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RETAINING WALL ANALYSIS

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

Tedds calculation version 2.9.22

Retaining wall details

Stem type;	Cantilever with stepped rear face
Stem height;	h_{stem} = **3750** mm
Number of steps;	N_{steps} = **4**
Height of step 1;	h_{s1} = **1200** mm
Thickness of step 1;	t_{s1} = **2950** mm
Height of step 2;	h_{s2} = **1350** mm
Thickness of step 2;	t_{s2} = **2000** mm
Height of step 3;	h_{s3} = **900** mm
Thickness of step 3;	t_{s3} = **1200** mm
Height of step 4;	h_{s4} = **300** mm
Thickness of step 4;	t_{s4} = **500** mm
Angle to rear face of stem;	α = **90** deg
Stem density;	γ_{stem} = **25** kN/m^3
Toe length;	l_{toe} = **200** mm
Heel length;	l_{heel} = **200** mm
Base thickness;	t_{base} = **100** mm
Base density;	γ_{base} = **25** kN/m^3
Height of retained soil;	h_{ret} = **3750** mm
Angle of soil surface;	β = **5** deg
Depth of cover;	d_{cover} = **0** mm

Retained soil properties

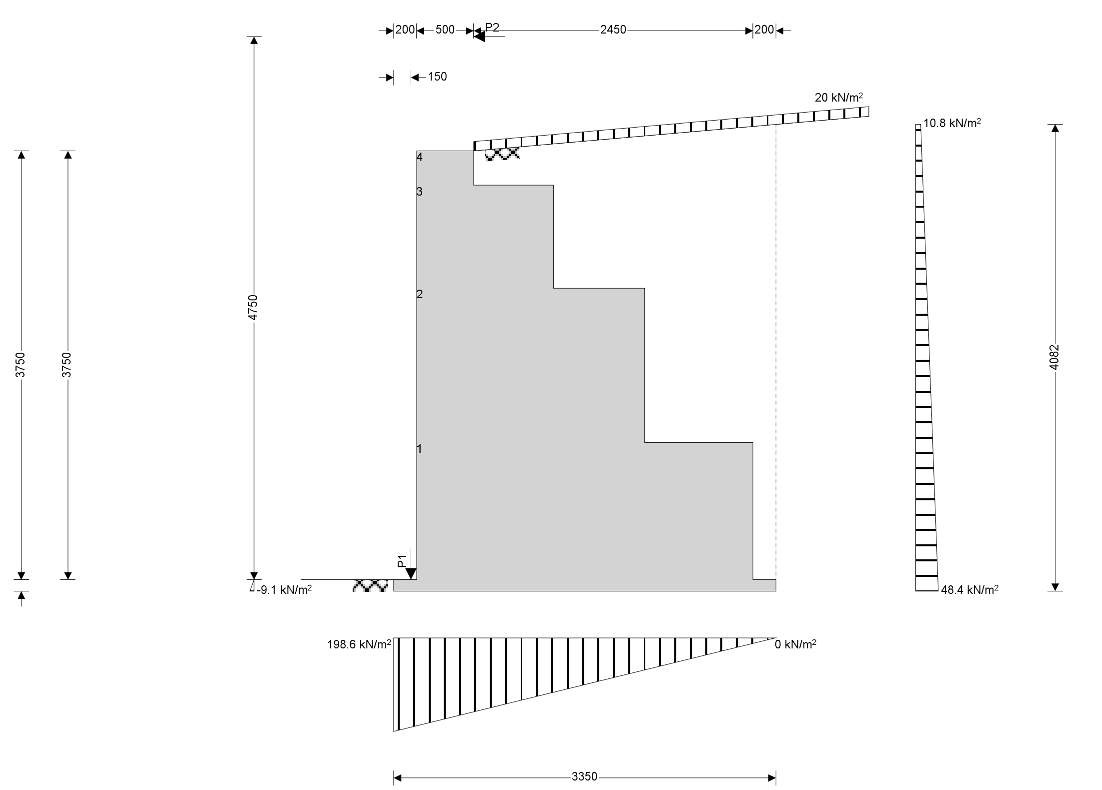
Soil type;	Medium dense gravel
Moist density;	γ_{mr} = **17** kN/m^3
Saturated density;	γ_{sr} = **20.5** kN/m^3
Characteristic effective shear resistance angle;	$\phi'_{r.k}$ = **30** deg
Characteristic wall friction angle;	$\delta_{r.k}$ = **15** deg

Base soil properties

Soil type;	Dense rock fill
Soil density;	γ_b = **18** kN/m^3
Characteristic effective shear resistance angle;	$\phi'_{b.k}$ = **42** deg
Characteristic wall friction angle;	$\delta_{b.k}$ = **20** deg
Characteristic base friction angle;	$\delta_{bb.k}$ = **42** deg
Presumed bearing capacity;	$P_{bearing}$ = **200** kN/m^2

Loading details

Variable surcharge load;	$Surcharge_Q$ = **20** kN/m^2
Vertical line load at 150 mm;	P_{G1} = **5** kN/m
Horizontal line load at 4750 mm;	P_{Q2} = **1.5** kN/m



General arrangement - sketch pressures relate to bearing check

Calculate retaining wall geometry

Base length; $l_{base} = l_{toe} + t_{s1} + l_{heel} = \mathbf{3350}$ mm

Moist soil height; $h_{moist} = h_{soil} = \mathbf{3750}$ mm

Length of surcharge load; $l_{sur} = (l_{heel} + t_{s1} - t_{s4}) = \mathbf{2650}$ mm

 - Distance to vertical component; $x_{sur\_v} = l_{base} - (l_{heel} + t_{s1} - t_{s4}) / 2 = \mathbf{2025}$ mm

Effective height of wall; $h_{eff} = h_{base} + d_{cover} + h_{ret} + l_{sur} \times \tan(\beta) = \mathbf{4082}$ mm

 - Distance to horizontal component; $x_{sur\_h} = h_{eff} / 2 = \mathbf{2041}$ mm

Area of wall stem; $A_{stem} = h_{s1} \times t_{s1} + h_{s2} \times t_{s2} + h_{s3} \times t_{s3} + h_{s4} \times t_{s4} = \mathbf{7.47}$ m^2

 - Distance to vertical component; $x_{stem} = l_{base} - (h_{s1} \times t_{s1} \times (l_{heel} + t_{s1} - t_{s1} / 2) + h_{s2} \times t_{s2} \times (l_{heel} + t_{s1} - t_{s2} / 2) + h_{s3} \times t_{s3} \times (l_{heel} + t_{s1} - t_{s3} / 2) + h_{s4} \times t_{s4} \times (l_{heel} + t_{s1} - t_{s4} / 2)) / A_{stem} = \mathbf{1352}$ mm

Area of wall base; $A_{base} = l_{base} \times t_{base} = \mathbf{0.335}$ m^2

 - Distance to vertical component; $x_{base} = l_{base} / 2 = \mathbf{1675}$ mm

Area of moist soil; $A_{moist} = l_{heel} \times h_{s1} + (l_{heel} + t_{s1} - t_{s2}) \times h_{s2} + (l_{heel} + t_{s1} - t_{s3}) \times h_{s3} + (l_{heel} + t_{s1} - t_{s4}) \times h_{s4} + \tan(\beta) \times (l_{heel} + t_{s1} - t_{s4})^2 / 2 = \mathbf{4.65}$ m^2

 - Distance to vertical component; $x_{moist\_v} = l_{base} - (l_{heel} \times h_{s1} \times l_{heel} / 2 + (l_{heel} + t_{s1} - t_{s2}) \times h_{s2} \times (l_{heel} + t_{s1} - t_{s2}) / 2 + (l_{heel} + t_{s1} - t_{s3}) \times h_{s3} \times (l_{heel} + t_{s1} - t_{s3}) / 2 + (l_{heel} + t_{s1} - t_{s4}) \times h_{s4} \times (l_{heel} + t_{s1} - t_{s4}) / 2 + \tan(\beta) \times (l_{heel} + t_{s1} - t_{s4})^3 / 6) / A_{moist} = \mathbf{2500}$ mm

 - Distance to horizontal component; $x_{moist\_h} = h_{eff} / 3 = \mathbf{1361}$ mm

Using Rankine theory

At rest pressure coefficient; $K_0 = (1 - \sin(\phi'_{r.k})) \times (1 + \sin(\beta)) \times \cos(\beta) = \mathbf{0.542}$

Passive pressure coefficient; $K_P = (1 + \sin(\phi'_{b.k})) / (1 - \sin(\phi'_{b.k})) = \mathbf{5.045}$

Bearing pressure check

Vertical forces on wall

Wall stem; $F_{stem} = A_{stem} \times \gamma_{stem} =$ **186.8** kN/m

Wall base; $F_{base} = A_{base} \times \gamma_{base} =$ **8.4** kN/m

Surcharge load; $F_{sur\_v} = Surcharge_Q \times (l_{heel} + t_{s1} - t_{s4}) =$ **53** kN/m

Line loads; $F_{P\_v} = P_{G1} =$ **5** kN/m

Moist retained soil; $F_{moist\_v} = A_{moist} \times \gamma_{mr} =$ **79** kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{sur\_v} + F_{P\_v} + F_{moist\_v} =$ **332.2** kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_0 \times Surcharge_Q \times h_{eff} =$ **44.2** kN/m

Line loads; $F_{P\_h} = P_{Q2} =$ **1.5** kN/m

Moist retained soil; $F_{moist\_h} = K_0 \times \gamma_{mr} \times h_{eff}^2 / 2 =$ **76.7** kN/m

Base soil; $F_{pass\_h} = -K_P \times \gamma_b \times (d_{cover} + h_{base})^2 / 2 =$ **-0.5** kN/m

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

Moments on wall

Wall stem; $M_{stem} = F_{stem} \times x_{stem} =$ **252.5** kNm/m

Wall base; $M_{base} = F_{base} \times x_{base} =$ **14** kNm/m

Surcharge load; $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h} =$ **17.1** kNm/m

Line loads; $M_P = P_{G1} \times p_1 - (P_{Q2} \times (p_2 + t_{base})) =$ **-6.5** kNm/m

Moist retained soil; $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h} =$ **93.3** kNm/m

Base soil; $M_{pass} = -F_{pass\_h} \times x_{pass\_h} =$ **0** kNm/m

Total; $M_{total} = M_{stem} + M_{base} + M_{sur} + M_P + M_{moist} + M_{pass} =$ **370.4** kNm/m

Check bearing pressure

Distance to reaction; $\bar{x} = M_{total} / F_{total\_v} =$ **1115** mm

Eccentricity of reaction; $e = \bar{x} - l_{base} / 2 =$ **-560** mm

Loaded length of base; $l_{load} = 3 \times \bar{x} =$ **3345** mm

Bearing pressure at toe; $q_{toe} = 2 \times F_{total\_v} / l_{load} =$ **198.6** kN/m²

Bearing pressure at heel; $q_{heel} =$ **0** kN/m²

Factor of safety; $FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) =$ **1.007**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Design approach 1

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

Partial factor set; A1

Permanent unfavourable action; $\gamma_G =$ **1.350**

Permanent favourable action; $\gamma_{Gf} =$ **1.000**

Variable unfavourable action; $\gamma_Q =$ **1.500**

Variable favourable action; $\gamma_{Qf} =$ **0.000**

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

Soil parameter set; M1

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

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

Weight density; $\gamma_\gamma =$ **1.00**

;**Retained soil properties**

Design moist density; $\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma =$ **17** kN/m³

Design saturated density; $\gamma_{sr}' = \gamma_{sr} / \gamma_{\gamma} = \mathbf{20.5}$ kN/m^3

Design effective shear resistance angle; $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{30}$ deg

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

Base soil properties

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

Design effective shear resistance angle; $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{42}$ deg

Design wall friction angle; $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{20}$ deg

Design base friction angle; $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{42}$ deg

;Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'} = \mathbf{0}$ kN/m^2

Using Rankine theory

At rest pressure coefficient; $K_0 = (1 - \sin(\phi'_{r.d})) \times (1 + \sin(\beta)) \times \cos(\beta) = \mathbf{0.542}$

Passive pressure coefficient; $K_P = (1 + \sin(\phi'_{b.d})) / (1 - \sin(\phi'_{b.d})) = \mathbf{5.045}$

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{186.8}$ kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{8.4}$ kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} = \mathbf{5}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{79}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{P\_v} + F_{moist\_v} = \mathbf{279.2}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_0 \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = \mathbf{66.3}$ kN/m

Line loads; $F_{P\_h} = \gamma_Q \times P_{Q2} = \mathbf{2.3}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_0 \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{103.5}$ kN/m

Total; $F_{total\_h} = F_{sur\_h} + F_{P\_h} + F_{moist\_h} = \mathbf{172.1}$ kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{0.5}$ kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d}) = \mathbf{251.4}$ kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} = \mathbf{251.8}$ kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} = \mathbf{1.463}$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{186.8}$ kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{8.4}$ kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} = \mathbf{5}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{79}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{P\_v} + F_{moist\_v} = \mathbf{279.2}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_0 \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = \mathbf{66.3}$ kN/m

Line loads; $F_{P\_h} = \gamma_Q \times P_{Q2} = \mathbf{2.3}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_0 \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{103.5}$ kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-0.5}$ kN/m

Total; $F_{total\_h} = F_{sur\_h} + F_{P\_h} + F_{moist\_h} + F_{exc\_h} = \mathbf{171.6}$ kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **135.3** kNm/m

Line loads; $M_{P\_OT} = abs(\gamma_Q \times P_{Q2}) \times (p_2 + t_{base}) =$ **10.9** kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} =$ **140.9** kNm/m

Total; $M_{total\_OT} = M_{sur\_OT} + M_{P\_OT} + M_{moist\_OT} =$ **287.1** kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} =$ **252.5** kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} =$ **14** kNm/m

Line loads; $M_{P\_R} = abs(\gamma_{Gf} \times P_{G1}) \times p_1 =$ **0.8** kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} =$ **197.6** kNm/m

Base soil; $M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h} =$ **0** kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{P\_R} + M_{moist\_R} + M_{exc\_R} =$ **464.9** kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **1.619**

PASS - Maximum restoring moment is greater than overturning moment

Design approach 1

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

Partial factor set; A2

Permanent unfavourable action; $\gamma_G =$ **1.000**

Permanent favourable action; $\gamma_{Gf} =$ **1.000**

Variable unfavourable action; $\gamma_Q =$ **1.300**

Variable favourable action; $\gamma_{Qf} =$ **0.000**

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

Soil parameter set; M2

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

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

Weight density; $\gamma_\gamma =$ **1.00**

;**Retained soil properties**

Design moist density; $\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma =$ **17** kN/m^3

Design saturated density; $\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma =$ **20.5** kN/m^3

Design effective shear resistance angle; $\phi'_{r.d} = atan(tan(\phi'_{r.k}) / \gamma_{\phi'}) =$ **24.8** deg

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

Base soil properties

Design soil density; $\gamma_b' = \gamma_b / \gamma_\gamma =$ **18** kN/m^3

Design effective shear resistance angle; $\phi'_{b.d} = atan(tan(\phi'_{b.k}) / \gamma_{\phi'}) =$ **35.8** deg

Design wall friction angle; $\delta_{b.d} = atan(tan(\delta_{b.k}) / \gamma_{\phi'}) =$ **16.2** deg

Design base friction angle; $\delta_{bb.d} = atan(tan(\delta_{bb.k}) / \gamma_{\phi'}) =$ **35.8** deg

;Design effective cohesion; $c'_{b.d} = c'_{b.k} / \gamma_{c'} =$ **0** kN/m^2

Using Rankine theory

At rest pressure coefficient; $K_0 = (1 - sin(\phi'_{r.d})) \times (1 + sin(\beta)) \times cos(\beta) =$ **0.629**

Passive pressure coefficient; $K_P = (1 + sin(\phi'_{b.d})) / (1 - sin(\phi'_{b.d})) =$ **3.813**

Sliding check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **186.8** kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{8.4}$ kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} = \mathbf{5}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{79}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{P\_v} + F_{moist\_v} = \mathbf{279.2}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_0 \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{66.7}$ kN/m

Line loads; $F_{P\_h} = \gamma_Q \times P_{Q2} = \mathbf{2}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_0 \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{89.1}$ kN/m

Total; $F_{total\_h} = F_{sur\_h} + F_{P\_h} + F_{moist\_h} = \mathbf{157.8}$ kN/m

Check stability against sliding

Base soil resistance; $F_{exc\_h} = \gamma_{Gf} \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{0.3}$ kN/m

Base friction; $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d}) = \mathbf{201.1}$ kN/m

Resistance to sliding; $F_{rest} = F_{exc\_h} + F_{friction} = \mathbf{201.4}$ kN/m

Factor of safety; $FoS_{sl} = F_{rest} / F_{total\_h} = \mathbf{1.277}$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem; $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{186.8}$ kN/m

Wall base; $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{8.4}$ kN/m

Line loads; $F_{P\_v} = \gamma_{Gf} \times P_{G1} = \mathbf{5}$ kN/m

Moist retained soil; $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{79}$ kN/m

Total; $F_{total\_v} = F_{stem} + F_{base} + F_{P\_v} + F_{moist\_v} = \mathbf{279.2}$ kN/m

Horizontal forces on wall

Surcharge load; $F_{sur\_h} = K_0 \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{66.7}$ kN/m

Line loads; $F_{P\_h} = \gamma_Q \times P_{Q2} = \mathbf{2}$ kN/m

Moist retained soil; $F_{moist\_h} = \gamma_G \times K_0 \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{89.1}$ kN/m

Base soil; $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-0.3}$ kN/m

Total; $F_{total\_h} = F_{sur\_h} + F_{P\_h} + F_{moist\_h} + F_{exc\_h} = \mathbf{157.4}$ kN/m

Overturning moments on wall

Surcharge load; $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} = \mathbf{136.2}$ kNm/m

Line loads; $M_{P\_OT} = abs(\gamma_Q \times P_{Q2}) \times (p_2 + t_{base}) = \mathbf{9.5}$ kNm/m

Moist retained soil; $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} = \mathbf{121.2}$ kNm/m

Total; $M_{total\_OT} = M_{sur\_OT} + M_{P\_OT} + M_{moist\_OT} = \mathbf{266.9}$ kNm/m

Restoring moments on wall

Wall stem; $M_{stem\_R} = F_{stem} \times x_{stem} = \mathbf{252.5}$ kNm/m

Wall base; $M_{base\_R} = F_{base} \times x_{base} = \mathbf{14}$ kNm/m

Line loads; $M_{P\_R} = abs(\gamma_{Gf} \times P_{G1}) \times p_1 = \mathbf{0.8}$ kNm/m

Moist retained soil; $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} = \mathbf{197.6}$ kNm/m

Base soil; $M_{exc\_R} = -F_{exc\_h} \times x_{exc\_h} = \mathbf{0}$ kNm/m

Total; $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{P\_R} + M_{moist\_R} + M_{exc\_R} = \mathbf{464.9}$ kNm/m

Check stability against overturning

Factor of safety; $FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{1.742}$

PASS - Maximum restoring moment is greater than overturning moment