 0 \text{ mm} \]

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

| Permanent unfavourable action; | \[ \gamma_{\text{f}} = 1.35 \] |
| Permanent favourable action; | \[ \gamma_{\text{f}} = 1.00 \] |
| Variable unfavourable action; | \[ \gamma_{\text{r}} = 1.50 \] |
| Variable favourable action; | \[ \gamma_{\text{r}} = 0.00 \] |

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; | \[ \phi_{1,a} = \text{atan}(\tan(\phi_{1,k}) / \gamma_{\phi}) = 26 \text{ deg} \] |
| Design wall friction angle; | \[ \delta_{1,a} = \text{atan}(\tan(\delta_{1,k}) / \gamma_{\phi}) = 13 \text{ deg} \] |

Base soil properties

| Design effective shear resistance angle; | \[ \phi_{b,a} = \text{atan}(\tan(\phi_{b,k}) / \gamma_{\phi}) = 18 \text{ deg} \] |
| Design wall friction angle; | \[ \delta_{b,a} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi}) = 9 \text{ deg} \] |
| Design base friction angle; | \[ \delta_{bb,a} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi}) = 12 \text{ deg} \] |
| Design effective cohesion; | \[ c_{b,a} = c_{bb,k} / \gamma_{c} = 25 \text{ kN/m}^2 \] |
| Design adhesion; | \[ a_{b,a} = a_{bb,k} / \gamma_{c} = 20 \text{ kN/m}^2 \] |

Using Coulomb theory

| Active pressure coefficient; | \[ K_{\text{A}} = \sin(\alpha + \phi_{1,a})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{1,a}) \times [1 + \sqrt{\sin(\phi_{1,a} + \delta_{1,a}) \times \sin(\phi_{1,a} - \beta) / (\sin(\alpha - \delta_{1,a}) \times \sin(\alpha + \beta))^2}] = 0.353 \] |
| Passive pressure coefficient; | \[ K_{\text{P}} = \sin(90 - \phi_{1,a})^2 / (\sin(90 + \delta_{1,a}) \times [1 - \sqrt{\sin(\phi_{1,a} + \delta_{1,a}) \times \sin(\phi_{1,a}) / (\sin(90 + \delta_{1,a}))}]^2 = 2.359 \] |

Bearing pressure check

Vertical forces on wall

| Wall stem; | \[ F_{\text{stem}} = \gamma_{\text{f}} \times A_{\text{stem}} \times \gamma_{\text{stem}} = 92.8 \text{ kN/m} \] |
| Wall base; | \[ F_{\text{base}} = \gamma_{\text{f}} \times A_{\text{base}} \times \gamma_{\text{base}} = 81.8 \text{ kN/m} \] |
| Surcharge load; | \[ F_{\text{sur} \_ v} = \gamma_{\text{f}} \times \text{Surcharge}_{\text{Q}} \times l_{\text{heel}} = 225 \text{ kN/m} \] |
| Saturated retained soil; | \[ F_{\text{sat} \_ v} = \gamma_{\text{f}} \times A_{\text{sat}} \times \gamma_{\text{sat}} = 26.8 \text{ kN/m} \] |
| Water; | \[ F_{\text{water} \_ v} = \gamma_{\text{f}} \times A_{\text{water}} \times \gamma_{w} = 25.8 \text{ kN/m} \] |
| Moist retained soil; | \[ F_{\text{moist} \_ v} = \gamma_{\text{f}} \times A_{\text{moist}} \times \gamma_{\text{mr}} = 314.3 \text{ kN/m} \] |
| Base soil; | \[ F_{\text{pass} \_ v} = \gamma_{\text{f}} \times A_{\text{pass}} \times \gamma_{\text{mb}} = 12.2 \text{ kN/m} \] |
#### Retaining wall Analysis & Design (EN1997-1:2004 incorporating Corrigendum dated February 2009)

**Section:** Civil & Geotechnical Engineering  
**Date:** 23/05/2013  
**Chk’d by:** -  
**App’d by:** -  

**Total:**

\[ F_{\text{total_v}} = F_{\text{stem}} + F_{\text{base}} + F_{\text{sat_v}} + F_{\text{moist_v}} + F_{\text{pass_v}} + F_{\text{water_v}} + F_{\text{sur_v}} = 778.7 \text{ kNm} \]

**Horizontal forces on wall**

- **Surcharge load:**
  \[ F_{\text{sur}} = K_A \times \cos(\delta_{b,d}) \times \gamma_Q \times \text{Surcharge}_{Q} \times h_{\text{eff}} = 167.8 \text{ kN/m} \]

- **Saturated retained soil:**
  \[ F_{\text{sat}} = \gamma_Q \times K_A \times \cos(\delta_{b,d}) \times (\gamma_{w} - \gamma_{w}) \times (h_{\text{sat}} + h_{\text{base}})^2 / 2 = 6.4 \text{ kN/m} \]

- **Water:**
  \[ F_{\text{water}} = \gamma_Q \times \gamma_{w} \times (h_{\text{water}} + d_{\text{cover}} + h_{\text{base}})^2 / 2 = 18 \text{ kN/m} \]

- **Moist retained soil:**
  \[ F_{\text{moist}} = \gamma_Q \times K_A \times \cos(\delta_{b,d}) \times \gamma_{w} \times ((h_{\text{eff}} - h_{\text{sat}} - h_{\text{base}})^2 / 2 + (h_{\text{eff}} - h_{\text{sat}} - h_{\text{base}}) \times (h_{\text{sat}} + h_{\text{base}})) = 146.9 \text{ kN/m} \]

- **Total:**
  \[ F_{\text{total}} = F_{\text{sat}} + F_{\text{moist}} + F_{\text{water}} + F_{\text{sur}} = 339.2 \text{ kN/m} \]

**Moments on wall**

- **Wall stem:**
  \[ M_{\text{stem}} = F_{\text{stem}} \times x_{\text{stem}} = 116 \text{ kNm/m} \]

- **Wall base:**
  \[ M_{\text{base}} = F_{\text{base}} \times x_{\text{base}} = 196.4 \text{ kNm/m} \]

- **Surcharge load:**
  \[ M_{\text{sur}} = F_{\text{sur}} \times x_{\text{sur}} \times h_{\text{sur}} = 213.6 \text{ kNm/m} \]

- **Saturated load:**
  \[ M_{\text{sat}} = F_{\text{sat}} \times x_{\text{sat}} \times h_{\text{sat}} = 80.2 \text{ kNm/m} \]

- **Water:**
  \[ M_{\text{water}} = F_{\text{water}} \times x_{\text{water}} \times h_{\text{water}} = 76.6 \text{ kNm/m} \]

- **Moist retained soil:**
  \[ M_{\text{moist}} = F_{\text{moist}} \times x_{\text{moist}} \times h_{\text{moist}} = 681.6 \text{ kNm/m} \]

- **Base soil:**
  \[ M_{\text{pass}} = F_{\text{pass}} \times x_{\text{pass}} = 6.1 \text{ kNm/m} \]

- **Total:**
  \[ M_{\text{total}} = M_{\text{stem}} + M_{\text{base}} + M_{\text{sat}} + M_{\text{moist}} + M_{\text{pass}} + M_{\text{water}} + M_{\text{sur}} = 1370.5 \text{ kNm/m} \]

**Check bearing pressure**

- **Maximum friction force:**
  \[ F_{\text{friction_max}} = F_{\text{total}} \times \tan(\delta_{bb,d}) = 165.5 \text{ kN/m} \]

- **Maximum base soil resistance:**
  \[ F_{\text{pass_max}} = \gamma_{Q} \times K_p \times \cos(\delta_{b,d}) \times \gamma_{mb} \times (d_{\text{cover}} + h_{\text{base}})^2 / 2 = 47.2 \text{ kN/m} \]

- **Base soil resistance:**
  \[ F_{\text{pass}} = \min(\max(M_{\text{total}} + F_{\text{total}} \times (h_{\text{prop}} + t_{\text{base}}) + F_{\text{friction_max}} \times (h_{\text{prop}} + t_{\text{base}}) - F_{\text{total}} \times h_{\text{base}} / 2 / (h_{\text{pass}} - h_{\text{prop}} - t_{\text{base}}), 0 \text{ kN/m}), F_{\text{pass}} = 0 \text{ kN/m} \]

- **Propping force:**
  \[ F_{\text{prop}} = \min(F_{\text{total}} \times t_{\text{base}} / 2 - M_{\text{total}} / (h_{\text{prop}} + t_{\text{base}}), F_{\text{total}} = 76.3 \text{ kNm/m} \]

- **Friction force:**
  \[ F_{\text{friction}} = F_{\text{total}} \times F_{\text{pass}} \times F_{\text{prop}} = 262.8 \text{ kNm/m} \]

- **Moment from propping force:**
  \[ M_{\text{prop}} = F_{\text{prop}} \times (h_{\text{prop}} + t_{\text{base}}) = 381.7 \text{ kNm/m} \]

- **Distance to reaction:**
  \[ x = (M_{\text{total}} + M_{\text{prop}}) / F_{\text{total}} = 2250 \text{ mm} \]

- **Eccentricity of reaction:**
  \[ e = x - h_{\text{base}} / 2 = 0 \text{ mm} \]

- **Loaded length of base:**
  \[ l_{\text{load}} = h_{\text{base}} = 4500 \text{ mm} \]
Partial factors on actions - Table A.3 - Combination 2

Permanent unfavourable action;  \( \gamma_P = 1.00 \)
Permanent favourable action;  \( \gamma_{Fr} = 1.00 \)
Variable unfavourable action;  \( \gamma_P = 1.30 \)
Variable favourable action;  \( \gamma_{Fr} = 0.00 \)

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;  \( \gamma_t = 1.00 \)

Retained soil properties
Design effective shear resistance angle;  \( \phi'_{r,d} = \tan(\tan(\phi_{r,k}) / \gamma_{\phi}) = 21.3 \) deg
Design wall friction angle;  \( \delta_{r,d} = \tan(\tan(\delta_{r,k}) / \gamma_t) = 10.5 \) deg

Base soil properties
Design effective shear resistance angle;  \( \phi_{b,d} = \tan(\tan(\phi_{b,k}) / \gamma_c) = 14.6 \) deg
Design wall friction angle;  \( \delta_{b,d} = \tan(\tan(\delta_{b,k}) / \gamma_t) = 7.2 \) deg
Design base friction angle;  \( \delta_{bb,d} = \tan(\tan(\delta_{bb,k}) / \gamma_t) = 9.7 \) deg
Design effective cohesion;  \( c'_{b,d} = c'_{b,k} / \gamma_c = 20 \) kN/m²
Design adhesion;  \( a_{b,d} = a_{b,k} / \gamma_c = 16 \) kN/m²

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure
### Using Coulomb theory

Active pressure coefficient;  
\[ K_A = \sin(\alpha + \psi_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt[3]{\sin(\psi_{r.d} + \delta_{r.d}) \times \sin(\psi_{r.d} - \beta) / \sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta)^2}]) = 0.425 \]

Passive pressure coefficient;  
\[ K_p = \sin(90 - \phi_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 + \sqrt[3]{\sin(\phi_{b.d} + \delta_{b.d}) \times \sin(\phi_{b.d} - \beta) / \sin(90 + \delta_{b.d})})^2] = 1.965 \]

### Bearing pressure check

#### Vertical forces on wall

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall stem</td>
<td>( F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = 68.8 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Wall base</td>
<td>( F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = 60.6 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Surcharge load</td>
<td>( F_{sur_v} = \gamma_G \times \text{Surcharge}<em>{Q} \times k</em>{heel} = 195 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Saturated retained soil</td>
<td>( F_{sat_v} = \gamma_G \times A_{sat} \times (\gamma_r + \gamma_w) = 19.9 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>( F_{water_v} = \gamma_G \times \gamma_{water} \times \gamma_w = 19.1 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Moist retained soil</td>
<td>( F_{moist_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = 232.8 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Base soil</td>
<td>( F_{pass_v} = \gamma_G \times A_{pass} \times \gamma_{mb} = 9 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>( F_{total_v} = F_{stem} + F_{base} + F_{sat_v} + F_{moist_v} + F_{pass_v} + F_{water_v} + F_{sur_v} = 605.2 \text{kN/m} )</td>
<td></td>
</tr>
</tbody>
</table>

#### Horizontal forces on wall

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surcharge load</td>
<td>( F_{sur_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_G \times \text{Surcharge}<em>{Q} \times h</em>{eff} = 176.5 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Saturated retained soil</td>
<td>( F_{sat_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_r + \gamma_w) \times (h_{sat} + h_{base})^2 / 2 = 13.4 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>( F_{water_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 = 132.1 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Moist retained soil</td>
<td>( 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}) = 327.8 \text{kN/m} )</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>( F_{total_h} = F_{sat_h} + F_{moist_h} + F_{water_h} + F_{sur_h} = 327.8 \text{kN/m} )</td>
<td></td>
</tr>
</tbody>
</table>

#### Moments on wall

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall stem</td>
<td>( M_{stem} = F_{stem} \times x_{stem} = 85.9 \text{kNm/m} )</td>
<td></td>
</tr>
<tr>
<td>Wall base</td>
<td>( M_{base} = F_{base} \times x_{base} = 145.5 \text{kNm/m} )</td>
<td></td>
</tr>
<tr>
<td>Surcharge load</td>
<td>( M_{sur} = F_{sur_v} \times x_{sur_v} + F_{sur_h} \times x_{sur_h} = 99.5 \text{kNm/m} )</td>
<td></td>
</tr>
<tr>
<td>Saturated retained soil</td>
<td>( M_{sat} = F_{sat_v} \times x_{sat_v} + F_{sat_h} \times x_{sat_h} = 59.3 \text{kNm/m} )</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>( M_{water} = F_{water_v} \times x_{water_v} + F_{water_h} \times x_{water_h} = 56.7 \text{kNm/m} )</td>
<td></td>
</tr>
<tr>
<td>Moist retained soil</td>
<td>( M_{moist} = F_{moist_v} \times x_{moist_v} + F_{moist_h} \times x_{moist_h} = 463.5 \text{kNm/m} )</td>
<td></td>
</tr>
<tr>
<td>Base soil</td>
<td>( M_{pass} = F_{pass_v} \times x_{pass_v} = 4.5 \text{kNm/m} )</td>
<td></td>
</tr>
</tbody>
</table>
Check bearing pressure

Maximum friction force;
\[ F_{\text{friction max}} = F_{\text{total v}} \times \tan(\delta_{b.d}) = 102.9 \text{kN/m} \]

Maximum base soil resistance;
\[ F_{\text{pass h max}} = \frac{\gamma \text{friction} \times K_d \times \cos(\delta_{b.d}) \times \gamma_{\text{mb}} \times (d_{\text{cover}} + h_{\text{base}})^2}{2} = 39.5 \text{kN/m} \]

Base soil resistance;
\[ F_{\text{pass h}} = \min((M_{\text{total}} + F_{\text{total h}}) \times (\Delta_{\text{prop}} + t_{\text{base}}) + F_{\text{friction max}} \times (h_{\text{prop}} + t_{\text{base}}) - F_{\text{total v}} \times t_{\text{base}}) / 2) / (x_{\text{pass h}} - h_{\text{prop}} - t_{\text{base}}), 0 \text{kN/m}), F_{\text{pass h max}} = 0 \text{kN/m} \]

Propping force;
\[ F_{\text{prop stem}} = \min((F_{\text{total v}} \times t_{\text{base}} / 2 - M_{\text{total}}) / (\Delta_{\text{prop}} + t_{\text{base})), F_{\text{total h}}) = 89.3 \text{kN/m} \]

Friction force;
\[ F_{\text{friction}} = F_{\text{total h}} - F_{\text{pass h}} - F_{\text{prop stem}} = 238.5 \text{kN/m} \]

Moment from propping force;
\[ M_{\text{prop}} = F_{\text{prop stem}} \times (\Delta_{\text{prop}} + t_{\text{base}}) = 446.7 \text{kN/m} \]

Distance to reaction;
\[ x = (M_{\text{total}} + M_{\text{prop}}) / F_{\text{total v}} = 2250 \text{mm} \]

Eccentricity of reaction;
\[ e = x - t_{\text{base}} / 2 = 0 \text{mm} \]

Loaded length of base;
\[ l_{\text{load}} = t_{\text{base}} = 4500 \text{mm} \]

Bearing pressure at toe;
\[ q_{\text{toe}} = F_{\text{total v}} / l_{\text{base}} = 134.5 \text{kN/m}^2 \]

Bearing pressure at heel;
\[ q_{\text{heel}} = F_{\text{total v}} / l_{\text{base}} = 134.5 \text{kN/m}^2 \]

Effective overburden pressure;
\[ q = (t_{\text{base}} + d_{\text{cover}}) \times \gamma_{\text{mb}} - (t_{\text{base}} + d_{\text{cover}} + h_{\text{water}}) \times \gamma_w = 6.7 \text{kN/m}^2 \]

Design effective overburden pressure;
\[ q' = q / \gamma_{\text{mb}} = 6.7 \text{kN/m}^2 \]

Bearing resistance factors;
\[ N_q = \exp(\pi \times \tan(\phi_{b.d})) \times (\tan(45 \text{deg} + \phi'_{d, b}) / 2))^2 = 3.784 \]

\[ N_c = (N_q - 1) \times \cot(\phi_{b.d}) = 10.711 \]
\[ N_l = 2 \times (N_q - 1) \times \tan(\phi_{b.d}) = 1.447 \]

Foundation shape factors;
\[ s_q = 1 \]
\[ s_l = 1 \]
\[ s_c = 1 \]

Load inclination factors;
\[ H = F_{\text{total h}} - F_{\text{prop stem}} - F_{\text{friction}} = 0 \text{kN/m} \]
\[ V = F_{\text{total v}} = 605.2 \text{kN/m} \]
\[ m = 2 \]
\[ i_q = [1 - H / (V + l_{\text{load}} \times c_{b.d} \times \cot(\phi_{b.d}))]^{m} = 1 \]
\[ i_l = [1 - H / (V + l_{\text{load}} \times c_{b.d} \times \cot(\phi_{b.d}))]^{m + 1} = 1 \]
\[ i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi_{b.d})) = 1 \]

Net ultimate bearing capacity;
\[ n_i = c_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{\text{mb}} \times \gamma_w) \times l_{\text{load}} \times N_l \times s_l \times i_l = 266.3 \text{kN/m}^2 \]

Factor of safety;
\[ \text{FoS}_{\text{max}} = n_i / \max(q_{\text{toe}}, q_{\text{heel}}) = 1.98 \]

**PASS** - Allowable bearing pressure exceeds maximum applied bearing pressure
RETAILING 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; C30/37
Characteristic compressive cylinder strength; $f_{ck} = 30 \text{ N/mm}^2$
Characteristic compressive cube strength; $f_{ck,cube} = 37 \text{ N/mm}^2$
Mean value of compressive cylinder strength; $f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = 38 \text{ N/mm}^2$
Mean value of axial tensile strength; $f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck}/1 \text{ N/mm}^2)^{2/3} = 2.9 \text{ N/mm}^2$
5% fractile of axial tensile strength; $f_{ctk,0.05} = 0.7 \times f_{ctm} = 2.0 \text{ N/mm}^2$
Secant modulus of elasticity of concrete; $E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm}/10 \text{ N/mm}^2)^{0.3} = 32837 \text{ N/mm}^2$

Partial factor for concrete - Table 2.1N; $\gamma_C = 1.50$
Compressive strength coefficient - cl.3.1.6(1); $\alpha_{cc} = 1.00$
Design compressive concrete strength - exp.3.15; $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = 20.0 \text{ N/mm}^2$
Maximum aggregate size; $h_{agg} = 20 \text{ mm}$

Reinforcement details

Characteristic yield strength of reinforcement; $f_{yk} = 500 \text{ N/mm}^2$
Modulus of elasticity of reinforcement; $E_s = 210000 \text{ N/mm}^2$
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; $c_{sf} = 40 \text{ mm}$
Rear face of stem; $c_{sr} = 50 \text{ mm}$
Top face of base; $c_{bt} = 50 \text{ mm}$
Bottom face of base; $c_{bb} = 75 \text{ mm}$

Check stem design for maximum moment

Depth of section; $h = 500 \text{ mm}$

Rectangular section in flexure - Section 6.1

Design bending moment; $M = 94.6 \text{ kNm/m}$
Depth to tension reinforcement; $d = h - c_{sr} - \phi_{sr} / 2 = 442 \text{ mm}$
$K = M / (d^2 \times f_{ck}) = 0.016$
$K' = 0.196$

$K' > K$ - 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; $A_{sr,req} = M / (f_{yd} \times z) = 518 \text{ mm}^2$/m
Tension reinforcement provided; 16 dia.bars @ 200 c/c
Area of tension reinforcement provided; $A_{sr,prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = 1005 \text{ mm}^2$/m
Minimum area of reinforcement - exp.9.1N; \[ A_{sr,\text{min}} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 666 \text{ mm}^2/m \]

Maximum area of reinforcement - cl.9.2.1.1(3); \[ A_{sr,\text{max}} = 0.04 \times h = 20000 \text{ mm}^2/m \]

\[ \max(A_{sr,\text{req}}, A_{sr,\text{min}}) / A_{sr,\text{prov}} = 0.662 \]

**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; \[ \psi_2 = 0.3 \]

Serviceability bending moment; \[ M_{sds} = 44.8 \text{ kNm/m} \]

Tensile stress in reinforcement; \[ \sigma_s = M_{sds} / (A_{sr,\text{prov}} \times z) = 106.2 \text{ N/mm}^2 \]

Load duration; Long term \[ k_t = 0.4 \]

Effective area of concrete in tension; \[ A_{c,\text{eff}} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 145000 \text{ mm}^2/m \]

Mean value of concrete tensile strength; \[ f_{ct,\text{eff}} = f_{ctm} = 2.9 \text{ N/mm}^2 \]

Reinforcement ratio; \[ \rho_{p,\text{eff}} = A_{sr,\text{prov}} / A_{c,\text{eff}} = 0.007 \]

Modular ratio; \[ \alpha_e = E_s / E_{cm} = 6.395 \]

Bond property coefficient; \[ k_1 = 0.8 \]

Strain distribution coefficient; \[ k_2 = 0.5 \]

\[ k_3 = 3.4 \]

\[ k_4 = 0.425 \]

Maximum crack spacing - exp.7.11; \[ s_{r,max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \psi_{sr} / \rho_{p,\text{eff}} = 562 \text{ mm} \]

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

\[ w_k = 0.171 \text{ mm} \]

\[ w_k / w_{max} = 0.569 \]

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

Rectangular section in shear - Section 6.2

Design shear force; \[ V = 151.5 \text{ kN/m} \]

\[ C_{Rd.c} = 0.18 / \gamma_C = 0.120 \]

Longitudinal reinforcement ratio; \[ \rho_l = \min(A_{sr,prov} / d, 0.02) = 0.002 \]

\[ v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ct}^{0.5} = 0.415 \text{ N/mm}^2 \]

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

\[ V_{Rd,c} = 183.3 \text{ kN/m} \]

\[ V / V_{Rd,c} = 0.827 \]

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

Rectangular section in flexure - Section 6.1

Design bending moment; \[ M = 63.7 \text{ kNm/m} \]
## Project
Retaining wall Analysis & Design (EN1997-1:2004 incorporating Corrigendum dated February 2009)

### Section
Civil & Geotechnical Engineering

### Job Ref.

### Sheet no./rev.
1

### Calc. by
Dr. C. Sachpazis

### Date
23/05/2013

### Chk’d by
-

### Date
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### App’d by
-

### Date
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### Depth to tension reinforcement;

\[ d = h - c_{sf} - \phi_{sf} / 2 = 440 \text{ mm} \]

\[ K = M / (d^2 \times f_{ck}) = 0.011 \]

\[ K’ = 0.196 \]

\[ K’ > K - \text{No compression reinforcement is required} \]

### Lever arm;

\[ z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = 418 \text{ mm} \]

### Depth of neutral axis;

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

### Area of tension reinforcement required;

\[ A_{sf,req} = M / (f_{yd} \times z) = 351 \text{ mm}^2/m \]

### Tension reinforcement provided;

16 dia. bars @ 200 c/c

### Area of tension reinforcement provided;

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

### Minimum area of reinforcement - exp.9.1N;

\[ A_{sf,min} = \max(0.26 \times f_{dcm} / f_{yk}, 0.0013) \times d = 663 \text{ mm}^2/m \]

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

\[ A_{sf,max} = 0.04 \times h = 20000 \text{ mm}^2/m \]

\[ \max(A_{sf,req}, A_{sf,min}) / A_{sf,prov} = 0.659 \]

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

### Crack control - Section 7.3

**Limiting crack width**

\[ w_{\text{max}} = 0.3 \text{ mm} \]

**Variable load factor** - EN1990 – Table A1.1;

\[ \nu_2 = 0.3 \]

**Serviceability bending moment**;

\[ M_{ds} = 29.6 \text{ kNm/m} \]

**Tensile stress in reinforcement**;

\[ \sigma_s = M_{ds} / (A_{sf,prov} \times z) = 70.4 \text{ N/mm}^2 \]

**Load duration**;

Long term

**Load duration factor**;

\[ k_t = 0.4 \]

**Effective area of concrete in tension**;

\[ A_{c,eef} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 148333 \text{ mm}^2/m \]

**Mean value of concrete tensile strength**;

\[ f_{ct,eef} = f_{dcm} = 2.9 \text{ N/mm}^2 \]

**Reinforcement ratio**;

\[ \rho_{p,eef} = A_{sf,prov} / A_{c,eef} = 0.007 \]

**Modular ratio**;

\[ \alpha_e = E_s / E_{cm} = 6.395 \]

**Bond property coefficient**;

\[ k_1 = 0.8 \]

**Strain distribution coefficient**;

\[ k_2 = 0.5 \]

\[ k_3 = 3.4 \]

\[ k_4 = 0.425 \]

**Maximum crack spacing - exp.7.11**;

\[ s_{r,max} = k_3 \times c_{sf} + k_1 \times k_2 \times k_4 \times \phi_{sf} / \rho_{p,eef} = 537 \text{ mm} \]

**Maximum crack width - exp.7.8**;

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

\[ w_k = 0.108 \text{ mm} \]

\[ w_k / w_{\text{max}} = 0.36 \]

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

### Rectangular section in shear - Section 6.2

**Design shear force**;

\[ V = 151.5 \text{ kNm} \]

\[ C_{Rd,c} = 0.16 / \gamma_C = 0.120 \]

\[ k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.674 \]
Longitudinal reinforcement ratio; \[ \rho_l = \min(A_{sf,prov} / d, 0.02) = 0.002 \]

Design shear resistance - exp.6.2a & 6.2b;
\[ V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 N/mm^2 \times \rho_l \times f_{ck})^{1/3}, V_{min}) \times d \]
\[ V_{Rd,c} = 182.7 \text{kN/m} \]
\[ V / V_{Rd,c} = 0.829 \]

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

Maximum spacing of reinforcement – cl.9.6.3(2);
\[ s_{sx,\text{max}} = 400 \text{mm} \]

Maximum area of reinforcement - cl.9.2.1.1(3);
\[ A_{bb,\text{max}} = 0.04 \times h = 20000 \text{mm}^2/\text{m} \]

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

Check base design
Depth of section;
\[ h = 500 \text{mm} \]

Rectangular section in flexure - Section 6.1
Design bending moment at toe;
\[ M = 72 \text{kNm/m} \]

Depth to tension reinforcement;
\[ d = h - c_{bb} - \phi_{bb} / 2 = 417 \text{mm} \]
\[ K = M / (d^2 \times f_{ck}) = 0.014 \]
\[ K' = 0.196 \]

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

Lever arm;
\[ z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = 396 \text{mm} \]

Depth of neutral axis;
\[ x = 2.5 \times (d - z) = 52 \text{mm} \]

Area of tension reinforcement required;
\[ A_{bb,req} = M / (f_{yd} \times z) = 418 \text{mm}^2/\text{m} \]

Tension reinforcement provided;
\[ 16 \text{dia.bars} @ 200 \text{c/c} \]

Area of tension reinforcement provided;
\[ A_{bb,prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = 1005 \text{mm}^2/\text{m} \]

Minimum area of reinforcement - exp.9.1N;
\[ A_{bb,\text{min}} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 628 \]

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

Crack control - Section 7.3
Limiting crack width;
\[ w_{max} = 0.3 \text{mm} \]

Tensile stress in reinforcement;
\[ \sigma_s = M_{bs} / (A_{bb,prov} \times z) = 100 \text{N/mm}^2 \]

Load duration;
\[ k_t = 0.4 \]
Effective area of concrete in tension; $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 149292$ mm$^2$/m

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

Reinforcement ratio; $\rho_p.eff = A_{bb.prov} / A_{c.eff} = 0.007$

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

Bond property coefficient; $k_1 = 0.8$

Strain distribution coefficient; $k_2 = 0.5$

$k_3 = 3.4$

$k_4 = 0.425$

Maximum crack spacing - exp.7.11; $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} = 659$ mm

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

$w_k = 0.188$ mm

$w_k / w_{max} = 0.628$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; $V = 144$ kN/m

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

$K = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = 1.693$

Longitudinal reinforcement ratio; $\rho_l = \min(A_{bb.prov} / d, 0.02) = 0.002$

$V_{min} = 0.035 \text{ N/mm}^2 \times d^{0.5} \times f_{ck}^{0.5} = 0.422 \text{ N/mm}^2$

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

$V_{Rd.c} = 176$ kN/m

$V / V_{Rd.c} = 0.818$

PASS - Design shear resistance exceeds design shear force

Rectangular section in flexure - Section 6.1

Design bending moment at heel; $M = 186.4$ kNm/m

Depth to tension reinforcement; $d = h - c_{bt} - \phi_{bt} / 2 = 442$ mm

$K = M / (d^2 \times f_{ck}) = 0.032$

$K' = 0.196$

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

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

Depth of neutral axis; $x = 2.5 \times (d - z) = 55$ mm

Area of tension reinforcement required; $A_{bt.req} = M / (f_{yd} \times z) = 1021 \text{ mm}^2$/m

Tension reinforcement provided; 16 dia.bars @ 175 c/c

Area of tension reinforcement provided; $A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times S_{bt}) = 1149 \text{ mm}^2$/m

Minimum area of reinforcement - exp.9.1N; $A_{bt.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 666$

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{bt.max} = 0.04 \times h = 20000 \text{ mm}^2$/m
max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = 0.888

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

Crack control - Section 7.3

Limiting crack width; \( w_{\text{max}} = 0.3 \) mm

Variable load factor - EN1990 – Table A.1.1; \( \gamma_2 = 0.3 \)

Serviceability bending moment; \( M_{\text{bds}} = 81.2 \) kNm/m

Tensile stress in reinforcement; \( \sigma_s = M_{\text{bds}} / (A_{\text{bt,prov}} \times z) = 168.2 \) N/mm²

Load duration; Long term

Load duration factor; \( k_t = 0.4 \)

Effective area of concrete in tension; \( A_{\text{c,eff}} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 145000 \) mm²/m

Mean value of concrete tensile strength; \( f_{\text{ct,eff}} = f_{\text{ctm}} = 2.9 \) N/mm²

Reinforcement ratio; \( \rho_{\text{p,eff}} = A_{\text{bt,prov}} / A_{\text{c,eff}} = 0.008 \)

Modular ratio; \( \alpha_e = E_s / E_{\text{cm}} = 6.395 \)

Bond property coefficient; \( k_1 = 0.8 \)

Strain distribution coefficient; \( k_2 = 0.5 \)

Maximum crack spacing - exp.7.11; \( s_{r,\text{max}} = k_3 \times c_{\text{bt}} + k_1 \times k_2 \times k_4 \times \phi_{\text{bt}} / \rho_{\text{p,eff}} = 513 \) mm

Maximum crack width - exp.7.8; \( w_k = s_{r,\text{max}} \times \max(\sigma_s - k_3 \times (f_{\text{ct,eff}} / \rho_{\text{p,eff}}) \times (1 + \alpha_e \times \rho_{\text{p,eff}}), 0.6 \times \sigma_s) / E_s \)

\( w_k = 0.247 \) mm

\( w_k / w_{\text{max}} = 0.822 \)

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; \( V = 129.3 \) kN/m

\( C_{\text{Rd,c}} = 0.18 / \gamma_c = 0.120 \)

Longitudinal reinforcement ratio; \( \rho_l = \min(A_{\text{bt,prov}} / d, 0.02) = 0.003 \)

Minimum shear stress; \( \nu_{\min} = 0.035 \) N²/mm⁴ \times k²/3 \times f_{\text{ck}}^0.5 = 0.415 N/mm²

Design shear resistance - exp.6.2a & 6.2b; \( V_{\text{Rd,c}} = \max(C_{\text{Rd,c}} \times k \times (100 N²/mm⁴ \times \rho_l \times f_{\text{ck}})^{1/3}, \nu_{\min}) \times d \)

\( V_{\text{Rd,c}} = 183.3 \) kN/m

\( V / V_{\text{Rd,c}} = 0.705 \)

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); \( A_{\text{bx,req}} = 0.2 \times A_{\text{bt,prov}} = 230 \) mm²/m

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

Transverse reinforcement provided; 8 dia.bars @ 200 c/c

Area of transverse reinforcement provided; \( A_{\text{bx,prov}} = \pi \times \phi_{\text{bx}}^2 / (4 \times s_{\text{bx}}) = 251 \) mm²/m

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

<table>
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<th>Description</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Depth of section</td>
<td>350 mm</td>
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</tbody>
</table>

**Rectangular section in flexure - Section 6.1**

- Design bending moment at key: \( M = 1.3 \text{ kNm/m} \)
- Depth to tension reinforcement: \( d = h - c_{bb} - \phi_k / 2 = 269 \text{ mm} \)
- \( K = M / (d^2 \times f_{ck}) = 0.001 \)
- \( K' = 0.196 \)

**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: \( A_{k,req} = M / (f_{yd} \times z) = 12 \text{ mm}^2/m \)
- Tension reinforcement provided: 12 dia. bars @ 200 c/c
- Area of tension reinforcement provided: \( A_{k,prov} = \pi \times \phi_k^2 / (4 \times s_k) = 565 \text{ mm}^2/m \)
- Minimum area of reinforcement - exp.9.1N; \( A_{k,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 405 \text{ mm}^2/m \)
- Maximum area of reinforcement - cl.9.2.1.1(3); \( A_{k,max} = 0.04 \times h = 14000 \text{ mm}^2/m \)
- \( \max(A_{k,req}, A_{k,min}) / A_{k,prov} = 0.716 \)

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

**Crack control - Section 7.3**

- Limiting crack width: \( w_{\text{max}} = 0.3 \text{ mm} \)
- Variable load factor - EN1990 – Table A1.1; \( \psi_2 = 0.3 \)
- Serviceability bending moment; \( M_{\text{sys}} = 3.3 \text{ kNm/m} \)
- Tensile stress in reinforcement; \( \sigma_s = M_{\text{sys}} / (A_{k,prov} \times z) = 23 \text{ N/mm}^2 \)
- Load duration; Long term
- Load duration factor; \( k_t = 0.4 \)
- Effective area of concrete in tension; \( A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = 105458 \text{ mm}^2 \)
- Mean value of concrete tensile strength: \( f_{ct,eff} = f_{ctm} = 2.9 \text{ N/mm}^2 \)
- Reinforcement ratio; \( \rho_{p,eff} = A_{k,prov} / A_{c,eff} = 0.005 \)
- Modular ratio; \( \alpha_e = E_s / E_{ctm} = 6.395 \)
- 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; \( w_k = s_{r,max} \times \max(\sigma_s - k_1 \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s \)
- \( w_k = 0.042 \text{ mm} \)
- \( w_k / w_{\text{max}} = 0.139 \)

**PASS - Maximum crack width is less than limiting crack width**
**Project**
Retaining wall Analysis & Design (EN1997-1:2004 incorporating Corrigendum dated February 2009)

**Section**
Civil & Geotechnical Engineering

**Calc. by**
Dr. C. Sachpazis

**Date**
23/05/2013

**Job Ref.**

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**Rectangular section in shear - Section 6.2**

**Design shear force;**

\[ V = 4 \text{kN/m} \]

\[ C_{Rd.c} = 0.18 / \gamma_c = 0.120 \]

\[ k = \min(1 + \sqrt{200 \text{ mm} / d}), 2) = 1.862 \]

**Longitudinal reinforcement ratio;**

\[ \rho_l = \min(A_{k,prov} / d, 0.02) = 0.002 \]

\[ v_{\text{min}} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = 0.487 \text{ N/mm}^2 \]

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

\[ V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3} \]

\[ V_{Rd.c} = 131.1 \text{kN/m} \]

\[ V / V_{Rd.c} = 0.030 \]

**PASS - Design shear resistance exceeds design shear force**
Retaining wall Analysis & Design (EN1997-1:2004 incorporating Corrigendum dated February 2009)

Project

Calc. by: Dr. C. Sachpazis
Date: 23/05/2013

16 dia. bars @ 200 c/c
horizonal reinforcement
parallel to face of stem

12 dia. bars @ 200 c/c
transverse reinforcement
in base

16 dia. bars @ 175 c/c

12 dia. bars @ 200 c/c