

STRUCTURAL CALCULATIONS

FOR

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ISSUE	PREPARED BY	CHECKED BY	APPROVED BY	DATE
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1.0 BRIEF

To provide structural calculations for various retaining walls required for a cut and fill exercise to create a new driveway and car park.

2.0 INSPECTION / INVESTIGATION

Our inspection and investigation comprised the following: -

2.1 SITE INSPECTION

A walk around inspection using a measuring tape and camera and taking measurements and photographs as necessary.

3.0 REFERENCES

The design has been carried out in accordance with the following documents: -

- BS EN 1990:2002+A1:2005 Eurocode – Basic of structural design
- NA to BS EN 1990:2002+A1:2005 UK National Annex for Eurocode – Basic of structural design
- BS EN 1991-1-1:2002 Eurocode 1: Actions on structures – Part 1-1: General actions
 - Densities, self-weight, imposed loads for buildings
- BS EN 1997-1-1:2004 Eurocode 7: Geotechnical Design

3.1 SCHEDULE OF DESIGN SOFTWARE USED

- Tekla TEDDS

3.2 DESIGNER

Calculations are completed by Karl Jones BSc (Hons) Civil Engineering, MSc.

4.0 CALCULATIONS

4.1 Unreinforced blockwork retaining wall

The highest construction of the blockwork retaining wall will sit at a height of 2m exactly. This will be supporting the bank that slopes down from the existing dwelling, behind the retaining wall will be backfilled with granular material.

No SI works were completed for the site and historical borehole data was examined, it indicates that the existing soil profile consists of a layer of made ground underlain by silty sand clays. As the existing property is located on a hillside, it is assumed that all soils underneath will be silty sandy clay.

No variable loads will be acting on the wall and a permanent surcharge weight of 5kN/m^2 will be implemented.

The wall be constructed with the following profile:-

Step 1 – Height of 900mm and thickness of 1800mm

Step 2 – Height of 450mm and thickness of 1350mm

Step 3 – Height of 225mm and thickness of 900mm

Step 4 – Height of 450mm and thickness of 675mm

Step 5 – Height of 450mm and thickness of 440mm

It will be footed onto a concrete base at 600mm thick.

From TEDDS Output below the wall is satisfactory. Refer to Drawing C101-C105 inclusive for full construction details

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

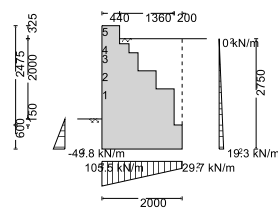
Stem type	Cantilever with stepped rear face
Stem height	$h_{\text{stem}} = 2475 \text{ mm}$
Number of steps	$N_{\text{steps}} = 5$
Height of step 1	$h_{s1} = 900 \text{ mm}$
Thickness of step 1	$t_{s1} = 1800 \text{ mm}$
Height of step 2	$h_{s2} = 450 \text{ mm}$
Thickness of step 2	$t_{s2} = 1350 \text{ mm}$
Height of step 3	$h_{s3} = 450 \text{ mm}$
Thickness of step 3	$t_{s3} = 900 \text{ mm}$
Height of step 4	$h_{s4} = 225 \text{ mm}$
Thickness of step 4	$t_{s4} = 675 \text{ mm}$
Height of step 5	$h_{s5} = 450 \text{ mm}$
Thickness of step 5	$t_{s5} = 440 \text{ mm}$
Angle to rear face of stem	$\alpha = 90 \text{ deg}$
Stem density	$\gamma_{\text{stem}} = 25 \text{ kN/m}^3$
Heel length	$l_{\text{heel}} = 200 \text{ mm}$
Base thickness	$t_{\text{base}} = 600 \text{ mm}$
Base density	$\gamma_{\text{base}} = 25 \text{ kN/m}^3$
Height of retained soil	$h_{\text{ret}} = 2000 \text{ mm}$
Angle of soil surface	$\beta = 0 \text{ deg}$
Depth of cover	$d_{\text{cover}} = 150 \text{ mm}$

Retained soil properties

Soil type	Medium dense well graded sand
Moist density	$\gamma_{\text{mr}} = 21 \text{ kN/m}^3$
Saturated density	$\gamma_{\text{sr}} = 23 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{r,k} = 30 \text{ deg}$
Characteristic wall friction angle	$\delta_{r,k} = 0 \text{ deg}$

Base soil properties

Soil type	Firm sandy clay
Soil density	$\gamma_b = 18 \text{ kN/m}^3$
Characteristic effective shear resistance angle	$\phi'_{b,k} = 26 \text{ deg}$
Characteristic wall friction angle	$\delta_{b,k} = 13 \text{ deg}$
Characteristic base friction angle	$\delta_{bb,k} = 17.3 \text{ deg}$
Presumed bearing capacity	$P_{\text{bearing}} = 150 \text{ kN/m}^2$



General arrangement - sketch pressures relate to bearing check

Calculate retaining wall geometry

Base length

$$l_{base} = t_{s1} + l_{heel} = \mathbf{2000 \text{ mm}}$$

Moist soil height

$$h_{moist} = h_{soil} = \mathbf{2150 \text{ mm}}$$

Retained surface length

$$l_{sur} = (l_{heel} + t_{s1} - t_{s5}) = \mathbf{1560 \text{ mm}}$$

Effective height of wall

$$h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{2750 \text{ mm}}$$

Area of wall stem

$$A_{stem} = h_{s1} \times t_{s1} + h_{s2} \times t_{s2} + h_{s3} \times t_{s3} + h_{s4} \times t_{s4} + h_{s5} \times t_{s5} = \mathbf{2.982 \text{ m}^2}$$

- Distance to vertical component

$$X_{stem} = l_{base} - (h_{s1} \times t_{s1} \times (l_{heel} + t_{s1} - t_{s1} / 2) + h_{s2} \times t_{s2} \times (l_{heel} + t_{s1} - t_{s2} / 2) + h_{s3} \times t_{s3} \times (l_{heel} + t_{s1} - t_{s3} / 2) + h_{s4} \times t_{s4} \times (l_{heel} + t_{s1} - t_{s4} / 2) + h_{s5} \times t_{s5} \times (l_{heel} + t_{s1} - t_{s5} / 2)) / A_{stem} = \mathbf{719 \text{ mm}}$$

Area of wall base

$$A_{base} = l_{base} \times t_{base} = \mathbf{1.2 \text{ m}^2}$$

- Distance to vertical component

$$X_{base} = l_{base} / 2 = \mathbf{1000 \text{ mm}}$$

Area of moist soil

$$A_{moist} = l_{heel} \times h_{s1} + (l_{heel} + t_{s1} - t_{s2}) \times h_{s2} + (l_{heel} + t_{s1} - t_{s3}) \times h_{s3} + (l_{heel} + t_{s1} - t_{s4}) \times h_{s4} + (l_{heel} + t_{s1} - t_{s5}) \times (h_{soil} - (h_{s1} + h_{s2} + h_{s3} + h_{s4})) = \mathbf{1.461 \text{ m}^2}$$

- Distance to vertical component

$$X_{moist_v} = l_{base} - (l_{heel} \times h_{s1} \times l_{heel} / 2 + (l_{heel} + t_{s1} - t_{s2}) \times h_{s2} \times (l_{heel} + t_{s1} - t_{s2}) / 2 + (l_{heel} + t_{s1} - t_{s3}) \times h_{s3} \times (l_{heel} + t_{s1} - t_{s3}) / 2 + (l_{heel} + t_{s1} - t_{s4}) \times h_{s4} \times (l_{heel} + t_{s1} - t_{s4}) / 2 + (l_{heel} + t_{s1} - t_{s5}) \times (h_{soil} - (h_{s1} + h_{s2} + h_{s3} + h_{s4})) \times (l_{heel} + t_{s1} - t_{s5}) / 2) / A_{moist} = \mathbf{1497 \text{ mm}}$$

- Distance to horizontal component

$$X_{moist_h} = h_{eff} / 3 = \mathbf{917 \text{ mm}}$$

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k}) \times [1 + \sqrt{[\sin(\phi'_{r,k}) + \delta_{r,k}] \times \sin(\phi'_{r,k} - \beta) / (\sin(\alpha - \delta_{r,k}) \times \sin(\alpha + \beta))}]^2) = \mathbf{0.333}$$

Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,k})^2 / (\sin(90 + \delta_{b,k}) \times [1 - \sqrt{[\sin(\phi'_{b,k}) + \delta_{b,k}] \times \sin(\phi'_{b,k}) / (\sin(90 + \delta_{b,k}))}]^2) = \mathbf{3.787}$$

Bearing pressure check

Vertical forces on wall

Wall stem

$$F_{\text{stem}} = A_{\text{stem}} \times \gamma_{\text{stem}} = \mathbf{74.6 \text{ kN/m}}$$

Wall base

$$F_{\text{base}} = A_{\text{base}} \times \gamma_{\text{base}} = \mathbf{30 \text{ kN/m}}$$

Moist retained soil

$$F_{\text{moist}_v} = A_{\text{moist}} \times \gamma_{\text{mr}} = \mathbf{30.7 \text{ kN/m}}$$

Total

$$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{moist}_v} = \mathbf{135.2 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

$$F_{\text{moist}_h} = K_A \times \gamma_{\text{mr}} \times h_{\text{eff}}^2 / 2 = \mathbf{26.5 \text{ kN/m}}$$

Base soil

$$F_{\text{pass}_h} = -K_P \times \cos(\delta_{b,k}) \times \gamma_b \times (d_{\text{cover}} + h_{\text{base}})^2 / 2 = \mathbf{-18.7 \text{ kN/m}}$$

Total

$$F_{\text{total}_h} = \max(F_{\text{moist}_h} + F_{\text{pass}_h} - F_{\text{total}_v} \times \tan(\delta_{bb,k}), 0 \text{ kN/m}) = \mathbf{0 \text{ kN/m}}$$

Moments on wall

Wall stem

$$M_{\text{stem}} = F_{\text{stem}} \times x_{\text{stem}} = \mathbf{53.6 \text{ kNm/m}}$$

Wall base

$$M_{\text{base}} = F_{\text{base}} \times x_{\text{base}} = \mathbf{30 \text{ kNm/m}}$$

Moist retained soil

$$M_{\text{moist}} = F_{\text{moist}_v} \times x_{\text{moist}_v} - F_{\text{moist}_h} \times x_{\text{moist}_h} = \mathbf{21.6 \text{ kNm/m}}$$

Base soil

$$M_{\text{pass}} = -F_{\text{pass}_h} \times x_{\text{pass}_h} = \mathbf{4.7 \text{ kNm/m}}$$

Total

$$M_{\text{total}} = M_{\text{stem}} + M_{\text{base}} + M_{\text{moist}} + M_{\text{pass}} = \mathbf{109.9 \text{ kNm/m}}$$

Check bearing pressure

Distance to reaction

$$\bar{x} = M_{\text{total}} / F_{\text{total}_v} = \mathbf{813 \text{ mm}}$$

Eccentricity of reaction

$$e = \bar{x} - l_{\text{base}} / 2 = \mathbf{-187 \text{ mm}}$$

Loaded length of base

$$l_{\text{load}} = l_{\text{base}} = \mathbf{2000 \text{ mm}}$$

Bearing pressure at toe

$$q_{\text{toe}} = F_{\text{total}_v} / l_{\text{base}} \times (1 - 6 \times e / l_{\text{base}}) = \mathbf{105.5 \text{ kN/m}^2}$$

Bearing pressure at heel

$$q_{\text{heel}} = F_{\text{total}_v} / l_{\text{base}} \times (1 + 6 \times e / l_{\text{base}}) = \mathbf{29.7 \text{ kN/m}^2}$$

Factor of safety

$$FOS_{\text{bp}} = P_{\text{bearing}} / \max(q_{\text{toe}}, q_{\text{heel}}) = \mathbf{1.421}$$

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

$$\gamma_G = \mathbf{1.350}$$

Permanent favourable action

$$\gamma_{Gf} = \mathbf{1.000}$$

Variable unfavourable action

$$\gamma_Q = \mathbf{1.500}$$

Variable favourable action

$$\gamma_{Qf} = \mathbf{0.000}$$

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

Soil parameter set

M1

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 moist density

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

Design saturated density

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

Design effective shear resistance angle
Design wall friction angle

$$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_\phi) = \mathbf{30 \text{ deg}}$$
$$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_\phi) = \mathbf{0 \text{ deg}}$$

Base soil properties

Design soil density
Design effective shear resistance angle
Design wall friction angle
Design base friction angle
Design effective cohesion

$$\gamma_b' = \gamma_b / \gamma_\gamma = \mathbf{18 \text{ kN/m}^3}$$
$$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_\phi) = \mathbf{26 \text{ deg}}$$
$$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_\phi) = \mathbf{13 \text{ deg}}$$
$$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_\phi) = \mathbf{17.3 \text{ deg}}$$
$$c'_{b,d} = c'_{b,k} / \gamma_c = \mathbf{0 \text{ kN/m}^2}$$

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{[\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{b,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))]}])^2 = \mathbf{0.333}$$

Passive pressure coefficient

$$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{[\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d}) / (\sin(90 + \delta_{b,d}))]}])^2 = \mathbf{3.787}$$

Sliding check

Vertical forces on wall

Wall stem
Wall base
Moist retained soil
Total

$$F_{\text{stem}} = \gamma_{Gf} \times A_{\text{stem}} \times \gamma_{\text{stem}} = \mathbf{74.6 \text{ kN/m}}$$
$$F_{\text{base}} = \gamma_{Gf} \times A_{\text{base}} \times \gamma_{\text{base}} = \mathbf{30 \text{ kN/m}}$$
$$F_{\text{moist}_v} = \gamma_{Gf} \times A_{\text{moist}} \times \gamma_{mr}' = \mathbf{30.7 \text{ kN/m}}$$
$$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{moist}_v} = \mathbf{135.2 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil
Total

$$F_{\text{moist}_h} = \gamma_G \times K_A \times \gamma_{mr}' \times h_{\text{eff}}^2 / 2 = \mathbf{35.7 \text{ kN/m}}$$
$$F_{\text{total}_h} = F_{\text{moist}_h} = \mathbf{35.7 \text{ kN/m}}$$

Check stability against sliding

Base soil resistance
18.7 kN/m
Base friction
Resistance to sliding
Factor of safety

$$F_{\text{exc}_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 =$$
$$F_{\text{friction}} = F_{\text{total}_v} \times \tan(\delta_{bb,d}) = \mathbf{42.1 \text{ kN/m}}$$
$$F_{\text{rest}} = F_{\text{exc}_h} + F_{\text{friction}} = \mathbf{60.8 \text{ kN/m}}$$
$$FoS_{sl} = F_{\text{rest}} / F_{\text{total}_h} = \mathbf{1.702}$$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem
Wall base
Moist retained soil
Total

$$F_{\text{stem}} = \gamma_{Gf} \times A_{\text{stem}} \times \gamma_{\text{stem}} = \mathbf{74.6 \text{ kN/m}}$$
$$F_{\text{base}} = \gamma_{Gf} \times A_{\text{base}} \times \gamma_{\text{base}} = \mathbf{30 \text{ kN/m}}$$
$$F_{\text{moist}_v} = \gamma_{Gf} \times A_{\text{moist}} \times \gamma_{mr}' = \mathbf{30.7 \text{ kN/m}}$$
$$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{moist}_v} = \mathbf{135.2 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil
Base soil

$$F_{\text{moist}_h} = \gamma_G \times K_A \times \gamma_{mr}' \times h_{\text{eff}}^2 / 2 = \mathbf{35.7 \text{ kN/m}}$$
$$F_{\text{exc}_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{\text{pass}} + h_{\text{base}})^2 / 2 = -$$
$$\mathbf{18.7 \text{ kN/m}}$$
$$F_{\text{total}_h} = F_{\text{moist}_h} + F_{\text{exc}_h} = \mathbf{17.1 \text{ kN/m}}$$

Total

Overturning moments on wall

Moist retained soil
Total

$$M_{\text{moist}_OT} = F_{\text{moist}_h} \times X_{\text{moist}_h} = \mathbf{32.8 \text{ kNm/m}}$$
$$M_{\text{total}_OT} = M_{\text{moist}_OT} = \mathbf{32.8 \text{ kNm/m}}$$

Restoring moments on wall

Wall stem
Wall base

$$M_{\text{stem}_R} = F_{\text{stem}} \times X_{\text{stem}} = \mathbf{53.6 \text{ kNm/m}}$$
$$M_{\text{base}_R} = F_{\text{base}} \times X_{\text{base}} = \mathbf{30 \text{ kNm/m}}$$

Moist retained soil	$M_{\text{moist}_R} = F_{\text{moist}_v} \times X_{\text{moist}_v} = \mathbf{45.9 \text{ kNm/m}}$
Base soil	$M_{\text{exc}_R} = -F_{\text{exc}_h} \times X_{\text{exc}_h} = \mathbf{4.7 \text{ kNm/m}}$
Total	$M_{\text{total}_R} = M_{\text{stem}_R} + M_{\text{base}_R} + M_{\text{moist}_R} + M_{\text{exc}_R} = \mathbf{134.2 \text{ kNm/m}}$

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{\text{total}_R} / M_{\text{total}_{OT}} = \mathbf{4.097}$
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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	$\gamma_G = \mathbf{1.000}$
Permanent favourable action	$\gamma_{Gf} = \mathbf{1.000}$
Variable unfavourable action	$\gamma_Q = \mathbf{1.300}$
Variable favourable action	$\gamma_{Qf} = \mathbf{0.000}$

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

Soil parameter set	M2
Angle of shearing resistance	$\gamma_{\phi'} = \mathbf{1.25}$
Effective cohesion	$\gamma_{c'} = \mathbf{1.25}$
Weight density	$\gamma_\gamma = \mathbf{1.00}$

Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma = \mathbf{21 \text{ kN/m}^3}$
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma = \mathbf{23 \text{ kN/m}^3}$
Design effective shear resistance angle	$\phi'_{r,d} = \text{atan}(\tan(\phi'_{r,k}) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$
Design wall friction angle	$\delta_{r,d} = \text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}) = \mathbf{0 \text{ deg}}$

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_\gamma = \mathbf{18 \text{ kN/m}^3}$
Design effective shear resistance angle	$\phi'_{b,d} = \text{atan}(\tan(\phi'_{b,k}) / \gamma_{\phi'}) = \mathbf{21.3 \text{ deg}}$
Design wall friction angle	$\delta_{b,d} = \text{atan}(\tan(\delta_{b,k}) / \gamma_{\phi'}) = \mathbf{10.5 \text{ deg}}$
Design base friction angle	$\delta_{bb,d} = \text{atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = \mathbf{14 \text{ deg}}$
Design effective cohesion	$c'_{b,d} = c'_{b,k} / \gamma_{c'} = \mathbf{0 \text{ kN/m}^2}$

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times [1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))}]^2) = \mathbf{0.409}$
Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b,d})^2 / (\sin(90 + \delta_{b,d}) \times [1 - \sqrt{(\sin(\phi'_{b,d} + \delta_{b,d}) \times \sin(\phi'_{b,d}) / (\sin(90 + \delta_{b,d}))}]^2) = \mathbf{2.827}$

Sliding check

Vertical forces on wall

Wall stem	$F_{\text{stem}} = \gamma_{Gf} \times A_{\text{stem}} \times \gamma_{\text{stem}} = \mathbf{74.6 \text{ kN/m}}$
Wall base	$F_{\text{base}} = \gamma_{Gf} \times A_{\text{base}} \times \gamma_{\text{base}} = \mathbf{30 \text{ kN/m}}$
Moist retained soil	$F_{\text{moist}_v} = \gamma_{Gf} \times A_{\text{moist}} \times \gamma_{mr}' = \mathbf{30.7 \text{ kN/m}}$
Total	$F_{\text{total}_v} = F_{\text{stem}} + F_{\text{base}} + F_{\text{moist}_v} = \mathbf{135.2 \text{ kN/m}}$

Horizontal forces on wall

Moist retained soil	$F_{\text{moist}_h} = \gamma_G \times K_A \times \gamma_{mr}' \times h_{\text{eff}}^2 / 2 = \mathbf{32.5 \text{ kN/m}}$
Total	$F_{\text{total}_h} = F_{\text{moist}_h} = \mathbf{32.5 \text{ kN/m}}$

Check stability against sliding

Base soil resistance

14.1 kN/m

Base friction

Resistance to sliding

Factor of safety

$$F_{exc_h} = \gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 =$$

$$F_{friction} = F_{total_v} \times \tan(\delta_{bb,d}) = \mathbf{33.7 \text{ kN/m}}$$

$$F_{rest} = F_{exc_h} + F_{friction} = \mathbf{47.8 \text{ kN/m}}$$

$$FoS_{sl} = F_{rest} / F_{total_h} = \mathbf{1.47}$$

PASS - Resistance to sliding is greater than sliding force

Overturning check

Vertical forces on wall

Wall stem

Wall base

Moist retained soil

Total

$$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{74.6 \text{ kN/m}}$$

$$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{30 \text{ kN/m}}$$

$$F_{moist_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}' = \mathbf{30.7 \text{ kN/m}}$$

$$F_{total_v} = F_{stem} + F_{base} + F_{moist_v} = \mathbf{135.2 \text{ kN/m}}$$

Horizontal forces on wall

Moist retained soil

Base soil

Total

$$F_{moist_h} = \gamma_G \times K_A \times \gamma_{mr}' \times h_{eff}^2 / 2 = \mathbf{32.5 \text{ kN/m}}$$

$$F_{exc_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b,d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = -\mathbf{14.1 \text{ kN/m}}$$

$$F_{total_h} = F_{moist_h} + F_{exc_h} = \mathbf{18.4 \text{ kN/m}}$$

Overturning moments on wall

Moist retained soil

Total

$$M_{moist_OT} = F_{moist_h} \times X_{moist_h} = \mathbf{29.8 \text{ kNm/m}}$$

$$M_{total_OT} = M_{moist_OT} = \mathbf{29.8 \text{ kNm/m}}$$

Restoring moments on wall

Wall stem

Wall base

Moist retained soil

Base soil

Total

$$M_{stem_R} = F_{stem} \times X_{stem} = \mathbf{53.6 \text{ kNm/m}}$$

$$M_{base_R} = F_{base} \times X_{base} = \mathbf{30 \text{ kNm/m}}$$

$$M_{moist_R} = F_{moist_v} \times X_{moist_v} = \mathbf{45.9 \text{ kNm/m}}$$

$$M_{exc_R} = -F_{exc_h} \times X_{exc_h} = \mathbf{3.5 \text{ kNm/m}}$$

$$M_{total_R} = M_{stem_R} + M_{base_R} + M_{moist_R} + M_{exc_R} = \mathbf{133.1 \text{ kNm/m}}$$

Check stability against overturning

Factor of safety

$$FoS_{ot} = M_{total_R} / M_{total_OT} = \mathbf{4.468}$$

PASS - Maximum restoring moment is greater than overturning moment

RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum dated January 2008 and the UK National Annex incorporating National Amendment No.1 and EN1996-1-1:2005 incorporating Corrigenda dated February 2006 and July 2009 and the UK National Annex

Tedds calculation version 2.9.16

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

Concrete strength class

C32/40

Characteristic compressive cylinder strength

$f_{ck} = \mathbf{32 \text{ N/mm}^2}$

Characteristic compressive cube strength

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

Mean value of compressive cylinder strength

$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = \mathbf{40 \text{ N/mm}^2}$

Mean value of axial tensile strength

$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = \mathbf{3.0 \text{ N/mm}^2}$

5% fractile of axial tensile strength

$f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.1 \text{ N/mm}^2}$

Secant modulus of elasticity of concrete

$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = \mathbf{33346 \text{ N/mm}^2}$

Partial factor for concrete - Table 2.1N

$\gamma_C = \mathbf{1.50}$

Compressive strength coefficient - cl.3.1.6(1)

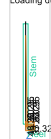
$\alpha_{cc} = \mathbf{0.85}$

Design compressive concrete strength - exp.3.15

$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = \mathbf{18.1 \text{ N/mm}^2}$

Maximum aggregate size	$h_{agg} = 20 \text{ mm}$
Ultimate strain - Table 3.1	$\varepsilon_{cu2} = 0.0035$
Shortening strain - Table 3.1	$\varepsilon_{cu3} = 0.0035$
Effective compression zone height factor	$\lambda = 0.80$
Effective strength factor	$\eta = 1.00$
Bending coefficient k_1	$K_1 = 0.40$
Bending coefficient k_2	$K_2 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2}) = 1.00$
Bending coefficient k_3	$K_3 = 0.40$
Bending coefficient k_4	$K_4 = 1.00 \times (0.6 + 0.0014/\varepsilon_{cu2}) = 1.00$
Reinforcement details	
Characteristic yield strength of reinforcement	$f_{yk} = 500 \text{ N/mm}^2$
Modulus of elasticity of reinforcement	$E_s = 200000 \text{ N/mm}^2$
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	
Top face of base	$C_{bt} = 50 \text{ mm}$
Bottom face of base	$C_{bb} = 75 \text{ mm}$
Masonry details - Section 3.1	
Masonry type	Aggregate concrete - Group 1
Normalised mean compressive strength	$f_b = 10.4 \text{ N/mm}^2$
Characteristic flexural strength - cl.6.3.4(1)	$f_{xk} = 0 \text{ N/mm}^2$
Initial shear strength - Table NA.5	$f_{vko} = 0.15 \text{ N/mm}^2$
Mortar details - Section 3.2	
Mortar type	General purpose - M6, prescribed mix
Compressive strength of mortar	$f_m = 6 \text{ N/mm}^2$
Ultimate limit states - Table NA.1	
Class of execution control	1
Category of manufacture control	1
Partial factor for direct or flexural compression	$\gamma_{Mc} = 2.3$
Partial factor for flexural tension	$\gamma_{Mt} = 2.3$
Partial factor for shear	$\gamma_{Mv} = 2.5$

Loading details - Combination N1

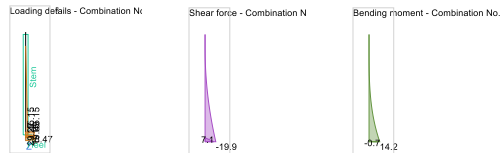


Shear force - Combination N



Bending moment - Combination No.





Check stem design at base of stem

Depth of section

$t = 1800 \text{ mm}$

Masonry characteristics

Compressive strength constants - Table NA.4

$K = 0.550$

Characteristic compressive strength - cl.3.6.1.2(1)

$f_k = K \times f_b^{0.7} \times f_m^{0.3} = 4.85 \text{ N/mm}^2$

Design compressive strength

$f_d = f_k / \gamma_{Mc} = 2.109 \text{ N/mm}^2$

Design flexural strength

$f_{xd} = f_{xk} / \gamma_{Mt} = 0 \text{ N/mm}^2$

Height of masonry

$h_{wt} = h_{stem} = 2475 \text{ mm}$

Compressive axial force combination 0

$F_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s1} \times t_{s1} + h_{s2} \times t_{s2} + h_{s3} \times t_{s3} + h_{s4} \times t_{s4} + h_{s5} \times t_{s5}) = 74.6 \text{ kN/m}$

Moment combination 0

$M_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s1} \times t_{s1} \times t_{s1} / 2 + h_{s2} \times t_{s2} \times t_{s2} / 2 + h_{s3} \times t_{s3} \times t_{s3} / 2 + h_{s4} \times t_{s4} \times t_{s4} / 2 + h_{s5} \times t_{s5} \times t_{s5} / 2) = 53.6 \text{ kNm/m}$

Eccentricity of axial load

$e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = 180.7 \text{ mm}$

Capacity reduction factor - exp.6.4

$\Phi = 1 - 2 \times e / t = 0.799$

Design vertical resistance - exp.6.2

$N_{Rd} = \Phi \times t \times f_d = 3033.4 \text{ kN/m}$

Design vertical compressive stress

$\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = 0.041 \text{ N/mm}^2$

Apparent design flexural strength - exp.6.16

$f_{xd,app} = f_{xd} + \sigma_d = 0.041 \text{ N/mm}^2$

Limit of charact. shear strength - exp. 3.1

$f_{vk,lim} = 0.065 \times f_b = 0.676 \text{ N/mm}^2$

Characteristic shear strength - exp.3.5

$f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk,lim}) = 0.167 \text{ N/mm}^2$

Design shear strength

$f_{vd} = f_{vk} / \gamma_{Mv} = 0.067 \text{ N/mm}^2$

Library item: Masonry characteristics output

Unreinforced masonry walls subjected to lateral loading - Section 6.3

Design bending moment combination 1

$M = 15.653 \text{ kNm/m}$

Elastic section modulus of wall

$Z = t^2 / 6 = 540000000 \text{ mm}^3/\text{m}$

Moment of resistance of masonry - exp.6.15

$M_{Rd} = f_{xd,app} \times Z = 22.368 \text{ kNm/m}$

$M / M_{Rd} = 0.700$

PASS - Moment of resistance exceeds applied design moment

Unreinforced masonry walls subjected to shear loading - Section 6.2

Design shear force

$V = 21.841 \text{ kN/m}$

Maximum compressive stress

$\sigma_{max} = F_x / t + M / Z = 0.070 \text{ N/mm}^2$

Minimum compressive stress	$\sigma_{\min} = F_x / t - M / Z = \mathbf{0.012 \text{ N/mm}^2}$
Thickness of wall in compression	$t_c = t = \mathbf{1800 \text{ mm}}$
Design shear resistance - exp.6.13	$V_{Rd} = f_{vd} \times t_c = \mathbf{119.93 \text{ kN/m}}$
	$V / V_{Rd} = \mathbf{0.182}$

PASS - Design shear resistance exceeds applied design shear force

Check stem design at 900 mm

Depth of section	$t = \mathbf{1350 \text{ mm}}$
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Masonry characteristics

Compressive strength constants - Table NA.4	$K = 0.550$
Characteristic compressive strength - cl.3.6.1.2(1)	$f_k = K \times f_b^{0.7} \times f_m^{0.3} = \mathbf{4.85 \text{ N/mm}^2}$
Design compressive strength	$f_d = f_k / \gamma_{Mc} = \mathbf{2.109 \text{ N/mm}^2}$
Design flexural strength	$f_{xd} = f_{xk} / \gamma_{Mt} = \mathbf{0 \text{ N/mm}^2}$
Height of masonry	$h_{wt} = h_{stem} - 900 \text{ mm} = \mathbf{1575 \text{ mm}}$
Compressive axial force combination 0	$F_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s2} \times t_{s2} + h_{s3} \times t_{s3} + h_{s4} \times t_{s4} + h_{s5} \times t_{s5})$ $= \mathbf{34.1 \text{ kN/m}}$
Moment combination 0	$M_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s2} \times t_{s2} \times t_{s2} / 2 + h_{s3} \times t_{s3} \times t_{s3} / 2 +$ $h_{s4} \times t_{s4} \times t_{s4} / 2 + h_{s5} \times t_{s5} \times t_{s5} / 2) = \mathbf{17.2 \text{ kNm/m}}$
Eccentricity of axial load	$e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = \mathbf{170.6 \text{ mm}}$
Capacity reduction factor - exp.6.4	$\Phi = 1 - 2 \times e / t = \mathbf{0.747}$
Design vertical resistance - exp.6.2	$N_{Rd} = \Phi \times t \times f_d = \mathbf{2127 \text{ kN/m}}$
Design vertical compressive stress	$\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = \mathbf{0.025 \text{ N/mm}^2}$
Apparent design flexural strength - exp.6.16	$f_{xd,app} = f_{xd} + \sigma_d = \mathbf{0.025 \text{ N/mm}^2}$
Limit of charact. shear strength - exp. 3.1	$f_{vk,lim} = 0.065 \times f_b = \mathbf{0.676 \text{ N/mm}^2}$
Characteristic shear strength - exp.3.5	$f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk,lim}) = \mathbf{0.16 \text{ N/mm}^2}$
Design shear strength	$f_{vd} = f_{vk} / \gamma_{Mv} = \mathbf{0.064 \text{ N/mm}^2}$

Library item: Masonry characteristics output

Unreinforced masonry walls subjected to lateral loading - Section 6.3

Design bending moment combination 1	$M = \mathbf{3.076 \text{ kNm/m}}$
Elastic section modulus of wall	$Z = t^2 / 6 = \mathbf{303750000 \text{ mm}^3/\text{m}}$
Moment of resistance of masonry - exp.6.15	$M_{Rd} = f_{xd,app} \times Z = \mathbf{7.663 \text{ kNm/m}}$
	$M / M_{Rd} = \mathbf{0.401}$

PASS - Moment of resistance exceeds applied design moment

Unreinforced masonry walls subjected to shear loading - Section 6.2

Design shear force	$V = \mathbf{7.383 \text{ kN/m}}$
Maximum compressive stress	$\sigma_{\max} = F_x / t + M / Z = \mathbf{0.035 \text{ N/mm}^2}$
Minimum compressive stress	$\sigma_{\min} = F_x / t - M / Z = \mathbf{0.015 \text{ N/mm}^2}$
Thickness of wall in compression	$t_c = t = \mathbf{1350 \text{ mm}}$
Design shear resistance - exp.6.13	$V_{Rd} = f_{vd} \times t_c = \mathbf{86.45 \text{ kN/m}}$
	$V / V_{Rd} = \mathbf{0.085}$

PASS - Design shear resistance exceeds applied design shear force

Check stem design at 1350 mm

Depth of section	$t = \mathbf{900 \text{ mm}}$
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Masonry characteristics

Compressive strength constants - Table NA.4	$K = 0.550$
Characteristic compressive strength - cl.3.6.1.2(1)	$f_k = K \times f_b^{0.7} \times f_m^{0.3} = \mathbf{4.85 \text{ N/mm}^2}$
Design compressive strength	$f_d = f_k / \gamma_{Mc} = \mathbf{2.109 \text{ N/mm}^2}$
Design flexural strength	$f_{xd} = f_{xk} / \gamma_{Mt} = \mathbf{0 \text{ N/mm}^2}$
Height of masonry	$h_{wt} = h_{stem} - 1350 \text{ mm} = \mathbf{1125 \text{ mm}}$

Compressive axial force combination 0	$F_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s3} \times t_{s3} + h_{s4} \times t_{s4} + h_{s5} \times t_{s5}) = \mathbf{18.9}$ kN/m
Moment combination 0	$M_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s3} \times t_{s3} \times t_{s3} / 2 + h_{s4} \times t_{s4} \times t_{s4} / 2 + h_{s5} \times t_{s5} \times t_{s5} / 2) = \mathbf{6.9}$ kNm/m
Eccentricity of axial load	$e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = \mathbf{83}$ mm
Capacity reduction factor - exp.6.4	$\Phi = 1 - 2 \times e / t = \mathbf{0.816}$
Design vertical resistance - exp.6.2	$N_{Rd} = \Phi \times t \times f_d = \mathbf{1547.9}$ kN/m
Design vertical compressive stress	$\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = \mathbf{0.021}$ N/mm ²
Apparent design flexural strength - exp.6.16	$f_{xd,app} = f_{xd} + \sigma_d = \mathbf{0.021}$ N/mm ²
Limit of charact. shear strength - exp. 3.1	$f_{vk,lim} = 0.065 \times f_b = \mathbf{0.676}$ N/mm ²
Characteristic shear strength - exp.3.5	$f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk,lim}) = \mathbf{0.158}$ N/mm ²
Design shear strength	$f_{vd} = f_{vk} / \gamma_{Mv} = \mathbf{0.063}$ N/mm ²

Library item: Masonry characteristics output

Unreinforced masonry walls subjected to lateral loading - Section 6.3

Design bending moment combination 1	$M = \mathbf{0.806}$ kNm/m
Elastic section modulus of wall	$Z = t^2 / 6 = \mathbf{135000000}$ mm ³ /m
Moment of resistance of masonry - exp.6.15	$M_{Rd} = f_{xd,app} \times Z = \mathbf{2.831}$ kNm/m
	$M / M_{Rd} = \mathbf{0.285}$

PASS - Moment of resistance exceeds applied design moment

Unreinforced masonry walls subjected to shear loading - Section 6.2

Design shear force	$V = \mathbf{3.024}$ kN/m
Maximum compressive stress	$\sigma_{max} = F_x / t + M / Z = \mathbf{0.027}$ N/mm ²
Minimum compressive stress	$\sigma_{min} = F_x / t - M / Z = \mathbf{0.015}$ N/mm ²
Thickness of wall in compression	$t_c = t = \mathbf{900}$ mm
Design shear resistance - exp.6.13	$V_{Rd} = f_{vd} \times t_c = \mathbf{57.02}$ kN/m
	$V / V_{Rd} = \mathbf{0.053}$

PASS - Design shear resistance exceeds applied design shear force

Check stem design at 1800 mm

Depth of section	$t = \mathbf{675}$ mm
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Masonry characteristics

Compressive strength constants - Table NA.4	$K = 0.550$
Characteristic compressive strength - cl.3.6.1.2(1)	$f_k = K \times f_b^{0.7} \times f_m^{0.3} = \mathbf{4.85}$ N/mm ²
Design compressive strength	$f_d = f_k / \gamma_{Mc} = \mathbf{2.109}$ N/mm ²
Design flexural strength	$f_{xd} = f_{xk} / \gamma_{Mt} = \mathbf{0}$ N/mm ²
Height of masonry	$h_{wt} = h_{stem} - 1800 \text{ mm} = \mathbf{675}$ mm
Compressive axial force combination 0	$F_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s4} \times t_{s4} + h_{s5} \times t_{s5}) = \mathbf{8.7}$ kN/m
Moment combination 0	$M_x = \gamma_{Gf} \times \gamma_{stem} \times (h_{s4} \times t_{s4} \times t_{s4} / 2 + h_{s5} \times t_{s5} \times t_{s5} / 2) = \mathbf{2.4}$ kNm/m
Eccentricity of axial load	$e = \max(\text{abs}(t / 2 - M_x / F_x), 0.05 \times t) = \mathbf{66.5}$ mm
Capacity reduction factor - exp.6.4	$\Phi = 1 - 2 \times e / t = \mathbf{0.803}$
Design vertical resistance - exp.6.2	$N_{Rd} = \Phi \times t \times f_d = \mathbf{1142.9}$ kN/m
Design vertical compressive stress	$\sigma_d = \min(F_x / t, 0.15 \times N_{Rd} / t) = \mathbf{0.013}$ N/mm ²
Apparent design flexural strength - exp.6.16	$f_{xd,app} = f_{xd} + \sigma_d = \mathbf{0.013}$ N/mm ²
Limit of charact. shear strength - exp. 3.1	$f_{vk,lim} = 0.065 \times f_b = \mathbf{0.676}$ N/mm ²
Characteristic shear strength - exp.3.5	$f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, f_{vk,lim}) = \mathbf{0.155}$ N/mm ²
Design shear strength	$f_{vd} = f_{vk} / \gamma_{Mv} = \mathbf{0.062}$ N/mm ²

Library item: Masonry characteristics output

Unreinforced masonry walls subjected to lateral loading - Section 6.3

Design bending moment combination 1	$M = 0.068 \text{ kNm/m}$
Elastic section modulus of wall	$Z = t^2 / 6 = 75937500 \text{ mm}^3/\text{m}$
Moment of resistance of masonry - exp.6.15	$M_{Rd} = f_{xd,app} \times Z = 0.984 \text{ kNm/m}$
	$M / M_{Rd} = 0.069$

PASS - Moment of resistance exceeds applied design moment**Unreinforced masonry walls subjected to shear loading - Section 6.2**

Design shear force	$V = 0.579 \text{ kN/m}$
Maximum compressive stress	$\sigma_{\max} = F_x / t + M / Z = 0.014 \text{ N/mm}^2$
Minimum compressive stress	$\sigma_{\min} = F_x / t - M / Z = 0.012 \text{ N/mm}^2$
Thickness of wall in compression	$t_c = t = 675 \text{ mm}$
Design shear resistance - exp.6.13	$V_{Rd} = f_{vd} \times t_c = 41.9 \text{ kN/m}$
	$V / V_{Rd} = 0.014$

PASS - Design shear resistance exceeds applied design shear force**Check stem design at 2025 mm**

Depth of section	$t = 440 \text{ mm}$
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Check base design at heel

Depth of section	$h = 600 \text{ mm}$
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Rectangular section in flexure - Section 6.1

Design bending moment combination 1	$M = 0.8 \text{ kNm/m}$
Depth to tension reinforcement	$d = h - C_{bt} - \phi_{bt} / 2 = 544 \text{ mm}$
	$K = M / (d^2 \times f_{ck}) = 0.000$
	$K' = (2 \times \eta \times \alpha_{cc} / \gamma_c) \times (1 - \lambda \times (\delta - K_1) / (2 \times K_2)) \times (\lambda \times (\delta - K_1) / (2 \times K_2))$
	$K' = 0.207$
	$K' > K$ - No compression reinforcement is required
Lever arm	$z = \min(0.5 + 0.5 \times (1 - 2 \times K / (\eta \times \alpha_{cc} / \gamma_c))^{0.5}, 0.95) \times d$
= 517 mm	
Depth of neutral axis	$x = 2.5 \times (d - z) = 68 \text{ mm}$
Area of tension reinforcement required	$A_{bt,req} = M / (f_{yd} \times z) = 4 \text{ mm}^2/\text{m}$
Tension reinforcement provided	12 dia.bars @ 100 c/c
Area of tension reinforcement provided	$A_{bt,prov} = \pi \times \phi_{bt}^2 / (4 \times S_{bt}) = 1131 \text{ mm}^2/\text{m}$
Minimum area of reinforcement - exp.9.1N	$A_{bt,min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = 855 \text{ mm}^2/\text{m}$
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bt,max} = 0.04 \times h = 24000 \text{ mm}^2/\text{m}$
	$\max(A_{bt,req}, A_{bt,min}) / A_{bt,prov} = 0.756$

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

Library item: Rectangular single output

Crack control - Section 7.3

Limiting crack width	$w_{\max} = 0.3 \text{ mm}$
Variable load factor - EN1990 – Table A1.1	$\psi_2 = 0.6$
Serviceability bending moment	$M_{sls} = 0.6 \text{ kNm/m}$
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bt,prov} \times z) = 1 \text{ N/mm}^2$
Load duration	Long term
Load duration factor	$k_t = 0.4$
Effective area of concrete in tension	$A_{c,eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$
	$A_{c,eff} = 140000 \text{ mm}^2/\text{m}$
Mean value of concrete tensile strength	$f_{ct,eff} = f_{ctm} = 3.0 \text{ N/mm}^2$
Reinforcement ratio	$\rho_{p,eff} = A_{bt,prov} / A_{c,eff} = 0.008$

Modular ratio	$\alpha_e = E_s / E_{cm} = \mathbf{5.998}$
Bond property coefficient	$k_1 = \mathbf{0.8}$
Strain distribution coefficient	$k_2 = \mathbf{0.5}$
	$k_3 = \mathbf{3.4}$
	$k_4 = \mathbf{0.425}$
Maximum crack spacing - exp.7.11	$s_{r,max} = k_3 \times c_{bt} + k_1 \times k_2 \times k_4 \times \phi_{bt} / \rho_{p,eff} = \mathbf{423 \text{ mm}}$
Maximum crack width - exp.7.8	$w_k = s_{r,max} \times \max(\sigma_s - k_t \times (f_{ct,eff} / \rho_{p,eff}) \times (1 + \alpha_e \times \rho_{p,eff}), 0.6 \times \sigma_s) / E_s$
	$w_k = \mathbf{0.001 \text{ mm}}$
	$w_k / w_{max} = \mathbf{0.004}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	$V = \mathbf{7.6 \text{ kN/m}}$
	$C_{Rd,c} = 0.18 / \gamma_c = \mathbf{0.120}$
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.606}$
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bt,prov} / d, 0.02) = \mathbf{0.002}$
	$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.403 \text{ N/mm}^2}$
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd,c} = \max(C_{Rd,c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd,c} = \mathbf{219.3 \text{ kN/m}}$
	$V / V_{Rd,c} = \mathbf{0.035}$

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)	$A_{bx,req} = 0.2 \times A_{bt,prov} = \mathbf{226 \text{ mm}^2/\text{m}}$
Maximum spacing of reinforcement – cl.9.3.1.1(3)	$s_{bx,max} = \mathbf{450 \text{ mm}}$
Transverse reinforcement provided	$\mathbf{10 \text{ dia.bars @ } 200 \text{ c/c}}$
Area of transverse reinforcement provided	$A_{bx,prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx}) = \mathbf{393 \text{ mm}^2/\text{m}}$

PASS - Area of reinforcement provided is greater than area o

4.2 Gabion Basket Wall

For the proposed car park the back elevation needs a maximum cut of 3500mm to allow pedestrian access from the dwelling to the new car park. Also this allows the finished level to be graded in a much shallow gradient.

Likewise with the masonry wall that no variable loading will be induced on the wall a permanent surcharge of 10kN/m² will be applied

The wall be constructed with the following profile:-

Constructed on a 7 degree angle

Step 1 – Height of 1500mm and thickness of 2000mm

Step 2 – Height of 1000mm and thickness of 1500mm

Step 3 – Height of 1000mm and thickness of 500mm

It will be footed onto a levelling pad comprising of SHW type 1 well graded material, compacted in 150mm thick layers..

From TEDDS Output below the wall is satisfactory. Refer to Drawing C101-C105 inclusive for full construction details

GABION RETAINING WALL ANALYSIS & DESIGN

In accordance with EN 1997-1:2004 - Code of Practice for Geotechnical design and the UK National Annex

Tedds calculation version 2.0.03

Design summary

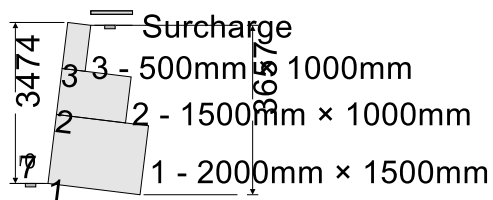
Combination 1

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning, sliding and bearing at base level					
Overturning (kNm/m)	158.1	90.1	1.754	1.000	PASS
Sliding (kN/m)	79.4	65.6	1.211	1.000	PASS
Bearing (kN/m ²)	150.0	133.0	1.128	1.000	PASS
Eccentricity (mm)	Reaction acts within the middle third of base				PASS
Overturning and sliding between courses 1 and 2					
Overturning (kNm/m)	48.8	20.4	2.394	1.000	PASS
Sliding (kN/m)	40.1	25.6	1.564	1.000	PASS
Overturning and sliding between courses 2 and 3					
Overturning (kNm/m)	3.2	2.3	1.395	1.000	PASS
Sliding (kN/m)	7.1	5.4	1.315	1.000	PASS

Combination 2

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning, sliding and bearing at base level					

Action	Resistance	Force	FoS	Allowable FoS	Status
Overturning (kNm/m)	160.9	80.5	1.998	1.000	PASS
Sliding (kN/m)	63.9	56.7	1.126	1.000	PASS
Bearing (kN/m ²)	150.0	133.0	1.128	1.000	PASS
Eccentricity (mm)	Reaction acts within the middle third of base				PASS
Overturning and sliding between courses 1 and 2					
Overturning (kNm/m)	49.7	18.1	2.745	1.000	PASS
Sliding (kN/m)	32.2	21.9	1.469	1.000	PASS
Overturning and sliding between courses 2 and 3					
Overturning (kNm/m)	3.2	2.2	1.440	1.000	PASS
Sliding (kN/m)	5.6	5.1	1.098	1.000	PASS



Wall geometry

Width of gabion 1	$w_1 = 2000$ mm
Height of gabion 1	$h_1 = 1500$ mm
Width of gabion 2	$w_2 = 1500$ mm
Height of gabion 2	$h_2 = 1000$ mm
Step to front face between courses 1 and 2	$s_2 = 0$ mm
Width of gabion 3	$w_3 = 500$ mm
Height of gabion 3	$h_3 = 1000$ mm
Step to front face between courses 2 and 3	$s_3 = 0$ mm
Wall inclination	$\varepsilon = 7$ deg

Gabion properties

Unit weight of fill	$\gamma_d = 16.0$ kN/m ³
Friction between gabions	$\delta_{bg,k} = 35.0$ deg

Loading

Permanent surcharge	$p_{0,G} = 10$ kN/m ²
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Soil properties

Slope of retained soil	$\beta = 0.0$ deg
Characteristic effective shearing resistance angle	$\phi'_{r,k} = 30.0$ deg
Characteristic saturated density of retained soil	$\gamma_{sr} = 21.0$ kN/m ³
Coefficient for wall friction	$k_{membrane} = 0.75$
Wall friction angle	$\delta_{r,k} = 22.5$ deg
Characteristic base friction angle	$\delta_{bb,k} = 30.0$ deg
Bearing capacity of founding soil	$q = 150$ kN/m ²

Wall geometry

Horizontal distance to centre of gravity gabion 1	$x_{g1} = w_1 / 2 = 1000$ mm
Vertical distance to centre of gravity gabion 1	$y_{g1} = h_1 / 2 = 750$ mm
Weight of gabion 1	$W_{g1} = \gamma_d \times w_1 \times h_1 = 48.0$ kN/m
Horizontal distance to centre of gravity gabion 2	$x_{g2} = w_2 / 2 + s_2 = 750$ mm
Vertical distance to centre of gravity gabion 2	$y_{g2} = h_2 / 2 + h_1 = 2000$ mm
Weight of gabion 2	$W_{g2} = \gamma_d \times w_2 \times h_2 = 24.0$ kN/m
Horizontal distance to centre of gravity gabion 3	$x_{g3} = w_3 / 2 + s_2 + s_3 = 250$ mm
Vertical distance to centre of gravity gabion 3	$y_{g3} = h_3 / 2 + h_1 + h_2 = 3000$ mm
Weight of gabion 3	$W_{g3} = \gamma_d \times w_3 \times h_3 = 8.0$ kN/m
Weight of entire gabion	$W_g = W_{g1} + W_{g2} + W_{g3} = 80.0$ kN/m
Horiz distance to centre of gravity entire gabion	$x_g = ((W_{g1} \times x_{g1}) + (W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3})) / W_g = 850$ mm
Vert distance to centre of gravity entire gabion	$y_g = ((W_{g1} \times y_{g1}) + (W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3})) / W_g = 1350$ mm
Correcting for wall inclination horiz dist	$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1008$ mm
Vertical change in height due to wall inclination	$H_f = y_{g3} + h_3/2 - ((y_{g3} + h_3/2) \times \cos(\epsilon) - (x_{g3} + w_3/2) \times \sin(\epsilon)) = 87$ mm

Design dimensions

Effective angle of rear plane of wall	$\alpha = 90\text{deg} - \text{Atan}((w_1 - (x_{g3} + (w_3 / 2))) / (y_{g3} + h_3 / 2)) + \epsilon = 73.8$ deg
Effective face angle	$\theta = 90\text{deg} - \epsilon = 83.0$ deg
Effective height of wall	$H = (y_{g3} + h_3 / 2) + (w_1 \times \sin(\epsilon)) - H_f = 3657$ mm
Height of wall from toe to front edge of top gabion	$H_{incl} = ((y_{g3} + h_3 / 2) \times \cos(\epsilon) - (x_{g3} - (w_3 / 2)) \times \sin(\epsilon)) = 3474$ mm
Active pressure using Coulomb theory	$K_a = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k}) \times (1 + \sqrt{(\sin(\phi'_{r,k} + \delta_{r,k}) \times \sin(\phi'_{r,k} - \beta) / (\sin(\alpha - \delta_{r,k}) \times \sin(\alpha + \beta))}))^2 = 0.439$
Active thrust due to soil	$P_{a,soil} = 0.5 \times K_a \times \gamma_{sr} \times H^2 = 61.6$ kN/m

Pressure at base

Horizontal forces

Retained soil	$F_{soil,h,q} = P_{a,soil} \times \cos(90 - \alpha + \delta_{r,k}) = 48.1$ kN/m
Height of soil thrust resolved vertically	$d_{h,soil} = H / 3 - w_1 \times \sin(\epsilon) = 975$ mm
Surcharge	$F_{surch,h,q} = p_{o,G} \times K_a \times H \times \cos(90 - \alpha + \delta_{r,k}) = 12.5$ kN/m
Height of surcharge thrust resolved vertically	$d_{h,surch} = H / 2 - w_1 \times \sin(\epsilon) = 1585$ mm

Vertical forces

Gabion weight	$F_{gabion,v,q} = W_g = 80.0$ kN/m
Retained soil	$F_{soil,v,q} = P_{a,soil} \times \sin(90 - \alpha + \delta_{r,k}) = 38.5$ kN/m
Horizontal dist to where soil thrust acts	$b_{v,soil} = w_1 \times \cos(\epsilon) - (H / 3) / \tan(\alpha) = 1631$ mm
Surcharge	$F_{surch,v,q} = p_{o,G} \times K_a \times H \times \sin(90 - \alpha + \delta_{r,k}) = 10.0$ kN/m

Horizontal dist to where surcharge thrust acts	$b_{v,surch} = w_1 \times \cos(\varepsilon) - (H / 2) / \tan(\alpha) = \mathbf{1454 \text{ mm}}$
Total horizontal unfactored force	$T_q = F_{soil_h,q} + F_{surch_h,q} = \mathbf{60.6 \text{ kN/m}}$
Total vertical unfactored force	$N_q = F_{gabion_v,q} + F_{soil_v,q} + F_{surch_v,q} = \mathbf{128.6 \text{ kN/m}}$
Force normal to base	$N_s = N_q \times \cos(\varepsilon) + T_q \times \sin(\varepsilon) = \mathbf{135.0 \text{ kN/m}}$
Total unfactored overturning force	$M_{o,q} = F_{soil_h,q} \times d_{h,soil} + F_{surch_h,q} \times d_{h,surch} = \mathbf{66.8 \text{ kNm/m}}$
Total unfactored restoring force	$M_{R,q} = F_{gabion_v,q} \times X_g + F_{soil_v,q} \times b_{v,soil} + F_{surch_v,q} \times b_{v,surch} = \mathbf{158.1 \text{ kNm/m}}$
Eccentricity	$e = w_1 / 2 - (M_{R,q} - M_{o,q}) / N_s = \mathbf{323 \text{ mm}}$
Reaction acts within middle third of base	
Pressure at toe	$\sigma_{toe} = N_s / w_1 \times (1 + (6 \times e / w_1)) = \mathbf{133.0 \text{ kN/m}^2}$
Pressure at heel	$\sigma_{heel} = N_s / w_1 \times (1 - (6 \times e / w_1)) = \mathbf{2.0 \text{ kN/m}^2}$
Factor of safety	$FoS_Q = q / \max(\sigma_{toe}, \sigma_{heel}) = \mathbf{1.128}$
Allowable factor of safety	$FoS_{Q_allow} = \mathbf{1.000}$

PASS - Design FoS for allowable bearing pressure exceeds min allowable pressure to base

Design approach 1

Partial factors on actions - Section A.3.1 - Combination 1

Permanent unfavourable action	$\gamma_G = \mathbf{1.35}$
Permanent favourable action	$\gamma_{G,f} = \mathbf{1.00}$
Variable unfavourable action	$\gamma_Q = \mathbf{1.50}$
Variable favourable action	$\gamma_{Q,f} = \mathbf{0.00}$

Partial factors for soil parameters - Section A.3.2 - Combination 1

Angle of shearing resistance	$\gamma_{\phi'} = \mathbf{1.00}$
Weight density	$\gamma_{\gamma} = \mathbf{1.00}$

Design soil properties

Design effective shearing resistance angle	$\phi'_{r,d} = \text{Atan}(\tan(\phi'_{r,k}) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$
Design saturated density of retained soil	$\gamma_{s,d} = \gamma_{sr} / \gamma_{\gamma} = \mathbf{21.0 \text{ kN/m}^3}$
Design wall friction angle	$\delta_{r,d} = \min(\text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}), \phi'_{r,d} \times k_{\text{membrane}}) = \mathbf{22.5 \text{ deg}}$
Design base friction angle	$\delta_{bb,d} = \text{Atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = \mathbf{30.0 \text{ deg}}$
Design friction between gabions	$\delta_{bg,d} = \text{Atan}(\tan(\delta_{bg,k}) / \gamma_{\phi'}) = \mathbf{35.0 \text{ deg}}$
Active pressure using Coulomb theory	$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))))^2) = \mathbf{0.439}$
Active thrust due to soil	$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{61.6 \text{ kN/m}}$

Horizontal forces

Retained soil	$F_{soil_h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{65.0 \text{ kN/m}}$
Surcharge	$F_{surch_h} = p_{o,G} \times \gamma_G \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{16.9 \text{ kN/m}}$

Vertical forces

Gabion weight	$F_{gabion_v,f} = \gamma_{G,f} \times W_g = \mathbf{80.0 \text{ kN/m}}$
Retained soil	$F_{soil_v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{38.5 \text{ kN/m}}$
Surcharge	$F_{surch_v,f} = p_{o,G} \times \gamma_{G,f} \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{10.0 \text{ kN/m}}$

Overturning stability - take moments about the toe

Overturning moment	$M_o = F_{soil_h} \times d_{h,soil} + F_{surch_h} \times d_{h,surch} = \mathbf{90.1 \text{ kNm/m}}$
Restoring moment	$M_R = F_{gabion_v,f} \times X_g + F_{soil_v,f} \times b_{v,soil} + F_{surch_v,f} \times b_{v,surch} = \mathbf{158.1 \text{ kNm/m}}$
Factor of safety	$FoS_M = M_R / M_o = \mathbf{1.754}$

Allowable factor of safety

$$FoS_{M_allow} = 1.000$$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force

$$T = F_{soil_h} + F_{surch_h} = 81.9 \text{ kN/m}$$

Total vertical force

$$N = F_{gabion_v,f} + F_{soil_v,f} + F_{surch_v,f} = 128.6 \text{ kN/m}$$

Sliding force

$$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon) = 65.6 \text{ kN/m}$$

Sliding resistance

$$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bb,d}) = 79.4 \text{ kN/m}$$

Factor of safety

$$FoS_S = F_R / F_f = 1.211$$

Allowable factor of safety

$$FoS_{S_allow} = 1.000$$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Check overturning and sliding between courses 1 and 2

Wall geometry

Horizontal distance to centre of gravity gabion 2

$$x_{g2} = w_2 / 2 = 750 \text{ mm}$$

Vertical distance to centre of gravity gabion 2

$$y_{g2} = h_2 / 2 = 500 \text{ mm}$$

Weight of gabion 2

$$W_{g2} = \gamma_d \times w_2 \times h_2 = 24.0 \text{ kN/m}$$

Horizontal distance to centre of gravity gabion 3

$$x_{g3} = w_3 / 2 + s_3 = 250 \text{ mm}$$

Vertical distance to centre of gravity gabion 3

$$y_{g3} = h_3 / 2 + h_2 = 1500 \text{ mm}$$

Weight of gabion 3

$$W_{g3} = \gamma_d \times w_3 \times h_3 = 8.0 \text{ kN/m}$$

Weight of entire gabion

$$W_g = W_{g2} + W_{g3} = 32.0 \text{ kN/m}$$

Horiz distance to centre of gravity entire gabion

$$x_g = ((W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3})) / W_g = 625 \text{ mm}$$

Vert distance to centre of gravity entire gabion

$$y_g = ((W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3})) / W_g = 750 \text{ mm}$$

Correcting for wall inclination horiz dist

$$X_g = x_g \times \cos(\varepsilon) + y_g \times \sin(\varepsilon) = 712 \text{ mm}$$

Vertical change in height due to wall inclination

$$H_f = y_{g3} + h_3/2 - ((y_{g3} + h_3/2) \times \cos(\varepsilon) - (x_{g3} + w_3/2) \times \sin(\varepsilon)) = 76 \text{ mm}$$

Design dimensions

Effective angle of rear plane of wall

$$\alpha = 90\text{deg} - \text{Atan}((w_2 - (x_{g3} + (w_3 / 2))) / (y_{g3} + h_3 / 2)) + \varepsilon = 70.4 \text{ deg}$$

Effective face angle

$$\theta = 90\text{deg} - \varepsilon = 83.0 \text{ deg}$$

Effective height of wall

$$H = (y_{g3} + h_3 / 2) + (w_2 \times \sin(\varepsilon)) - H_f = 2107 \text{ mm}$$

Height of wall from toe to front edge of top gabion

$$H_{incl} = ((y_{g3} + h_3 / 2) \times \cos(\varepsilon) - (x_{g3} - (w_3 / 2)) \times \sin(\varepsilon)) = 1985 \text{ mm}$$

Active pressure using Coulomb theory

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta)))^2}) = 0.477$$

Active thrust due to soil

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 22.3 \text{ kN/m}$$

Horizontal forces

Retained soil

$$F_{soil_h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 22.3 \text{ kN/m}$$

Surcharge

$$F_{surch_h} = p_{o,G} \times \gamma_G \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 10.1 \text{ kN/m}$$

Vertical forces

Gabion weight

$$F_{gabion_v,f} = \gamma_{G,f} \times W_g = 32.0 \text{ kN/m}$$

Retained soil

$$F_{soil_v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 14.9 \text{ kN/m}$$

Surcharge

$$F_{surch_v,f} = p_{o,G} \times \gamma_{G,f} \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 6.7 \text{ kN/m}$$

Overturning stability - take moments about the toe

Overturning moment

$$M_o = F_{soil_h} \times d_{h,soil} + F_{surch_h} \times d_{h,surch} = 20.4 \text{ kNm/m}$$

Restoring moment	$M_R = F_{gabion_v,f} \times X_g + F_{soil_v,f} \times b_{v,soil} + F_{surch_v,f} \times b_{v,surch} =$ 48.8 kNm/m
Factor of safety	$FoSM = M_R / M_o =$ 2.394
Allowable factor of safety	$FoSM_{allow} =$ 1.000

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force	$T = F_{soil_h} + F_{surch_h} =$ 32.4 kN/m
Total vertical force	$N = F_{gabion_v,f} + F_{soil_v,f} + F_{surch_v,f} =$ 53.7 kN/m
Sliding force	$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon) =$ 25.6 kN/m
Sliding resistance	$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bg,d}) =$ 40.1 kN/m
Factor of safety	$FoSS = F_R / F_f =$ 1.564
Allowable factor of safety	$FoSS_{allow} =$ 1.000

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Check overturning and sliding between courses 2 and 3

Wall geometry

Horizontal distance to centre of gravity gabion 3	$x_{g3} = w_3 / 2 =$ 250 mm
Vertical distance to centre of gravity gabion 3	$y_{g3} = h_3 / 2 =$ 500 mm
Weight of gabion 3	$W_{g3} = \gamma_d \times w_3 \times h_3 =$ 8.0 kN/m
Weight of entire gabion	$W_g = W_{g3} =$ 8.0 kN/m
Horiz distance to centre of gravity entire gabion	$x_g = ((W_{g3} \times x_{g3})) / W_g =$ 250 mm
Vert distance to centre of gravity entire gabion	$y_g = ((W_{g3} \times y_{g3})) / W_g =$ 500 mm
Correcting for wall inclination horiz dist	$X_g = x_g \times \cos(\varepsilon) + y_g \times \sin(\varepsilon) =$ 309 mm
Vertical change in height due to wall inclination	$H_f = y_{g3} + h_3/2 - ((y_{g3} + h_3/2) \times \cos(\varepsilon) - (x_{g3} + w_3/2) \times \sin(\varepsilon)) =$ 68 mm

Design dimensions

Effective angle of rear plane of wall	$\alpha = 90 \text{ deg} + \varepsilon =$ 97.0 deg
Effective face angle	$\theta = 90 \text{ deg} - \varepsilon =$ 83.0 deg
Effective height of wall	$H = (y_{g3} + h_3 / 2) + (w_3 \times \sin(\varepsilon)) - H_f =$ 993 mm
Height of wall from toe to front edge of top gabion	$H_{incl} = ((y_{g3} + h_3 / 2) \times \cos(\varepsilon) - (x_{g3} - (w_3 / 2)) \times \sin(\varepsilon)) =$ 993mm
Active pressure using Coulomb theory	$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d}) + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))})^2) =$ 0.249
Active thrust due to soil	$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 =$ 2.6 kN/m

Horizontal forces

Retained soil	$F_{soil_h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) =$ 3.3 kN/m
Surcharge	$F_{surch_h} = p_{o,G} \times \gamma_G \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) =$ 3.2 kN/m

Vertical forces

Gabion weight	$F_{gabion_v,f} = \gamma_{G,f} \times W_g =$ 8.0 kN/m
Retained soil	$F_{soil_v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) =$ 0.7 kN/m
Surcharge	$F_{surch_v,f} = p_{o,G} \times \gamma_{G,f} \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) =$ 0.7 kN/m

Overturning stability - take moments about the toe

Overturning moment	$M_o = F_{soil_h} \times d_{h,soil} + F_{surch_h} \times d_{h,surch} =$ 2.3 kNm/m
Restoring moment	$M_R = F_{gabion_v,f} \times X_g + F_{soil_v,f} \times b_{v,soil} + F_{surch_v,f} \times b_{v,surch} =$ 3.2 kNm/m

Factor of safety	$FoS_M = M_R / M_o = \mathbf{1.395}$
Allowable factor of safety	$FoS_{M_allow} = \mathbf{1.000}$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force	$T = F_{soil_h} + F_{surch_h} = \mathbf{6.6 \text{ kN/m}}$
Total vertical force	$N = F_{gabion_v,f} + F_{soil_v,f} + F_{surch_v,f} = \mathbf{9.3 \text{ kN/m}}$
Sliding force	$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = \mathbf{5.4 \text{ kN/m}}$
Sliding resistance	$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = \mathbf{7.1 \text{ kN/m}}$
Factor of safety	$FoS_S = F_R / F_f = \mathbf{1.315}$
Allowable factor of safety	$FoS_{S_allow} = \mathbf{1.000}$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Design approach 1

Partial factors on actions - Section A.3.1 - Combination 2

Permanent unfavourable action	$\gamma_G = \mathbf{1.00}$
Permanent favourable action	$\gamma_{G,f} = \mathbf{1.00}$
Variable unfavourable action	$\gamma_Q = \mathbf{1.30}$
Variable favourable action	$\gamma_{Q,f} = \mathbf{0.00}$

Partial factors for soil parameters - Section A.3.2 - Combination 2

Angle of shearing resistance	$\gamma_{\phi'} = \mathbf{1.25}$
Weight density	$\gamma_{\gamma} = \mathbf{1.00}$

Design soil properties

Design effective shearing resistance angle	$\phi'_{r,d} = \text{Atan}(\tan(\phi'_{r,k}) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$
Design saturated density of retained soil	$\gamma_{s,d} = \gamma_{sr} / \gamma_{\gamma} = \mathbf{21.0 \text{ kN/m}^3}$
Design wall friction angle	$\delta_{r,d} = \min(\text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi'}), \phi'_{r,d} \times k_{\text{membrane}}) = \mathbf{18.3 \text{ deg}}$
Design base friction angle	$\delta_{bb,d} = \text{Atan}(\tan(\delta_{bb,k}) / \gamma_{\phi'}) = \mathbf{24.8 \text{ deg}}$
Design friction between gabions	$\delta_{bg,d} = \text{Atan}(\tan(\delta_{bg,k}) / \gamma_{\phi'}) = \mathbf{29.3 \text{ deg}}$

Wall geometry

Horizontal distance to centre of gravity gabion 1	$x_{g1} = w_1 / 2 = \mathbf{1000 \text{ mm}}$
Vertical distance to centre of gravity gabion 1	$y_{g1} = h_1 / 2 = \mathbf{750 \text{ mm}}$
Weight of gabion 1	$W_{g1} = \gamma_d \times w_1 \times h_1 = \mathbf{48.0 \text{ kN/m}}$
Horizontal distance to centre of gravity gabion 2	$x_{g2} = w_2 / 2 + s_2 = \mathbf{750 \text{ mm}}$
Vertical distance to centre of gravity gabion 2	$y_{g2} = h_2 / 2 + h_1 = \mathbf{2000 \text{ mm}}$
Weight of gabion 2	$W_{g2} = \gamma_d \times w_2 \times h_2 = \mathbf{24.0 \text{ kN/m}}$
Horizontal distance to centre of gravity gabion 3	$x_{g3} = w_3 / 2 + s_2 + s_3 = \mathbf{250 \text{ mm}}$
Vertical distance to centre of gravity gabion 3	$y_{g3} = h_3 / 2 + h_1 + h_2 = \mathbf{3000 \text{ mm}}$
Weight of gabion 3	$W_{g3} = \gamma_d \times w_3 \times h_3 = \mathbf{8.0 \text{ kN/m}}$
Weight of entire gabion	$W_g = W_{g1} + W_{g2} + W_{g3} = \mathbf{80.0 \text{ kN/m}}$
Horiz distance to centre of gravity entire gabion	$x_g = ((W_{g1} \times x_{g1}) + (W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3})) / W_g = \mathbf{850 \text{ mm}}$
Vert distance to centre of gravity entire gabion	$y_g = ((W_{g1} \times y_{g1}) + (W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3})) / W_g = \mathbf{1350 \text{ mm}}$
Correcting for wall inclination horiz dist	$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = \mathbf{1008 \text{ mm}}$
Vertical change in height due to wall inclination	$H_f = y_{g3} + h_3/2 - ((y_{g3} + h_3/2) \times \cos(\epsilon) - (x_{g3} + w_3/2) \times \sin(\epsilon)) = \mathbf{87 \text{ mm}}$

Design dimensions

Effective angle of rear plane of wall	$\alpha = 90\text{deg} - \text{Atan}((w_1 - (x_{g3} + (w_3 / 2))) / (y_{g3} + h_3 / 2)) + \epsilon = \mathbf{73.8 \text{ deg}}$
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Effective face angle	$\theta = 90\text{deg} - \varepsilon = \mathbf{83.0\ deg}$
Effective height of wall	$H = (y_{g3} + h_3 / 2) + (w_1 \times \sin(\varepsilon)) - H_f = \mathbf{3657\ mm}$
Height of wall from toe to front edge of top gabion	$H_{incl} = ((y_{g3} + h_3 / 2) \times \cos(\varepsilon) - (x_{g3} - (w_3 / 2))) \times \sin(\varepsilon) = \mathbf{3474\ mm}$
Active pressure using Coulomb theory	$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d} + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))}))^2 = \mathbf{0.501}$
Active thrust due to soil	$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{70.4\ kN/m}$

Horizontal forces

Retained soil	$F_{soil_h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{58.0\ kN/m}$
Surcharge	$F_{surch_h} = p_{o,G} \times \gamma_G \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{15.1\ kN/m}$

Vertical forces

Gabion weight	$F_{gabion_v,f} = \gamma_{G,f} \times W_g = \mathbf{80.0\ kN/m}$
Retained soil	$F_{soil_v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{39.9\ kN/m}$
Surcharge	$F_{surch_v,f} = p_{o,G} \times \gamma_{G,f} \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{10.4\ kN/m}$

Overturning stability - take moments about the toe

Overturning moment	$M_o = F_{soil_h} \times d_{h,soil} + F_{surch_h} \times d_{h,surch} = \mathbf{80.5\ kNm/m}$
Restoring moment	$M_R = F_{gabion_v,f} \times X_g + F_{soil_v,f} \times b_{v,soil} + F_{surch_v,f} \times b_{v,surch} = \mathbf{160.9\ kNm/m}$
Factor of safety	$FoSM = M_R / M_o = \mathbf{1.998}$
Allowable factor of safety	$FoSM_{allow} = \mathbf{1.000}$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force	$T = F_{soil_h} + F_{surch_h} = \mathbf{73.1\ kN/m}$
Total vertical force	$N = F_{gabion_v,f} + F_{soil_v,f} + F_{surch_v,f} = \mathbf{130.3\ kN/m}$
Sliding force	$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon) = \mathbf{56.7\ kN/m}$
Sliding resistance	$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bb,d}) = \mathbf{63.9\ kN/m}$
Factor of safety	$FoSS = F_R / F_f = \mathbf{1.126}$
Allowable factor of safety	$FoSS_{allow} = \mathbf{1.000}$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Check overturning and sliding between courses 1 and 2

Wall geometry

Horizontal distance to centre of gravity gabion 2	$x_{g2} = w_2 / 2 = \mathbf{750\ mm}$
Vertical distance to centre of gravity gabion 2	$y_{g2} = h_2 / 2 = \mathbf{500\ mm}$
Weight of gabion 2	$W_{g2} = \gamma_d \times w_2 \times h_2 = \mathbf{24.0\ kN/m}$
Horizontal distance to centre of gravity gabion 3	$x_{g3} = w_3 / 2 + s_3 = \mathbf{250\ mm}$
Vertical distance to centre of gravity gabion 3	$y_{g3} = h_3 / 2 + h_2 = \mathbf{1500\ mm}$
Weight of gabion 3	$W_{g3} = \gamma_d \times w_3 \times h_3 = \mathbf{8.0\ kN/m}$
Weight of entire gabion	$W_g = W_{g2} + W_{g3} = \mathbf{32.0\ kN/m}$
Horiz distance to centre of gravity entire gabion	$X_g = ((W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3})) / W_g = \mathbf{625\ mm}$
Vert distance to centre of gravity entire gabion	$y_g = ((W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3})) / W_g = \mathbf{750\ mm}$
Correcting for wall inclination horiz dist	$X_g = x_g \times \cos(\varepsilon) + y_g \times \sin(\varepsilon) = \mathbf{712\ mm}$
Vertical change in height due to wall inclination	$H_f = y_{g3} + h_3/2 - ((y_{g3} + h_3/2) \times \cos(\varepsilon) - (x_{g3} + w_3/2) \times \sin(\varepsilon)) = \mathbf{76\ mm}$

Design dimensions

Effective angle of rear plane of wall	$\alpha = 90\text{deg} - \text{Atan}((w_2 - (x_{g3} + (w_3 / 2))) / (y_{g3} + h_3 / 2)) + \varepsilon$ = 70.4 deg
Effective face angle	$\theta = 90\text{deg} - \varepsilon = \mathbf{83.0\ deg}$
Effective height of wall	$H = (y_{g3} + h_3 / 2) + (w_2 \times \sin(\varepsilon)) - H_f = \mathbf{2107\ mm}$
Height of wall from toe to front edge of top gabion	$H_{\text{incl}} = ((y_{g3} + h_3 / 2) \times \cos(\varepsilon) - (x_{g3} - (w_3 / 2)) \times \sin(\varepsilon)) = \mathbf{1985\text{mm}}$
Active pressure using Coulomb theory	$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d}) + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))})^2) = \mathbf{0.539}$
Active thrust due to soil	$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{25.1\ kN/m}$

Horizontal forces

Retained soil	$F_{\text{soil}_h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{19.8\ kN/m}$
Surcharge	$F_{\text{surch}_h} = p_{o,G} \times \gamma_G \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{9.0\ kN/m}$

Vertical forces

Gabion weight	$F_{\text{gabion}_v,f} = \gamma_{G,f} \times W_g = \mathbf{32.0\ kN/m}$
Retained soil	$F_{\text{soil}_v,f} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{15.4\ kN/m}$
Surcharge	$F_{\text{surch}_v,f} = p_{o,G} \times \gamma_{G,f} \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{7.0\ kN/m}$

Overturning stability - take moments about the toe

Overturning moment	$M_o = F_{\text{soil}_h} \times d_{h,\text{soil}} + F_{\text{surch}_h} \times d_{h,\text{surch}} = \mathbf{18.1\ kNm/m}$
Restoring moment	$M_R = F_{\text{gabion}_v,f} \times X_g + F_{\text{soil}_v,f} \times b_{v,\text{soil}} + F_{\text{surch}_v,f} \times b_{v,\text{surch}} = \mathbf{49.7\ kNm/m}$
Factor of safety	$FoS_M = M_R / M_o = \mathbf{2.745}$
Allowable factor of safety	$FoS_{M,\text{allow}} = \mathbf{1.000}$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force	$T = F_{\text{soil}_h} + F_{\text{surch}_h} = \mathbf{28.8\ kN/m}$
Total vertical force	$N = F_{\text{gabion}_v,f} + F_{\text{soil}_v,f} + F_{\text{surch}_v,f} = \mathbf{54.4\ kN/m}$
Sliding force	$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon) = \mathbf{21.9\ kN/m}$
Sliding resistance	$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bg,d}) = \mathbf{32.2\ kN/m}$
Factor of safety	$FoS_S = F_R / F_f = \mathbf{1.469}$
Allowable factor of safety	$FoS_{S,\text{allow}} = \mathbf{1.000}$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding

Check overturning and sliding between courses 2 and 3

Wall geometry

Horizontal distance to centre of gravity gabion 3	$x_{g3} = w_3 / 2 = \mathbf{250\ mm}$
Vertical distance to centre of gravity gabion 3	$y_{g3} = h_3 / 2 = \mathbf{500\ mm}$
Weight of gabion 3	$W_{g3} = \gamma_d \times w_3 \times h_3 = \mathbf{8.0\ kN/m}$
Weight of entire gabion	$W_g = W_{g3} = \mathbf{8.0\ kN/m}$
Horiz distance to centre of gravity entire gabion	$x_g = ((W_{g3} \times x_{g3})) / W_g = \mathbf{250\ mm}$
Vert distance to centre of gravity entire gabion	$y_g = ((W_{g3} \times y_{g3})) / W_g = \mathbf{500\ mm}$
Correcting for wall inclination horiz dist	$X_g = x_g \times \cos(\varepsilon) + y_g \times \sin(\varepsilon) = \mathbf{309\ mm}$
Vertical change in height due to wall inclination	$H_f = y_{g3} + h_3/2 - ((y_{g3} + h_3/2) \times \cos(\varepsilon) - (x_{g3} + w_3/2) \times \sin(\varepsilon)) = \mathbf{68\ mm}$

Design dimensions

Effective angle of rear plane of wall

$$\alpha = 90 \text{ deg} + \varepsilon = \mathbf{97.0 \text{ deg}}$$

Effective face angle

$$\theta = 90 \text{ deg} - \varepsilon = \mathbf{83.0 \text{ deg}}$$

Effective height of wall

$$H = (y_{g3} + h_3 / 2) + (w_3 \times \sin(\varepsilon)) - H_f = \mathbf{993 \text{ mm}}$$

Height of wall from toe to front edge of top gabion

$$H_{\text{incl}} = ((y_{g3} + h_3 / 2) \times \cos(\varepsilon) - (x_{g3} - (w_3 / 2)) \times \sin(\varepsilon)) = \mathbf{993 \text{ mm}}$$

Active pressure using Coulomb theory

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d}) \times (1 + \sqrt{(\sin(\phi'_{r,d}) + \delta_{r,d}) \times \sin(\phi'_{r,d} - \beta) / (\sin(\alpha - \delta_{r,d}) \times \sin(\alpha + \beta))})^2) = \mathbf{0.314}$$

Active thrust due to soil

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{3.3 \text{ kN/m}}$$

Horizontal forces

Retained soil

$$F_{\text{soil}_h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{3.2 \text{ kN/m}}$$

Surcharge

$$F_{\text{surch}_h} = p_{o,G} \times \gamma_G \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{3.1 \text{ kN/m}}$$

Vertical forces

Gabion weight

$$F_{\text{gabion}_v,f} = \gamma_{G,f} \times W_g = \mathbf{8.0 \text{ kN/m}}$$

Retained soil

$$F_{\text{soil}_v,f} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{0.6 \text{ kN/m}}$$

Surcharge

$$F_{\text{surch}_v,f} = p_{o,G} \times \gamma_{G,f} \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{0.6 \text{ kN/m}}$$

Overturning stability - take moments about the toe

Overturning moment

$$M_o = F_{\text{soil}_h} \times d_{h,\text{soil}} + F_{\text{surch}_h} \times d_{h,\text{surch}} = \mathbf{2.2 \text{ kNm/m}}$$

Restoring moment

$$M_R = F_{\text{gabion}_v,f} \times X_g + F_{\text{soil}_v,f} \times b_{v,\text{soil}} + F_{\text{surch}_v,f} \times b_{v,\text{surch}} = \mathbf{3.2 \text{ kNm/m}}$$

Factor of safety

$$FoS_M = M_R / M_o = \mathbf{1.440}$$

Allowable factor of safety

$$FoS_{M,\text{allow}} = \mathbf{1.000}$$

PASS - Design FOS for overturning exceeds min allowable FOS for overturning

Sliding stability - ignore any passive pressure in front of the structure

Total horizontal force

$$T = F_{\text{soil}_h} + F_{\text{surch}_h} = \mathbf{6.2 \text{ kN/m}}$$

Total vertical force

$$N = F_{\text{gabion}_v,f} + F_{\text{soil}_v,f} + F_{\text{surch}_v,f} = \mathbf{9.3 \text{ kN/m}}$$

Sliding force

$$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon) = \mathbf{5.1 \text{ kN/m}}$$

Sliding resistance

$$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bg,d}) = \mathbf{5.6 \text{ kN/m}}$$

Factor of safety

$$FoS_S = F_R / F_f = \mathbf{1.098}$$

Allowable factor of safety

$$FoS_{S,\text{allow}} = \mathbf{1.000}$$

PASS - Design FOS for sliding exceeds min allowable FOS for sliding