GEODOMISI Ltd. - Dr. Costas Sachpazis
Civil & Geotechnical Engineering Consulting Company for Structural Engineering, Soil Mechanics, Rock Mechanics, Foundation Engineering & Retaining Structures.
Tel.: (+30) 210 5238127, 210 5711263 - Fax.:+30 210 5711461 - Mobile: (+30) 6936425722 & (+44) 7585939944, costas@sachpazis.info

Project: Sloped rear face retaining wall Analysis & Design, In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the recommended values				Job Ref.	
Section: Civil & Geotechnical Engineering				Sheet no./rev. 1	
Calc. by: Dr. C. Sachpazis	Date: 22/12/2013	Chk'd by	Date	App'd by	Date

RETAINING WALL ANALYSIS

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

Retaining wall details

Stem type;	Cantilever with inclined rear face
Stem height;	h_{stem} = **4700** mm
Stem thickness;	t_{stem} = **300** mm
Slope length to rear of stem;	l_{slr} = **400** mm
Angle to rear face of stem;	α = atan(h_{stem} / l_{slr}) = **85.1** deg
Stem density;	γ_{stem} = **25** kN/m^3
Toe length;	l_{toe} = **3000** mm
Heel length;	l_{heel} = **2500** mm
Base thickness;	t_{base} = **550** mm
Key position;	p_{key} = **5700** mm
Key depth;	d_{key} = **500** mm
Key thickness;	t_{key} = **500** mm
Base density;	γ_{base} = **25** kN/m^3
Height of retained soil;	h_{ret} = **4000** mm
Angle of soil surface;	β = **10** deg
Depth of cover;	d_{cover} = **700** mm
Depth of excavation;	d_{exc} = **700** mm
Height of water;	h_{water} = **500** mm

Water density; γ_w = **9.8** kN/m^3

Retained soil properties

Soil type; Organic clay

Moist density; γ_{mr} = **15** kN/m^3

Saturated density; γ_{sr} = **16** kN/m^3

Characteristic effective shear resistance angle; $\phi'_{r.k}$ = **29** deg

Characteristic wall friction angle; $\delta_{r.k}$ = **16** deg

Base soil properties

Soil type; Organic clay

Moist density; γ_{mb} = **17** kN/m^3

Characteristic cohesion; $c'_{b.k}$ = **55** kN/m^2

Characteristic adhesion; $a_{b.k}$ = **52** kN/m^2

Characteristic effective shear resistance angle; $\phi'_{b.k}$ = **26** deg

Characteristic wall friction angle; $\delta_{b.k}$ = **15** deg

Characteristic base friction angle; $\delta_{bb.k}$ = **26** deg

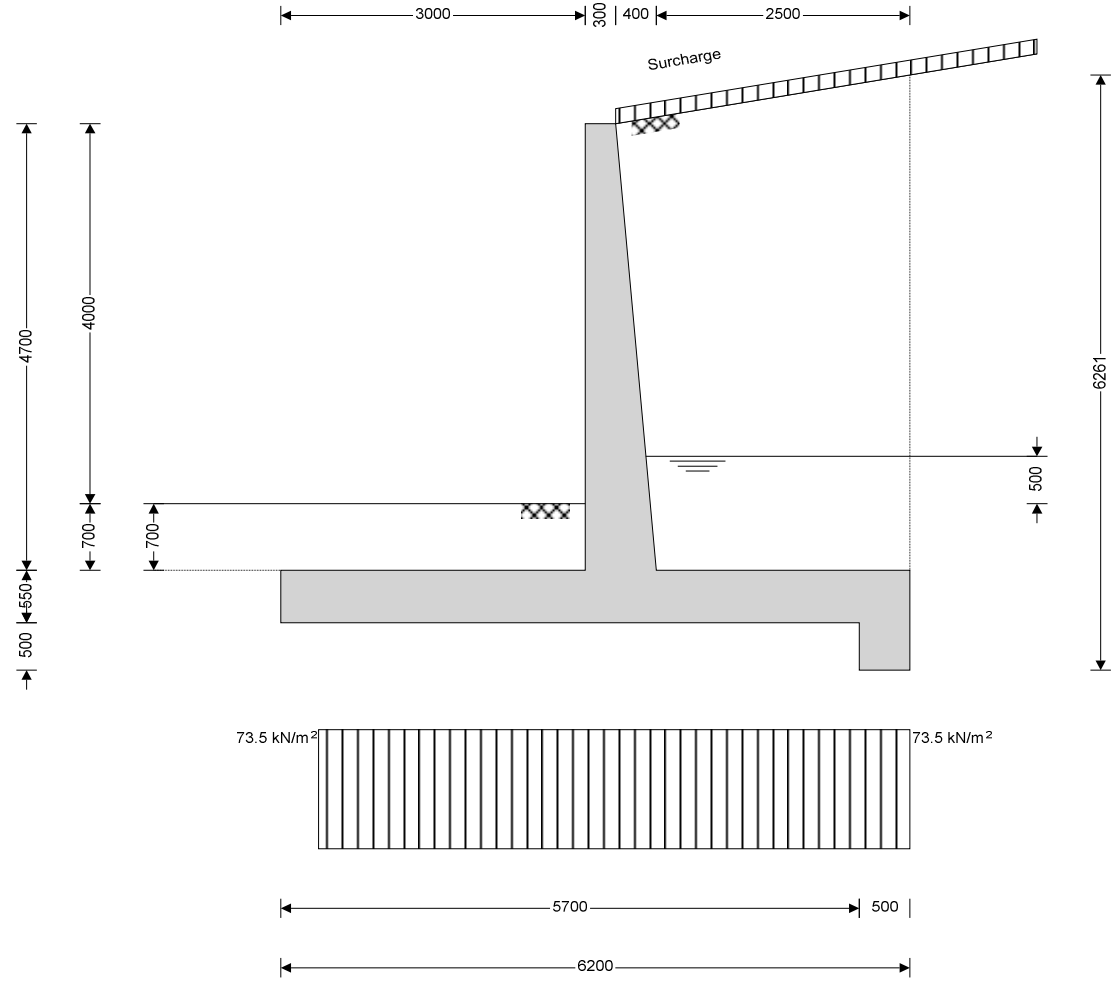
Loading details

Variable surcharge load; $Surcharge_Q$ = **10** kN/m^2

GEODOMISI Ltd.

GEODOMISI Ltd. - Dr. Costas Sachpazis
Civil & Geotechnical Engineering Consulting Company for Structural Engineering, Soil Mechanics, Rock Mechanics, Foundation Engineering & Retaining Structures.
Tel.: (+30) 210 5238127, 210 5711263 - Fax.:+30 210 5711461 - Mobile: (+30) 6936425722 & (+44) 7585939944, costas@sachpazis.info

Project: Sloped rear face retaining wall Analysis & Design, In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the recommended values				Job Ref.	
Section: Civil & Geotechnical Engineering				Sheet no./rev. 1	
Calc. by: Dr. C. Sachpazis	Date: 22/12/2013	Chk'd by	Date	App'd by	Date



GEODOMISI Ltd. - Dr. Costas Sachpazis
Civil & Geotechnical Engineering Consulting Company for Structural Engineering, Soil Mechanics, Rock Mechanics, Foundation Engineering & Retaining Structures.
Tel.: (+30) 210 5238127, 210 5711263 - Fax.:+30 210 5711461 - Mobile: (+30) 6936425722 & (+44) 7585939944, costas@sachpazis.info

Project: Sloped rear face retaining wall Analysis & Design, In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the recommended values				Job Ref.	
Section: Civil & Geotechnical Engineering				Sheet no./rev. 1	
Calc. by: Dr. C. Sachpazis	Date: 22/12/2013	Chk'd by	Date	App'd by	Date

Calculate retaining wall geometry

Base length; $l_{base} = l_{toe} + t_{stem} + l_{slr} + l_{heel} = \mathbf{6200}$ mm

Base height; $h_{base} = t_{base} + d_{key} = \mathbf{1050}$ mm

Saturated soil height; $h_{sat} = h_{water} + d_{cover} = \mathbf{1200}$ mm

Moist soil height; $h_{moist} = h_{ret} - h_{water} = \mathbf{3500}$ mm

Length of surcharge load; $l_{sur} = (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) = \mathbf{2900}$ mm

- Distance to vertical component; $x_{sur\_v} = l_{base} - (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) / 2 = \mathbf{4750}$ mm

Effective height of wall; $h_{eff} = h_{base} + d_{cover} + h_{ret} + l_{sur} \times \tan(\beta) = \mathbf{6261}$ mm

- Distance to horizontal component; $x_{sur\_h} = h_{eff} / 2 - d_{key} = \mathbf{2631}$ mm

Area of wall stem; $A_{stem} = h_{stem} \times (t_{stem} + l_{slr} / 2) = \mathbf{2.35}$ m^2

- Distance to vertical component; $x_{stem} = (h_{stem} \times t_{stem} \times (l_{toe} + t_{stem} / 2) + h_{stem} \times l_{slr} / 2 \times (l_{toe} + t_{stem} + l_{slr} / 3)) / A_{stem} = \mathbf{3263}$ mm

Area of wall base; $A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key} = \mathbf{3.66}$ m^2

- Distance to vertical component; $x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base} = \mathbf{3295}$ mm

Area of saturated soil; $A_{sat} = h_{sat} \times (l_{heel} + l_{slr} \times h_{sat} / (2 \times h_{stem})) = \mathbf{3.061}$ m^2

- Distance to vertical component; $x_{sat\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2 + l_{slr} \times h_{sat}^2 / (2 \times h_{stem}) \times (l_{heel} + l_{slr} \times h_{sat} / (3 \times h_{stem}))) / A_{sat} = \mathbf{4924}$ mm

- Distance to horizontal component; $x_{sat\_h} = (h_{sat} + h_{base}) / 3 - d_{key} = \mathbf{250}$ mm

Area of water; $A_{water} = h_{sat} \times (l_{heel} + l_{slr} \times h_{sat} / (2 \times h_{stem})) = \mathbf{3.061}$ m^2

- Distance to vertical component; $x_{water\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2 + l_{slr} \times h_{sat}^2 / (2 \times h_{stem}) \times (l_{heel} + l_{slr} \times h_{sat} / (3 \times h_{stem}))) / A_{sat} = \mathbf{4924}$ mm

- Distance to horizontal component; $x_{water\_h} = (h_{sat} + h_{base}) / 3 - d_{key} = \mathbf{250}$ mm

Area of moist soil; $A_{moist} = (h_{ret} - h_{water}) \times (l_{heel} + l_{slr} \times (h_{moist} + 2 \times h_{sat}) / (2 \times h_{stem})) + \tan(\beta) \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem})^2 / 2 = \mathbf{10.37}$ m^2

- Distance to vertical component; $x_{moist\_v} = l_{base} - (h_{moist} \times (l_{heel} + l_{slr} \times h_{sat} / h_{stem})^2 / 2 + l_{slr} \times h_{moist}^2 / (2 \times h_{stem}) \times ((l_{heel} + l_{slr} \times h_{sat} / h_{stem}) + l_{slr} \times h_{moist} / (3 \times h_{stem})) + \tan(\beta) \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem})^3 / 6) / A_{moist} = \mathbf{4852}$ mm

- Distance to horizontal component; $x_{moist\_h} = ((h_{eff} - h_{sat} - h_{base}) \times (t_{base} + h_{sat} + (h_{eff} - h_{sat} - h_{base}) / 3) / 2 + (h_{sat} + h_{base}) \times ((h_{sat} + h_{base})/2 - d_{key})) / (h_{sat} + h_{base} + (h_{eff} - h_{sat} - h_{base}) / 2) = \mathbf{1785}$ mm

Area of base soil; $A_{pass} = d_{cover} \times l_{toe} = \mathbf{2.1}$ m^2

- Distance to vertical component; $x_{pass\_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} = \mathbf{1500}$ mm
- Distance to horizontal component; $x_{pass\_h} = (d_{cover} + h_{base}) / 3 - d_{key} = \mathbf{83}$ mm

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

Permanent unfavourable action; $\gamma_G = \mathbf{1.35}$

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

Variable unfavourable action; $\gamma_Q = \mathbf{1.50}$

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

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

Angle of shearing resistance; $\gamma_{\phi'} = \mathbf{1.00}$

Effective cohesion; $\gamma_{c'} = \mathbf{1.00}$

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

Retained soil properties

Design effective shear resistance angle; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{29}$ deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{16}$ deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{26}$ deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{15}$ deg

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{26}$ deg

Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'} = \mathbf{55}$ kN/m^2

Design adhesion; $a_{b.d} = a_{b.k} / \gamma_{c'} = \mathbf{52}$ kN/m^2

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.400}$

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2) =$ **4.051**

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **58.8** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **91.5** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **18.9** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w =$ **30** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr} =$ **155.6** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{water\_v} =$ **354.8** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} =$ **35.1** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **7.9** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **33.5** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **129.3** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h} =$ **205.9** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 =$ **36.7** kN/m

Base friction; $F_{friction} = a_{b.d} \times b + F_{total\_v} \times \tan(\delta_{bb.d}) =$ **225** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} =$ **261.7** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} =$ **1.271**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **92.4** kNm/m

Saturated retained soil; $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h} =$ **2** kNm/m

Water; $M_{water\_OT} = F_{water\_h} \times x_{water\_h} =$ **8.4** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} =$ **230.9** kNm/m

Base soil; $M_{exc\_OT} = -F_{exc\_h} \times x_{exc\_h} =$ **5.5** kNm/m

Total; $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{exc\_OT} + M_{water\_OT} + M_{sur\_OT} =$ **339.2** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} =$ **191.7** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} =$ **301.5** kNm/m

Saturated retained soil; $M_{sat\_R} = F_{sat\_v} \times x_{sat\_v} =$ **93.3** kNm/m

Water; $M_{water\_R} = F_{water\_v} \times x_{water\_v} =$ **147.9** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} =$ **754.8** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{sat\_R} + M_{moist\_R} + M_{water\_R} =$ **1489.2** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **4.39**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} =$ **79.3** kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} =$ **123.5** kN/m

Surcharge load; $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) =$ **43.5** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_G \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **25.6** kN/m

Water; $F_{water\_v} = \gamma_G \times A_{water} \times \gamma_w =$ **40.5** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} =$ **210** kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} =$ **48.2** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{pass\_v} + F_{water\_v} + F_{sur\_v} =$ **570.7** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} =$ **35.1** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **7.9** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **33.5** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **129.3** kN/m

Base soil; $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2 =$ **-101.9** kN/m

Total; $F_{total\_h} = \max(F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h} - (a_{b.d} \times b + F_{total\_v} \times \tan(\delta_{bb.d})), 0 \text{ kN/m}) =$ **0** kN/m

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} =$ **258.8** kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} =$ **407** kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} =$ **114.2** kNm/m

Saturated retained soil; $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h} =$ **124** kNm/m

Water; $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h} =$ **191.3** kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} =$ **788.1** kNm/m

Base soil; $M_{pass} = F_{pass\_v} \times x_{pass\_v} - F_{pass\_h} \times x_{pass\_h} =$ **80.8** kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur} =$ **1964.1** kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} =$ **3442** mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 =$ **342** mm

Loaded length of base; $l_{load} = 2 \times (l_{base} - \bar{x}) =$ **5516** mm

Bearing pressure at toe; q_{toe} = **0** kN/m^2

Bearing pressure at heel; $q_{heel} = F_{total\_v} / l_{load}$ = **103.4** kN/m^2

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb} - (t_{base} + d_{cover} + h_{water}) \times \gamma_w$ = **4.1** kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma$ = **4.1** kN/m^2

Bearing resistance factors; $N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2$ = **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; $H = F_{total\_h}$ = **0** kN/m

$V = F_{total\_v}$ = **570.7** kN/m

$m = 2$

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

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

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

Net ultimate bearing capacity; $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma$ = **1482.4** kN/m^2

Factor of safety; $FoS_{bp} = n_f / \max(q_{toe}, q_{heel})$ = **14.329**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

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

Permanent unfavourable action; γ_G = **1.00**

Permanent favourable action; γ_{Gf} = **1.00**

Variable unfavourable action; γ_Q = **1.30**

Variable favourable action; γ_{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; γ_{γ} = **1.00**

Retained soil properties

Design effective shear resistance angle; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **23.9** deg

Design wall friction angle; $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **12.9** deg

Base soil properties

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **21.3** deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **12.1** deg

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **21.3** deg

Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **44** kN/m^2

Design adhesion; $a_{b.d} = a_{b.k} / \gamma_{c'}$ = **41.6** kN/m^2

Using Coulomb theory

Active pressure coefficient; $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2)$ = **0.489**

Passive pressure coefficient; $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2)$ = **2.961**

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **58.8** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **91.5** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_{Gf} \times A_{sat} \times (\gamma_{sr} - \gamma_w)$ = **18.9** kN/m

Water; $F_{water\_v} = \gamma_{Gf} \times A_{water} \times \gamma_w$ = **30** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **155.6** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{water\_v} =$ **354.8** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **37.9** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **7.3** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **24.8** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **119.3** kN/m

Total; $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h} =$ **189.3** kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2 =$ **27.1** kN/m

Base friction; $F_{friction} = a_{b.d} \times b + F_{total\_v} \times \tan(\delta_{bb.d}) =$ **180** kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} =$ **207.2** kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} =$ **1.094**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **99.8** kNm/m

Saturated retained soil; $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h} =$ **1.8** kNm/m

Water; $M_{water\_OT} = F_{water\_h} \times x_{water\_h} =$ **6.2** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} =$ **213** kNm/m

Base soil; $M_{exc\_OT} = -F_{exc\_h} \times x_{exc\_h} =$ **4.1** kNm/m

Total; $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{exc\_OT} + M_{water\_OT} + M_{sur\_OT} =$ **324.8** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} =$ **191.7** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} =$ **301.5** kNm/m

Saturated retained soil; $M_{sat\_R} = F_{sat\_v} \times x_{sat\_v} =$ **93.3** kNm/m

Water; $M_{water\_R} = F_{water\_v} \times x_{water\_v} =$ **147.9** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} =$ **754.8** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{sat\_R} + M_{moist\_R} + M_{water\_R} =$ **1489.2** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **4.584**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} =$ **58.8** kN/m

Wall base; $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} =$ **91.5** kN/m

Surcharge load; $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times (l_{heel} + l_{slr} \times h_{soil} / h_{stem}) =$ **37.7** kN/m

Saturated retained soil; $F_{sat\_v} = \gamma_G \times A_{sat} \times (\gamma_{sr} - \gamma_w) =$ **18.9** kN/m

Water; $F_{water\_v} = \gamma_G \times A_{water} \times \gamma_w =$ **30** kN/m

Moist retained soil; $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} =$ **155.6** kN/m

Base soil; $F_{pass\_v} = \gamma_G \times A_{pass} \times \gamma_{mb} =$ **35.7** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{pass\_v} + F_{water\_v} + F_{sur\_v} =$ **428.2** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **37.9** kN/m

Saturated retained soil; $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **7.3** kN/m

Water; $F_{water\_h} = \gamma_G \times \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **24.8** kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d} + (90 - \alpha)) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **119.3** kN/m

Base soil; $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2 =$ **-75.4** kN/m

Total; $F_{total\_h} = \max(F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h} - (a_{b.d} \times b + F_{total\_v} \times \tan(\delta_{bb.d})), 0\ kN/m) =$ **0** kN/m

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} =$ **191.7** kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} =$ **301.5** kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} =$ **79.3** kNm/m

Saturated retained soil; $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h} =$ **91.5** kNm/m

Water; $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h} =$ **141.7** kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} =$ **541.8** kNm/m

Base soil; $M_{pass} = F_{pass\_v} \times x_{pass\_v} - F_{pass\_h} \times x_{pass\_h} =$ **59.8** kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur} =$ **1407.3** kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} =$ **3287** mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 =$ **187** mm

Loaded length of base; $l_{load} = 2 \times (l_{base} - \bar{x}) =$ **5826** mm

Bearing pressure at toe; $q_{toe} =$ **0** kN/m^2

Bearing pressure at heel; $q_{heel} = F_{total\_v} / l_{load} =$ **73.5** kN/m^2

Effective overburden pressure; $q = (t_{base} + d_{cover}) \times \gamma_{mb} - (t_{base} + d_{cover} + h_{water}) \times \gamma_w =$ **4.1** kN/m^2

Design effective overburden pressure; $q' = q / \gamma_\gamma =$ **4.1** kN/m^2

Bearing resistance factors; $N_q = \text{Exp}(\pi \times \tan(\phi'_{b.d})) \times (\tan(45\ deg + \phi'_{b.d} / 2))^2 =$ **7.298**

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

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) =$ **4.915**

Foundation shape factors; $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

Load inclination factors;

$H = F_{total\_h} = \mathbf{0}$ kN/m

$V = F_{total\_v} = \mathbf{428.2}$ kN/m

$m = 2$

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

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

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

Net ultimate bearing capacity;

$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_{mb} - \gamma_w) \times I_{load} \times N_\gamma \times s_\gamma \times i_\gamma = \mathbf{843}$ kN/m^2

Factor of safety;

$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{11.471}$

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; C32/40

Characteristic compressive cylinder strength; $f_{ck} = \mathbf{32}$ N/mm^2

Characteristic compressive cube strength; $f_{ck,cube} = \mathbf{40}$ N/mm^2

Mean value of compressive cylinder strength; $f_{cm} = f_{ck} + 8$ N/mm^2 $= \mathbf{40}$ N/mm^2

Mean value of axial tensile strength; $f_{ctm} = 0.3$ N/mm^2 $\times (f_{ck} / 1$ N/mm$^2)^{2/3} = \mathbf{3.0}$ N/mm^2

5% fractile of axial tensile strength; $f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.1}$ N/mm^2

Secant modulus of elasticity of concrete; $E_{cm} = 22$ kN/mm^2 $\times (f_{cm} / 10$ N/mm$^2)^{0.3} = \mathbf{33346}$ N/mm^2

Partial factor for concrete - Table 2.1N; $\gamma_C = \mathbf{1.50}$

Compressive strength coefficient - cl.3.1.6(1); α_{cc} = **1.00**

Design compressive concrete strength - exp.3.15; $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C$ = **21.3** N/mm^2

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

Reinforcement details

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

Modulus of elasticity of reinforcement; E_s = **200000** N/mm^2

Partial factor for reinforcing steel - Table 2.1N; γ_S = **1.15**

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

Cover to reinforcement

Front face of stem; c_{sf} = **40** mm

Rear face of stem; c_{sr} = **50** mm

Top face of base; c_{bt} = **50** mm

Bottom face of base; c_{bb} = **75** mm

Check stem design at base of stem

Depth of section; h = **700** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **243.2** kNm/m

Depth to tension reinforcement; $d = h - c_{sr} - \phi_{sr} / 2$ = **640** mm

$K = M / (d^2 \times f_{ck})$ = **0.019**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **608** mm

Depth of neutral axis; $x = 2.5 \times (d - z)$ = **80** mm

Area of tension reinforcement required; $A_{sr.req} = M / (f_{yd} \times z)$ = **920** mm^2/m

Tension reinforcement provided; 20 dia.bars @ 200 c/c

Area of tension reinforcement provided;	$A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **1571** mm^2/m
Minimum area of reinforcement - exp.9.1N;	$A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **1006** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3);	$A_{sr.max} = 0.04 \times h$ = **28000** mm^2/m
	$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.641**

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

Crack control - Section 7.3

Limiting crack width;	w_{max} = **0.3** mm
Variable load factor - EN1990 – Table A1.1;	ψ_2 = **0.3**
Serviceability bending moment;	M_{sls} = **146.7** kNm/m
Tensile stress in reinforcement;	$\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **153.6** N/mm^2
Load duration;	Long term
Load duration factor;	k_t = **0.4**
Effective area of concrete in tension;	$A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **150000** mm^2/m
Mean value of concrete tensile strength;	$f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2
Reinforcement ratio;	$\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.010**
Modular ratio;	$\alpha_e = E_s / E_{cm}$ = **5.998**
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;	$s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **495** 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 = **0.228** mm
	w_k / w_{max} = **0.76**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **135.6** kN/m

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

$k = \min(1 + \sqrt{(200\ mm / d)}, 2)$ = **1.559**

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

$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.385** N/mm^2

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

$V_{Rd.c}$ = **246.7** kN/m

$V / V_{Rd.c}$ = **0.550**

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); $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times (t_{stem} + l_{slr}))$ = **700** mm^2/m

Maximum spacing of reinforcement – cl.9.6.3(2); s_{sx_max} = **400** mm

Transverse reinforcement provided; 16 dia.bars @ 200 c/c

Area of transverse reinforcement provided; $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **1005** mm^2/m

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

Check base design

Depth of section; h = **550** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 2; M = **138.1** kNm/m

Depth to tension reinforcement; $d = h - c_{bb} - \phi_{bb} / 2$ = **465** mm

$K = M / (d^2 \times f_{ck})$ = **0.020**

K' = **0.196**

K' > K - No compression reinforcement is required

Lever arm; $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **442** mm

Depth of neutral axis;	$x = 2.5 \times (d - z) =$ **58** mm
Area of tension reinforcement required;	$A_{bb.req} = M / (f_{yd} \times z) =$ **719** mm^2/m
Tension reinforcement provided;	20 dia.bars @ 200 c/c
Area of tension reinforcement provided;	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) =$ **1571** mm^2/m
Minimum area of reinforcement - exp.9.1N;	$A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **731** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3);	$A_{bb.max} = 0.04 \times h =$ **22000** mm^2/m
	$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} =$ **0.465**
	PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Limiting crack width;	$w_{max} =$ **0.3** mm
Variable load factor - EN1990 – Table A1.1;	$\psi_2 =$ **0.3**
Serviceability bending moment;	$M_{sls} =$ **85.4** kNm/m
Tensile stress in reinforcement;	$\sigma_s = M_{sls} / (A_{bb.prov} \times z) =$ **123** N/mm^2
Load duration;	Long term
Load duration factor;	$k_t =$ **0.4**
Effective area of concrete in tension;	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) =$ **163958** mm^2/m
Mean value of concrete tensile strength;	$f_{ct.eff} = f_{ctm} =$ **3.0** N/mm^2
Reinforcement ratio;	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff} =$ **0.010**
Modular ratio;	$\alpha_e = E_s / E_{cm} =$ **5.998**
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;	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} =$ **610** mm
Maximum crack width - exp.7.8;	$w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	$w_k =$ **0.225** mm

w_k / w_{max} = **0.75**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force; V = **135.7** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.656**

Longitudinal reinforcement ratio; ρ_l = min($A_{bb.prov}$ / d, 0.02) = **0.003**

v_{min} = 0.035 $N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.422** N/mm^2

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

$V_{Rd.c}$ = **204.3** kN/m

V / $V_{Rd.c}$ = **0.664**

PASS - Design shear resistance exceeds design shear force

Rectangular section in flexure - Section 6.1

Design bending moment combination 1; M = **126.1** kNm/m

Depth to tension reinforcement; d = h - c_{bt} - ϕ_{bt} / 2 = **492** 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 × (1 – 3.53 × K)$^{0.5}$, 0.95) × d = **467** mm

Depth of neutral axis; x = 2.5 × (d – z) = **62** mm

Area of tension reinforcement required; $A_{bt.req}$ = M / (f_{yd} × z) = **621** mm^2/m

Tension reinforcement provided; 16 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{bt.prov}$ = $\pi \times \phi_{bt}^2$ / (4 × s_{bt}) = **1005** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{bt.min}$ = max(0.26 × f_{ctm} / f_{yk}, 0.0013) × d = **774** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{bt.max}$ = 0.04 × h = **22000** mm^2/m

max($A_{bt.req}$, $A_{bt.min}$) / $A_{bt.prov}$ = **0.77**

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

Crack control - Section 7.3

Limiting crack width;	w_{max} = **0.3** mm
Variable load factor - EN1990 – Table A1.1;	ψ_2 = **0.3**
Serviceability bending moment;	M_{sls} = **68.9** kNm/m
Tensile stress in reinforcement;	$\sigma_s = M_{sls} / (A_{bt.prov} \times z)$ = **146.7** 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** mm^2/m
Mean value of concrete tensile strength;	$f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2
Reinforcement ratio;	$\rho_{p.eff} = A_{bt.prov} / A_{c.eff}$ = **0.007**
Modular ratio;	$\alpha_e = E_s / E_{cm}$ = **5.998**
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;	$s_{r.max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p.eff}$ = **562** 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 = **0.247** mm
	w_k / w_{max} = **0.825**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force;	V = **90.4** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.638**
Longitudinal reinforcement ratio;	$\rho_l = \min(A_{bt.prov} / d, 0.02)$ = **0.002**

v_{min} = 0.035 $N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.415** N/mm^2

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

$V_{Rd.c}$ = **204.1** kN/m

$V / V_{Rd.c}$ = **0.443**

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section; h = **500** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 0; M = **7.1** kNm/m

Depth to tension reinforcement; $d = h - c_{bb} - \phi_k / 2$ = **417** mm

$K = M / (d^2 \times f_{ck})$ = **0.001**

K' = **0.196**

K' > K - No compression reinforcement is required

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

Depth of neutral axis; $x = 2.5 \times (d - z)$ = **52** mm

Area of tension reinforcement required; $A_{k.req} = M / (f_{yd} \times z)$ = **41** mm^2/m

Tension reinforcement provided; 16 dia.bars @ 200 c/c

Area of tension reinforcement provided; $A_{k.prov} = \pi \times \phi_k^2 / (4 \times s_k)$ = **1005** mm^2/m

Minimum area of reinforcement - exp.9.1N; $A_{k.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **656** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3); $A_{k.max} = 0.04 \times h$ = **20000** mm^2/m

$\max(A_{k.req}, A_{k.min}) / A_{k.prov}$ = **0.652**

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

Crack control - Section 7.3

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

Variable load factor - EN1990 – Table A1.1; ψ_2 = **0.3**

Serviceability bending moment;	M_{sls} = **7.1** kNm/m
Tensile stress in reinforcement;	$\sigma_s = M_{sls} / (A_{k.prov} \times z)$ = **17.7** N/mm^2
Load duration;	Long term
Load duration factor;	k_t = **0.4**
Effective area of concrete in tension;	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **149292** mm^2/m
Mean value of concrete tensile strength;	$f_{ct.eff} = f_{ctm}$ = **3.0** N/mm^2
Reinforcement ratio;	$\rho_{p.eff} = A_{k.prov} / A_{c.eff}$ = **0.007**
Modular ratio;	$\alpha_e = E_s / E_{cm}$ = **5.998**
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;	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p.eff}$ = **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 = **0.035** mm
	w_k / w_{max} = **0.117**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force;	V = **26** 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;	$\rho_l = \min(A_{k.prov} / d, 0.02)$ = **0.002**
	$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.436** N/mm^2
Design shear resistance - exp.6.2a & 6.2b;	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **181.8** kN/m
	$V / V_{Rd.c}$ = **0.143**

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); $A_{bx.req} = 0.2 \times A_{bb.prov}$ = **314** mm^2/m

Maximum spacing of reinforcement – cl.9.3.1.1(3); s_{bx_max} = **450** 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** mm^2/m

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

GEODOMISI Ltd. - Dr. Costas Sachpazis
Civil & Geotechnical Engineering Consulting Company for Structural Engineering, Soil Mechanics, Rock Mechanics, Foundation Engineering & Retaining Structures.
Tel.: (+30) 210 5238127, 210 5711263 - Fax.:+30 210 5711461 - Mobile: (+30) 6936425722 & (+44) 7585939944, costas@sachpazis.info

Project: Sloped rear face retaining wall Analysis & Design, In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the recommended values				Job Ref.	
Section: Civil & Geotechnical Engineering				Sheet no./rev. 1	
Calc. by: Dr. C. Sachpazis	Date: 22/12/2013	Chk'd by	Date	App'd by	Date