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 2.9.16

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **900** mm
Stem thickness	t_{stem} = **500** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **300** mm
Base thickness	t_{base} = **300** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **700** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **200** mm
Depth of excavation	d_{exc} = **150** mm

Retained soil properties

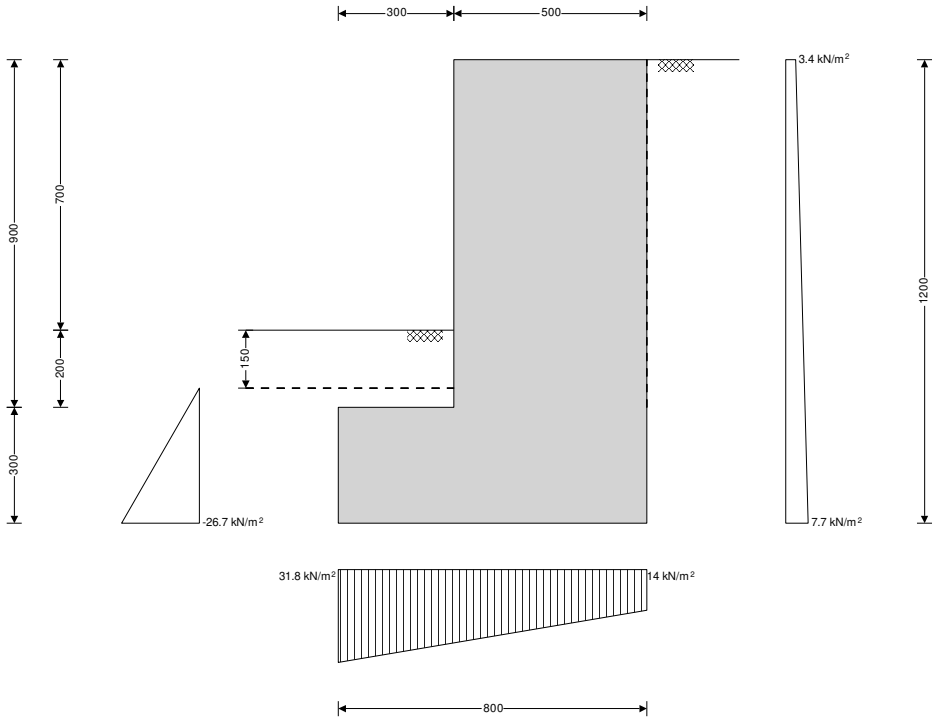
Soil type	Very dense well graded sand and gravel
Moist density	γ_{mr} = **21** kN/m^3
Saturated density	γ_{sr} = **23** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **42** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **21** deg

Base soil properties

Soil type	Dense gravel
Soil density	γ_b = **17.5** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **36** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **18** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **24** deg
Presumed bearing capacity	$P_{bearing}$ = **100** kN/m^2

Loading details

Variable surcharge load	$Surcharge_Q$ = **20** kN/m^2



General arrangement - sketch pressures relate to bearing check

Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} =$ **800** mm
Moist soil height	$h_{moist} = h_{soil} =$ **900** mm
Length of surcharge load	$l_{sur} = l_{heel} =$ **0** mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2 =$ **800** mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} =$ **1200** mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 =$ **600** mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} =$ **0.45** m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 =$ **550** mm
Area of wall base	$A_{base} = l_{base} \times t_{base} =$ **0.24** m^2
- Distance to vertical component	$x_{base} = l_{base} / 2 =$ **400** mm
Area of base soil	$A_{pass} = d_{cover} \times l_{toe} =$ **0.06** m^2
- Distance to vertical component	$x_{pass\_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} =$ **150** mm
- Distance to horizontal component	$x_{pass\_h} = (d_{cover} + h_{base}) / 3 =$ **167** mm
Area of excavated base soil	$A_{exc} = h_{pass} \times l_{toe} =$ **0.015** m^2
- Distance to vertical component	$x_{exc\_v} = l_{base} - (h_{pass} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{exc} =$ **150** mm
- Distance to horizontal component	$x_{exc\_h} = (h_{pass} + h_{base}) / 3 =$ **117** mm

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r.k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.k}) \times [1 + \sqrt{[\sin(\phi'_{r.k} + \delta_{r.k}) \times \sin(\phi'_{r.k} - \beta) / (\sin(\alpha - \delta_{r.k}) \times \sin(\alpha + \beta))]]^2}) =$$ **0.183**

Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b.k})^2 / (\sin(90 + \delta_{b.k}) \times [1 - \sqrt{[\sin(\phi'_{b.k} + \delta_{b.k}) \times \sin(\phi'_{b.k}) / (\sin(90 + \delta_{b.k}))]}]^2) =$ **8.022**

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = A_{stem} \times \gamma_{stem} =$ **11.3** kN/m
Wall base	$F_{base} = A_{base} \times \gamma_{base} =$ **6** kN/m
Base soil	$F_{pass\_v} = A_{pass} \times \gamma_b =$ **1.1** kN/m
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{pass\_v} =$ **18.3** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.k}) \times Surcharge_Q \times h_{eff} =$ **4.1** kN/m
Moist retained soil	$F_{moist\_h} = K_A \times \cos(\delta_{r.k}) \times \gamma_{mr} \times h_{eff}^2 / 2 =$ **2.6** kN/m
Base soil	$F_{pass\_h} = \max(-K_P \times \cos(\delta_{b.k}) \times \gamma_b \times (d_{cover} + h_{base})^2 / 2, -(F_{moist\_h} + F_{sur\_h})) =$ **-6.7** kN/m
Total	$F_{total\_h} = \max(F_{sur\_h} + F_{moist\_h} + F_{pass\_h} - F_{total\_v} \times \tan(\delta_{bb.k}), 0$ kN/m$) =$ **0** kN/m

Moments on wall

Wall stem	$M_{stem} = F_{stem} \times x_{stem} =$ **6.2** kNm/m
Wall base	$M_{base} = F_{base} \times x_{base} =$ **2.4** kNm/m
Surcharge load	$M_{sur} = -F_{sur\_h} \times x_{sur\_h} =$ **-2.5** kNm/m
Moist retained soil	$M_{moist} = -F_{moist\_h} \times x_{moist\_h} =$ **-1** kNm/m
Base soil	$M_{pass} = F_{pass\_v} \times x_{pass\_v} - F_{pass\_h} \times x_{pass\_h} =$ **1.3** kNm/m
Total	$M_{total} = M_{stem} + M_{base} + M_{sur} + M_{moist} + M_{pass} =$ **6.4** kNm/m

Check bearing pressure

Distance to reaction	$\bar{x} = M_{total} / F_{total\_v} =$ **348** mm
Eccentricity of reaction	$e = \bar{x} - l_{base} / 2 =$ **-52** mm
Loaded length of base	$l_{load} = l_{base} =$ **800** mm
Bearing pressure at toe	$q_{toe} = F_{total\_v} / l_{base} \times (1 - 6 \times e / l_{base}) =$ **31.8** kN/m^2
Bearing pressure at heel	$q_{heel} = F_{total\_v} / l_{base} \times (1 + 6 \times e / l_{base}) =$ **14** kN/m^2
Factor of safety	$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) =$ **3.145**

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 $\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma = \mathbf{21}$ kN/m^3

Design saturated density $\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma = \mathbf{23}$ kN/m^3

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

Design wall friction angle $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{21}$ deg

Base soil properties

Design soil density $\gamma_b' = \gamma_b / \gamma_\gamma = \mathbf{17.5}$ kN/m^3

Design effective shear resistance angle $\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{36}$ deg

Design wall friction angle $\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{18}$ deg

Design base friction angle $\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{24}$ deg

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

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2}) = \mathbf{0.183}$

Passive pressure coefficient $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2}) = \mathbf{8.022}$

Sliding check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{11.3}$ kN/m

Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{6}$ kN/m

Base soil $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = \mathbf{0.3}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{exc\_v} = \mathbf{17.5}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = \mathbf{6.1}$ kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{3.5}$ kN/m

Total $F_{total\_h} = F_{sur\_h} + F_{moist\_h} = \mathbf{9.6}$ kN/m

Check stability against sliding

Base soil resistance $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{8.2}$ kN/m

Base friction $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d}) = \mathbf{7.8}$ kN/m

Resistance to sliding $F_{rest} = F_{exc\_h} + F_{friction} = \mathbf{16}$ kN/m

Factor of safety $FoS_{sl} = F_{rest} / F_{total\_h} = \mathbf{1.66}$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{11.3}$ kN/m

Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{6}$ kN/m

Base soil $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' = \mathbf{0.3}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{exc\_v} = \mathbf{17.5}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = \mathbf{6.1}$ kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{3.5}$ kN/m

Base soil $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-8.2}$ kN/m

Total $F_{total\_h} = F_{sur\_h} + F_{moist\_h} + F_{exc\_h} = \mathbf{1.4}$ kN/m

Overturning moments on wall

Surcharge load	$M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **3.7** kNm/m
Moist retained soil	$M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} =$ **1.4** kNm/m
Total	$M_{total\_OT} = M_{sur\_OT} + M_{moist\_OT} =$ **5.1** kNm/m

Restoring moments on wall

Wall stem	$M_{stem\_R} = F_{stem} \times x_{stem} =$ **6.2** kNm/m
Wall base	$M_{base\_R} = F_{base} \times x_{base} =$ **2.4** kNm/m
Base soil	$M_{exc\_R} = F_{exc\_v} \times x_{exc\_v} - F_{exc\_h} \times x_{exc\_h} =$ **1** kNm/m
Total	$M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{exc\_R} =$ **9.6** kNm/m

Check stability against overturning

Factor of safety $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **1.887**

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	$\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma =$ **21** kN/m^3
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma =$ **23** kN/m^3
Design effective shear resistance angle	$\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) =$ **35.8** deg
Design wall friction angle	$\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) =$ **17.1** deg

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_\gamma =$ **17.5** kN/m^3
Design effective shear resistance angle	$\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) =$ **30.2** deg
Design wall friction angle	$\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) =$ **14.6** deg
Design base friction angle	$\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) =$ **19.6** deg
Design effective cohesion	$c'_{b.d} = c'_{b.k} / \gamma_{c'} =$ **0** kN/m^2

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2) =$ **0.239**
Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2) =$ **4.938**

Sliding check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **11.3** kN/m

Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **6** kN/m

Base soil $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' =$ **0.3** kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{exc\_v} =$ **17.5** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **7.1** kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 =$ **3.5** kN/m

Total $F_{total\_h} = F_{sur\_h} + F_{moist\_h} =$ **10.6** kN/m

Check stability against sliding

Base soil resistance $F_{exc\_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 =$ **5.1** kN/m

Base friction $F_{friction} = F_{total\_v} \times \tan(\delta_{bb.d}) =$ **6.2** kN/m

Resistance to sliding $F_{rest} = F_{exc\_h} + F_{friction} =$ **11.4** kN/m

Factor of safety $FoS_{sl} = F_{rest} / F_{total\_h} =$ **1.074**

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} =$ **11.3** kN/m

Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} =$ **6** kN/m

Base soil $F_{exc\_v} = \gamma_{Gf} \times A_{exc} \times \gamma_b' =$ **0.3** kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{exc\_v} =$ **17.5** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} =$ **7.1** kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times h_{eff}^2 / 2 =$ **3.5** kN/m

Base soil $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 =$ **-5.1** kN/m

Total $F_{total\_h} = F_{sur\_h} + F_{moist\_h} + F_{exc\_h} =$ **5.5** kN/m

Overturning moments on wall

Surcharge load $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} =$ **4.3** kNm/m

Moist retained soil $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} =$ **1.4** kNm/m

Total $M_{total\_OT} = M_{sur\_OT} + M_{moist\_OT} =$ **5.7** kNm/m

Restoring moments on wall

Wall stem $M_{stem\_R} = F_{stem} \times x_{stem} =$ **6.2** kNm/m

Wall base $M_{base\_R} = F_{base} \times x_{base} =$ **2.4** kNm/m

Base soil $M_{exc\_R} = F_{exc\_v} \times x_{exc\_v} - F_{exc\_h} \times x_{exc\_h} =$ **0.6** kNm/m

Total $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{exc\_R} =$ **9.2** kNm/m

Check stability against overturning

Factor of safety $FoS_{ot} = M_{total\_R} / M_{total\_OT} =$ **1.631**

PASS - Maximum restoring moment is greater than overturning moment