

CONDITION & DILAPIDATIONS REPORT

OF

Retaining Wall

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REPORT OF

Ashley France

DATED

22<sup>nd</sup> November 2022

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On instructions of : Rafeen Bi

Reference : 20750

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## 1 Introduction

### 1.1 Formal details

- 1 I am Ashley France. I am Managing Director of Batty France Ltd, 1 Rosse Street, Shipley, Bradford BD18 3SX, Chartered Quantity Surveyors and Chartered Building Consultants.

### 1.2 Instructions

- 1 Instructions were given to me by Mr I and Mrs R Bi
- 2 My instructions are to carry out a survey of a newly constructed retaining wall to the south/west side of the property and provide a Condition and Dilapidations Report
- 3 The principal purpose is to record the Condition of the retaining wall which supports the property's garden and driveway

### 1.3 Site inspection

- 1 I or my colleagues carried out site inspections on the following dates, namely:
  - a. 13<sup>th</sup> October 2021; and
  - b. 18<sup>th</sup> October 2021; and
  - c. 24<sup>th</sup> November 2021; and

### 1.4 Limitations

- 1 Inspection was visual and non-intrusive
- 2 I was provided with the documents as recorded in Section 3

### 1.5 Disclosure

- 1 I have no connection with any of the parties in this matter.

## 2 Description

### 2.1 Site

- 1 The site in question is on an elevated platform over off Upper Brow Road, in Huddersfield
- 2 The site is south of a main train line from the West into Huddersfield City Centre
- 3 The site comprises a large irregularly shaped plot containing a stone-built detached dwelling and single car garage with associated tarmacked driveway, other external paving and immature gardens
- 4 The pertinent site boundary to the south / south-west backs on to brownfield site to a lower level, approx. 4m below. The land on this boundary edge is now retained by a substantial stone-filled gabion basket retaining wall
- 5 The most southerly portion of the gabion retaining wall is approx 4m high, from the base of the adjacent site, approx 22m long. On top of this gabion basket wall is an earth bund of approx 1.8m, sloped and shaped into the site
- 6 The south-westerly portion of the gabion retaining wall is a reducing height 3.5m high reducing to zero, from the upper part of an existing stone wall] of the adjacent site, over approx 30m
- 7 In restriction, there is a new approx 1.8m high timber slatted fence erected. This fence is based at the top of the earth bund on timber posts on the southerly boundary and atop of the existing gabion wall adjoining the south-westerly portion

## 2.2 Retaining Structure; Design

- 1 The design intent is as described in Elysium Structures details as follows:
  - a. Drawing ref ES453-01rD
  - b. Design Calculations, planned [11 pgs]
  - c. Design Calculations, as-built [8 pgs]
- 2 Intended / as-built commentary:
  - a. Intended: A 300mm sloping [to an 8deg slope] RC concrete base to be constructed as formation to the gabion basket retaining wall  
Actual: Same to a 3deg slope
  - b. Intended / Actual: a 4500mm thick gabion basket base, in a single layer, rubble filled; on which was to be placed
  - c. Intended / Actual: a 3000mm thick 2<sup>nd</sup> layer gabion basket, in a single layer, rubble filled; on which was to be placed
  - d. Intended / Actual: a 2500mm thick 3<sup>rd</sup> layer gabion basket, in a single layer, rubble filled; on which was to be placed
  - e. Intended / Actual: a final 2000mm thick 4<sup>th</sup> layer gabion basket, in a single layer, rubble filled
  - f. Intended: the outward face of the gabion baskets was to be sloped inwards to an 8 deg angle  
Actual: Same to a 3 deg angle
  - g. Intended / Actual: behind the gabion basket construction was to be generally backfilled with granular material to min 40mm particle size
  - h. Intended: on top of the 4<sup>th</sup> layer of gabion basket, from the rear face of the basket, there was to be constructed an earth bund at a 70-degree max angle comprising Terramesh brackets at 760mm intervals backfilled behind with granular material to min 40mm particle size. The bund was to be faced with well compacted structural fil, base of batter to be set at approx 50/50 point of top gabion basket
  - i. Actual: Same but base of batter is set at front edge of top gabion basket, the earth bund is now covered in a mature layer of grass / vegetation and soil

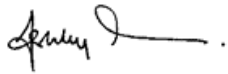
3 Other Information, I understand that

- a. Richard Williams of Williams Walling Ltd<sup>1</sup> undertook the construction works on site
- b. Williams Walling Ltd constructed the gabion basket wall using the Maccaferri Limited gabion walling solution.

**Prepared by**

Ashley France

BSc [HONS] MSc MRICS FCIoB MSoEW FQSi FInstCPD  
MCIArb



Date: 22<sup>nd</sup> November 2022

### 3 Documents Reviewed

Elysium Structures	ES453.01D Gabion Basket Layout ES453 Design Calculations ES453 Design Calculations, as built
Kirklees Council	Planning Application dated 16 <sup>th</sup> April 2021 ref 2021/91604 Planning Application dated 16 <sup>th</sup> April 2021 ref 2021/91795
Sk Drawings	2709 [100] 01 Proposed Site Plan & Site Section 2709 [100] 02 Location Plan 2709 [100] 03 Proposed Rear Elevation

## 4 Photographic Record



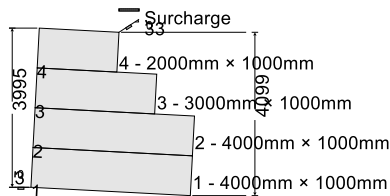
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Project		115 Upperbrow Lane, Huddersfield		Job Ref.		ES453	
Section				Gabion Basket Retaining Wall Insitu			
Sheet no./rev.							
Calc. by	Date	Chk'd by	Date	App'd by	Date		
SB	22/08/22	SB	22/08/22				

**GABION RETAINING WALL ANALYSIS & DESIGN**

In accordance with BS8002:2015 - Code of Practice for Earth Retaining Structures and the UK National Annex

Tedds calculation version 2.0.01



**Wall geometry**

Width of gabion 1	$W_1 = 4000$ mm
Height of gabion 1	$h_1 = 1000$ mm
Width of gabion 2	$W_2 = 4000$ 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	$W_3 = 3000$ mm
Height of gabion 3	$h_3 = 1000$ mm
Step to front face between courses 2 and 3	$S_3 = 0$ mm
Width of gabion 4	$W_4 = 2000$ mm
Height of gabion 4	$h_4 = 1000$ mm
Step to front face between courses 3 and 4	$S_4 = 0$ mm
Wall inclination	$\epsilon = 3$ deg

**Gabion properties**

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

**Loading**

Permanent surcharge	$p_{o,G} = 5$ kN/m <sup>2</sup>
Variable surcharge	$p_{o,Q} = 3$ kN/m <sup>2</sup>

**Soil properties**

Slope of retained soil	$\beta = 33.0$ deg
Characteristic peak shearing resistance angle	$\phi'_{pk,k} = 26.0$ deg
Characteristic saturated density of retained soil	$\gamma_{sr} = 14.0$ kN/m <sup>3</sup>
Coefficient for wall friction	$k_{membrane} = 0.75$
Wall friction angle	$\delta_{r,k} = 19.5$ deg
Characteristic base friction angle	$\delta_{bb,k} = 30.0$ deg
Bearing capacity of founding soil	$q = 200$ kN/m <sup>2</sup>

**Wall geometry**

Horizontal distance to centre of gravity gabion 1	$x_{g1} = W_1 / 2 = 2000$ mm
Vertical distance to centre of gravity gabion 1	$y_{g1} = h_1 / 2 = 500$ mm
Weight of gabion 1	$W_{g1} = \gamma_d \times W_1 \times h_1 = 64.0$ kN/m
Horizontal distance to centre of gravity gabion 2	$x_{g2} = W_2 / 2 + S_2 = 2000$ mm
Vertical distance to centre of gravity gabion 2	$y_{g2} = h_2 / 2 + h_1 = 1500$ mm
Weight of gabion 2	$W_{g2} = \gamma_d \times W_2 \times h_2 = 64.0$ kN/m
Horizontal distance to centre of gravity gabion 3	$x_{g3} = W_3 / 2 + S_2 + S_3 = 1500$ mm



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Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$y_{g3} = h_3 / 2 + h_1 + h_2 = \mathbf{2500 \text{ mm}}$$

$$W_{g3} = \gamma_d \times W_3 \times h_3 = \mathbf{48.0 \text{ kN/m}}$$

$$x_{g4} = W_4 / 2 + S_2 + S_3 + S_4 = \mathbf{1000 \text{ mm}}$$

$$y_{g4} = h_4 / 2 + h_1 + h_2 + h_3 = \mathbf{3500 \text{ mm}}$$

$$W_{g4} = \gamma_d \times W_4 \times h_4 = \mathbf{32.0 \text{ kN/m}}$$

$$W_g = W_{g1} + W_{g2} + W_{g3} + W_{g4} = \mathbf{208.0 \text{ kN/m}}$$

$$x_g = ((W_{g1} \times x_{g1}) + (W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4})) / W_g = \mathbf{1731 \text{ mm}}$$

$$y_g = ((W_{g1} \times y_{g1}) + (W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4})) / W_g = \mathbf{1731 \text{ mm}}$$

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = \mathbf{1819 \text{ mm}}$$

$$H_f = y_{g4} + h_4/2 - ((y_{g4} + h_4/2) \times \cos(\epsilon)) - (x_{g4} + w_4/2) \times \sin(\epsilon) = \mathbf{110 \text{ mm}}$$

#### Design dimensions

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((w_1 - (x_{g4} + (w_4 / 2))) / (y_{g4} + h_4 / 2)) + \epsilon = \mathbf{66.4 \text{ deg}}$$

$$\theta = 90\text{deg} - \epsilon = \mathbf{87.0 \text{ deg}}$$

$$H = (y_{g4} + h_4 / 2) + (w_1 \times \sin(\epsilon)) - H_f = \mathbf{4099 \text{ mm}}$$

$$H_{\text{incl}} = ((y_{g4} + h_4 / 2) \times \cos(\epsilon)) - (x_{g4} - (w_4 / 2)) \times \sin(\epsilon) = \mathbf{3995 \text{ mm}}$$

$$K_a = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta'_{r,k})) = \mathbf{1.626}$$

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{\text{sr}} \times H^2 = \mathbf{191.3 \text{ kN/m}}$$

$$p_{o,\text{min}} = \min(H / H_{\text{ref}}, 1) \times q_{d,\text{min}} = \mathbf{10.0 \text{ kN/m}^2}$$

#### Pressure at base

##### Horizontal forces

Retained soil  
Height of soil thrust resolved vertically  
Surcharge  
Height of surcharge thrust resolved vertically

$$F_{\text{soil},h,q} = P_{a,\text{soil}} \times \cos(90 - \alpha + \delta'_{r,k}) = \mathbf{139.7 \text{ kN/m}}$$

$$d_{h,\text{soil}} = H / 3 - w_1 \times \sin(\epsilon) = \mathbf{1157 \text{ mm}}$$

$$F_{\text{surch},h,q} = \max((p_{o,G} + p_{o,Q}), p_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta'_{r,k}) = \mathbf{48.7 \text{ kN/m}}$$

$$d_{h,\text{surch}} = H / 2 - w_1 \times \sin(\epsilon) = \mathbf{1840 \text{ mm}}$$

##### Vertical forces

Gabion weight  
Retained soil  
Horizontal dist to where soil thrust acts  
Surcharge  
Horizontal dist to where surcharge thrust acts  
Total horizontal unfactored force  
Total vertical unfactored force  
Force normal to base  
Total unfactored overturning force  
Total unfactored restoring force  
Eccentricity

$$F_{\text{gabion},v,q} = W_g = \mathbf{208.0 \text{ kN/m}}$$

$$F_{\text{soil},v,q} = P_{a,\text{soil}} \times \sin(90 - \alpha + \delta'_{r,k}) = \mathbf{130.6 \text{ kN/m}}$$

$$b_{v,\text{soil}} = w_1 \times \cos(\epsilon) - (H / 3) / \tan(\alpha) = \mathbf{3399 \text{ mm}}$$

$$F_{\text{surch},v,q} = \max((p_{o,G} + p_{o,Q}), p_{o,\text{min}}) \times K_a \times H \times \sin(90 - \alpha + \delta'_{r,k}) = \mathbf{45.5 \text{ kN/m}}$$

$$b_{v,\text{surch}} = w_1 \times \cos(\epsilon) - (H / 2) / \tan(\alpha) = \mathbf{3101 \text{ mm}}$$

$$T_q = F_{\text{soil},h,q} + F_{\text{surch},h,q} = \mathbf{188.4 \text{ kN/m}}$$

$$N_q = F_{\text{gabion},v,q} + F_{\text{soil},v,q} + F_{\text{surch},v,q} = \mathbf{384.1 \text{ kN/m}}$$

$$N_s = N_q \times \cos(\epsilon) + T_q \times \sin(\epsilon) = \mathbf{393.5 \text{ kN/m}}$$

$$M_{o,q} = F_{\text{soil},h,q} \times d_{h,\text{soil}} + F_{\text{surch},h,q} \times d_{h,\text{surch}} = \mathbf{251.3 \text{ kNm/m}}$$

$$M_{R,q} = F_{\text{gabion},v,q} \times X_g + F_{\text{soil},v,q} \times b_{v,\text{soil}} + F_{\text{surch},v,q} \times b_{v,\text{surch}} = \mathbf{963.4 \text{ kNm/m}}$$

$$e = w_1 / 2 - (M_{R,q} - M_{o,q}) / N_s = \mathbf{190 \text{ mm}}$$

*Reaction acts within middle third of base*

Pressure at toe

$$\sigma_{\text{toe}} = N_s / w_1 \times (1 + (6 \times e / w_1)) = \mathbf{126.4 \text{ kN/m}^2}$$

Pressure at heel

$$\sigma_{\text{heel}} = N_s / w_1 \times (1 - (6 \times e / w_1)) = \mathbf{70.3 \text{ kN/m}^2}$$

Factor of safety

$$FoS_Q = q / \max(\sigma_{\text{toe}}, \sigma_{\text{heel}}) = \mathbf{1.582}$$

Allowable factor of safety

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

*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

$$\gamma_{\psi} = \mathbf{1.00}$$

Weight density

$$\gamma_{\gamma} = \mathbf{1.00}$$

##### Design soil properties

Design effective shearing resistance angle

$$\phi'_{r,d} = \text{Atan}(\tan(\phi'_{pk,k}) / \gamma_{\psi}) = \mathbf{26.0 \text{ deg}}$$

Design saturated density of retained soil

$$\gamma_{s,d} = \gamma_{sr} / \gamma_{\gamma} = \mathbf{14.0 \text{ kN/m}^3}$$

Design wall friction angle (cl.5.4.2.1)

$$\delta'_{r,d} = \min(\text{atan}(\tan(\delta'_{r,k}) / \gamma_{\psi}), \phi'_{r,d} \times k_{\text{membrane}}) = \mathbf{19.5 \text{ deg}}$$

Design base friction angle

$$\delta'_{bb,d} = \text{Atan}(\tan(\delta'_{bb,k}) / \gamma_{\psi}) = \mathbf{30.0 \text{ deg}}$$

Design friction between gabions

$$\delta'_{bg,d} = \text{Atan}(\tan(\delta'_{bg,k}) / \gamma_{\psi}) = \mathbf{35.0 \text{ deg}}$$

Active pressure using Coulomb theory

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta'_{r,d})) = \mathbf{1.626}$$

Active thrust due to soil

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{191.3 \text{ kN/m}}$$

Minimum surcharge (cl.4.6.3.2)

$$p_{o,\text{min}} = \min(H / H_{\text{ref}}, 1) \times q_{d,\text{min}} = \mathbf{10.0 \text{ kN/m}^2}$$

##### Horizontal forces

Retained soil

$$F_{\text{soil},h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta'_{r,d}) = \mathbf{188.7 \text{ kN/m}}$$

Surcharge

$$F_{\text{surch},h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta'_{r,d}) = \mathbf{51.1 \text{ kN/m}}$$

##### Vertical forces

Gabion weight

$$F_{\text{gabion},v,f} = \gamma_{G,f} \times W_g = \mathbf{208.0 \text{ kN/m}}$$



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Retained soil  
Surcharge

$$F_{soil\_vf} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 130.6 \text{ kN/m}$$

$$F_{surch\_vf} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 45.5 \text{ kN/m}$$

**Overturning stability - take moments about the toe**

Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil\_h} \times d_{h,soil} + F_{surch\_h} \times d_{h,surch} = 312.4 \text{ kNm/m}$$

$$M_R = F_{gabion\_vf} \times X_g + F_{soil\_vf} \times b_{v,soil} + F_{surch\_vf} \times b_{v,surch} = 963.4 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 3.084$$

$$FoS_{M\_allow} = 1.000$$

*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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil\_h} + F_{surch\_h} = 239.8 \text{ kN/m}$$

$$N = F_{gabion\_vf} + F_{soil\_vf} + F_{surch\_vf} = 384.1 \text{ kN/m}$$

$$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 219.4 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bb,d}) = 228.7 \text{ kN/m}$$

$$FoS_S = F_R / F_f = 1.043$$

$$FoS_{S\_allow} = 1.000$$

*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  
Vertical distance to centre of gravity gabion 2  
Weight of gabion 2  
Horizontal distance to centre of gravity gabion 3  
Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g2} = w_2 / 2 = 2000 \text{ mm}$$

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

$$W_{g2} = \gamma_d \times w_2 \times h_2 = 64.0 \text{ kN/m}$$

$$x_{g3} = w_3 / 2 + s_3 = 1500 \text{ mm}$$

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

$$W_{g3} = \gamma_d \times w_3 \times h_3 = 48.0 \text{ kN/m}$$

$$x_{g4} = w_4 / 2 + s_3 + s_4 = 1000 \text{ mm}$$

$$y_{g4} = h_4 / 2 + h_2 + h_3 = 2500 \text{ mm}$$

$$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$$

$$W_g = W_{g2} + W_{g3} + W_{g4} = 144.0 \text{ kN/m}$$

$$x_g = ((W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4})) / W_g = 1611 \text{ mm}$$

$$y_g = ((W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4})) / W_g = 1278 \text{ mm}$$

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1676 \text{ mm}$$

$$H_f = y_{g4} + h_4/2 - ((y_{g4} + h_4/2) \times \cos(\epsilon) - (x_{g4} + w_4/2) \times \sin(\epsilon)) = 109 \text{ mm}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((w_2 - (x_{g4} + (w_4 / 2))) / (y_{g4} + h_4 / 2)) + \epsilon = 59.3 \text{ deg}$$

$$\theta = 90\text{deg} - \epsilon = 87.0 \text{ deg}$$

$$H = (y_{g4} + h_4 / 2) + (w_2 \times \sin(\epsilon)) - H_f = 3101 \text{ mm}$$

$$H_{incl} = ((y_{g4} + h_4 / 2) \times \cos(\epsilon) - (x_{g4} - (w_4 / 2)) \times \sin(\epsilon)) = 2996 \text{ mm}$$

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 2.098$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 141.2 \text{ kN/m}$$

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 10.0 \text{ kN/m}^2$$

**Horizontal forces**

Retained soil  
Surcharge

$$F_{soil\_h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 122.0 \text{ kN/m}$$

$$F_{surch\_h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 43.7 \text{ kN/m}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

$$F_{gabion\_vf} = \gamma_{G,f} \times W_g = 144.0 \text{ kN/m}$$

$$F_{soil\_vf} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 108.5 \text{ kN/m}$$

$$F_{surch\_vf} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 50.0 \text{ kN/m}$$

**Overturning stability - take moments about the toe**

Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil\_h} \times d_{h,soil} + F_{surch\_h} \times d_{h,surch} = 159.2 \text{ kNm/m}$$

$$M_R = F_{gabion\_vf} \times X_g + F_{soil\_vf} \times b_{v,soil} + F_{surch\_vf} \times b_{v,surch} = 761.6 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 4.784$$

$$FoS_{M\_allow} = 1.000$$

*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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil\_h} + F_{surch\_h} = 165.8 \text{ kN/m}$$

$$N = F_{gabion\_vf} + F_{soil\_vf} + F_{surch\_vf} = 302.4 \text{ kN/m}$$

$$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 149.7 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 217.5 \text{ kN/m}$$

$$FoS_S = F_R / F_f = 1.453$$

$$FoS_{S\_allow} = 1.000$$

*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  
Vertical distance to centre of gravity gabion 3

$$x_{g3} = w_3 / 2 = 1500 \text{ mm}$$

$$y_{g3} = h_3 / 2 = 500 \text{ mm}$$



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Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$W_{g3} = \gamma_d \times W_3 \times h_3 = \mathbf{48.0 \text{ kN/m}}$$

$$x_{g4} = W_4 / 2 + s_4 = \mathbf{1000 \text{ mm}}$$

$$y_{g4} = h_4 / 2 + h_3 = \mathbf{1500 \text{ mm}}$$

$$W_{g4} = \gamma_d \times W_4 \times h_4 = \mathbf{32.0 \text{ kN/m}}$$

$$W_g = W_{g3} + W_{g4} = \mathbf{80.0 \text{ kN/m}}$$

$$x_g = ((W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4})) / W_g = \mathbf{1300 \text{ mm}}$$

$$y_g = ((W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4})) / W_g = \mathbf{900 \text{ mm}}$$

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = \mathbf{1345 \text{ mm}}$$

$$H_f = y_{g4} + h_4/2 - ((y_{g4} + h_4/2) \times \cos(\epsilon) - (x_{g4} + w_4/2) \times \sin(\epsilon)) = \mathbf{107 \text{ mm}}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((W_3 - (X_{g4} + (W_4 / 2))) / (y_{g4} + h_4 / 2)) + \epsilon = \mathbf{66.4 \text{ deg}}$$

$$\theta = 90\text{deg} - \epsilon = \mathbf{87.0 \text{ deg}}$$

$$H = (y_{g4} + h_4 / 2) + (w_3 \times \sin(\epsilon)) - H_f = \mathbf{2050 \text{ mm}}$$

$$H_{\text{incl}} = ((y_{g4} + h_4 / 2) \times \cos(\epsilon) - (X_{g4} - (W_4 / 2)) \times \sin(\epsilon)) = \mathbf{1997 \text{ mm}}$$

$$K_a = \sin(\alpha + \phi_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = \mathbf{1.626}$$

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{47.8 \text{ kN/m}}$$

$$p_{o,\text{min}} = \min(H / H_{\text{ref}}, 1) \times q_{d,\text{min}} = \mathbf{6.8 \text{ kN/m}^2}$$

**Horizontal forces**

Retained soil  
Surcharge

$$F_{\text{soil},h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{47.2 \text{ kN/m}}$$

$$F_{\text{surch},h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{25.6 \text{ kN/m}}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

$$F_{\text{gabion},v,f} = \gamma_{G,f} \times W_g = \mathbf{80.0 \text{ kN/m}}$$

$$F_{\text{soil},v,f} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{32.7 \text{ kN/m}}$$

$$F_{\text{surch},v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,\text{min}}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{15.5 \text{ kN/m}}$$

**Overturning stability - take moments about the toe**

Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{\text{soil},h} \times d_{h,\text{soil}} + F_{\text{surch},h} \times d_{h,\text{surch}} = \mathbf{47.0 \text{ kNm/m}}$$

$$M_R = F_{\text{gabion},v,f} \times X_g + F_{\text{soil},v,f} \times d_{v,\text{soil}} + F_{\text{surch},v,f} \times d_{v,\text{surch}} = \mathbf{235.4 \text{ kNm/m}}$$

$$FoS_M = M_R / M_o = \mathbf{5.007}$$

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

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{\text{soil},h} + F_{\text{surch},h} = \mathbf{72.7 \text{ kN/m}}$$

$$N = F_{\text{gabion},v,f} + F_{\text{soil},v,f} + F_{\text{surch},v,f} = \mathbf{128.2 \text{ kN/m}}$$

$$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = \mathbf{65.9 \text{ kN/m}}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = \mathbf{92.3 \text{ kN/m}}$$

$$FoS_S = F_f / F_f = \mathbf{1.400}$$

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

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

**Check overturning and sliding between courses 3 and 4**

**Wall geometry**

Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g4} = W_4 / 2 = \mathbf{1000 \text{ mm}}$$

$$y_{g4} = h_4 / 2 = \mathbf{500 \text{ mm}}$$

$$W_{g4} = \gamma_d \times W_4 \times h_4 = \mathbf{32.0 \text{ kN/m}}$$

$$W_g = W_{g4} = \mathbf{32.0 \text{ kN/m}}$$

$$x_g = ((W_{g4} \times x_{g4})) / W_g = \mathbf{1000 \text{ mm}}$$

$$y_g = ((W_{g4} \times y_{g4})) / W_g = \mathbf{500 \text{ mm}}$$

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = \mathbf{1025 \text{ mm}}$$

$$H_f = y_{g4} + h_4/2 - ((y_{g4} + h_4/2) \times \cos(\epsilon) - (X_{g4} + w_4/2) \times \sin(\epsilon)) = \mathbf{106 \text{ mm}}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90 \text{ deg} + \epsilon = \mathbf{93.0 \text{ deg}}$$

$$\theta = 90\text{deg} - \epsilon = \mathbf{87.0 \text{ deg}}$$

$$H = (y_{g4} + h_4 / 2) + (W_4 \times \sin(\epsilon)) - H_f = \mathbf{999 \text{ mm}}$$

$$H_{\text{incl}} = ((y_{g4} + h_4 / 2) \times \cos(\epsilon) - (X_{g4} - (W_4 / 2)) \times \sin(\epsilon)) = \mathbf{999 \text{ mm}}$$

$$K_a = \sin(\alpha + \phi_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = \mathbf{0.800}$$

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = \mathbf{5.6 \text{ kN/m}}$$

$$p_{o,\text{min}} = \min(H / H_{\text{ref}}, 1) \times q_{d,\text{min}} = \mathbf{3.3 \text{ kN/m}^2}$$

**Horizontal forces**

Retained soil  
Surcharge

$$F_{\text{soil},h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{7.2 \text{ kN/m}}$$

$$F_{\text{surch},h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = \mathbf{8.0 \text{ kN/m}}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

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

$$F_{\text{soil},v,f} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{1.6 \text{ kN/m}}$$

$$F_{\text{surch},v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,\text{min}}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = \mathbf{1.1 \text{ kN/m}}$$

**Overturning stability - take moments about the toe**

Overturning moment

$$M_o = F_{\text{soil},h} \times d_{h,\text{soil}} + F_{\text{surch},h} \times d_{h,\text{surch}} = \mathbf{4.8 \text{ kNm/m}}$$



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Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_R = F_{\text{gabion\_v,f}} \times X_g + F_{\text{soil\_v,f}} \times b_{\text{v,soil}} + F_{\text{surch\_v,f}} \times b_{\text{v,surch}} = 38.3 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 7.937$$

$$FoS_{M\_allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{\text{soil\_h}} + F_{\text{surch\_h}} = 15.3 \text{ kN/m}$$

$$N = F_{\text{gabion\_v,f}} + F_{\text{soil\_v,f}} + F_{\text{surch\_v,f}} = 34.7 \text{ kN/m}$$

$$F_f = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 13.4 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{\text{bg,d}}) = 24.8 \text{ kN/m}$$

$$FoS_S = F_R / F_f = 1.849$$

$$FoS_{S\_allow} = 1.000$$

**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  
Permanent favourable action  
Variable unfavourable action  
Variable favourable action

$$\gamma_G = 1.00$$

$$\gamma_{G,f} = 1.00$$

$$\gamma_Q = 1.30$$

$$\gamma_{Q,f} = 0.00$$

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

Angle of shearing resistance  
Weight density

$$\gamma_\psi = 1.25$$

$$\gamma_\gamma = 1.00$$

##### Design soil properties

Design effective shearing resistance angle  
Design saturated density of retained soil  
Design wall friction angle (cl.5.4.2.1)  
Design base friction angle  
Design friction between gabions

$$\phi'_{r,d} = \text{Atan}(\tan(\phi'_{pk,k}) / \gamma_\psi) = 21.3 \text{ deg}$$

$$\gamma_{s,d} = \gamma_{sr} / \gamma_\gamma = 14.0 \text{ kN/m}^3$$

$$\delta_{r,d} = \min(\text{atan}(\tan(\delta_{rk,k}) / \gamma_\psi), \phi'_{r,d} \times k_{\text{membrane}}) = 15.8 \text{ deg}$$

$$\delta_{bb,d} = \text{Atan}(\tan(\delta_{bb,k}) / \gamma_\psi) = 24.8 \text{ deg}$$

$$\delta_{bg,d} = \text{Atan}(\tan(\delta_{bg,k}) / \gamma_\psi) = 29.3 \text{ deg}$$

##### Wall geometry

Horizontal distance to centre of gravity gabion 1  
Vertical distance to centre of gravity gabion 1  
Weight of gabion 1  
Horizontal distance to centre of gravity gabion 2  
Vertical distance to centre of gravity gabion 2  
Weight of gabion 2  
Horizontal distance to centre of gravity gabion 3  
Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$X_{g1} = w_1 / 2 = 2000 \text{ mm}$$

$$Y_{g1} = h_1 / 2 = 500 \text{ mm}$$

$$W_{g1} = \gamma_d \times w_1 \times h_1 = 64.0 \text{ kN/m}$$

$$X_{g2} = w_2 / 2 + s_2 = 2000 \text{ mm}$$

$$Y_{g2} = h_2 / 2 + h_1 = 1500 \text{ mm}$$

$$W_{g2} = \gamma_d \times w_2 \times h_2 = 64.0 \text{ kN/m}$$

$$X_{g3} = w_3 / 2 + s_2 + s_3 = 1500 \text{ mm}$$

$$Y_{g3} = h_3 / 2 + h_1 + h_2 = 2500 \text{ mm}$$

$$W_{g3} = \gamma_d \times w_3 \times h_3 = 48.0 \text{ kN/m}$$

$$X_{g4} = w_4 / 2 + s_2 + s_3 + s_4 = 1000 \text{ mm}$$

$$Y_{g4} = h_4 / 2 + h_1 + h_2 + h_3 = 3500 \text{ mm}$$

$$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$$

$$W_g = W_{g1} + W_{g2} + W_{g3} + W_{g4} = 208.0 \text{ kN/m}$$

$$X_g = ((W_{g1} \times X_{g1}) + (W_{g2} \times X_{g2}) + (W_{g3} \times X_{g3}) + (W_{g4} \times X_{g4})) / W_g = 1731 \text{ mm}$$

$$Y_g = ((W_{g1} \times Y_{g1}) + (W_{g2} \times Y_{g2}) + (W_{g3} \times Y_{g3}) + (W_{g4} \times Y_{g4})) / W_g = 1731 \text{ mm}$$

$$X_g = X_g \times \cos(\epsilon) + Y_g \times \sin(\epsilon) = 1819 \text{ mm}$$

$$H_f = Y_{g4} + h_4/2 - ((Y_{g4} + h_4/2) \times \cos(\epsilon) - (X_{g4} + w_4/2) \times \sin(\epsilon)) = 110 \text{ mm}$$

##### Design dimensions

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((w_1 - (X_{g4} + (w_4 / 2))) / (Y_{g4} + h_4 / 2)) + \epsilon = 66.4 \text{ deg}$$

$$\theta = 90\text{deg} - \epsilon = 87.0 \text{ deg}$$

$$H = (Y_{g4} + h_4 / 2) + (w_1 \times \sin(\epsilon)) - H_f = 4099 \text{ mm}$$

$$H_{\text{incl}} = ((Y_{g4} + h_4 / 2) \times \cos(\epsilon) - (X_{g4} - (w_4 / 2)) \times \sin(\epsilon)) = 3995 \text{ mm}$$

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.538$$

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 180.8 \text{ kN/m}$$

$$p_{o,\text{min}} = \min(H / H_{\text{ref}}, 1) \times q_{d,\text{min}} = 10.0 \text{ kN/m}^2$$

##### Horizontal forces

Retained soil  
Surcharge

$$F_{\text{soil\_h}} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = 139.8 \text{ kN/m}$$

$$F_{\text{surch\_h}} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 48.7 \text{ kN/m}$$

##### Vertical forces

Gabion weight  
Retained soil  
Surcharge

$$F_{\text{gabion\_v,f}} = \gamma_{G,f} \times W_g = 208.0 \text{ kN/m}$$

$$F_{\text{soil\_v,f}} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = 114.7 \text{ kN/m}$$

$$F_{\text{surch\_v,f}} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,\text{min}}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 40.0 \text{ kN/m}$$

##### Overturning stability - take moments about the toe

Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{\text{soil\_h}} \times d_{h,\text{soil}} + F_{\text{surch\_h}} \times d_{h,\text{surch}} = 251.4 \text{ kNm/m}$$

$$M_R = F_{\text{gabion\_v,f}} \times X_g + F_{\text{soil\_v,f}} \times b_{\text{v,soil}} + F_{\text{surch\_v,f}} \times b_{\text{v,surch}} = 892.3 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 3.550$$

$$FoS_{M\_allow} = 1.000$$

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



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

Total horizontal force	$T = F_{soil,h} + F_{surch,h} = 188.5 \text{ kN/m}$
Total vertical force	$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 362.7 \text{ kN/m}$
Sliding force	$F_t = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 169.3 \text{ kN/m}$
Sliding resistance	$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bb,d}) = 171.9 \text{ kN/m}$
Factor of safety	$FoS_S = F_R / F_t = 1.015$
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	$x_{g2} = w_2 / 2 = 2000 \text{ mm}$
Vertical distance to centre of gravity gabion 2	$y_{g2} = h_2 / 2 = 500 \text{ mm}$
Weight of gabion 2	$W_{g2} = \gamma_d \times w_2 \times h_2 = 64.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 3	$x_{g3} = w_3 / 2 + s_3 = 1500 \text{ mm}$
Vertical distance to centre of gravity gabion 3	$y_{g3} = h_3 / 2 + h_2 = 1500 \text{ mm}$
Weight of gabion 3	$W_{g3} = \gamma_d \times w_3 \times h_3 = 48.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 4	$x_{g4} = w_4 / 2 + s_3 + s_4 = 1000 \text{ mm}$
Vertical distance to centre of gravity gabion 4	$y_{g4} = h_4 / 2 + h_2 + h_3 = 2500 \text{ mm}$
Weight of gabion 4	$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$
Weight of entire gabion	$W_g = W_{g2} + W_{g3} + W_{g4} = 144.0 \text{ kN/m}$
Horiz distance to centre of gravity entire gabion	$x_g = ((W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4})) / W_g = 1611 \text{ mm}$
Vert distance to centre of gravity entire gabion	$y_g = ((W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4})) / W_g = 1278 \text{ mm}$
Correcting for wall inclination horiz dist	$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1676 \text{ mm}$
Vertical change in height due to wall inclination	$H_t = y_{g4} + h_4/2 - ((y_{g4} + h_4/2) \times \cos(\epsilon) - (x_{g4} + w_4/2) \times \sin(\epsilon)) = 109 \text{ mm}$

**Design dimensions**

Effective angle of rear plane of wall	$\alpha = 90\text{deg} - \text{Atan}((w_2 - (x_{g4} + (w_4 / 2))) / (y_{g4} + h_4 / 2)) + \epsilon = 59.3 \text{ deg}$
Effective face angle	$\theta = 90\text{deg} - \epsilon = 87.0 \text{ deg}$
Effective height of wall	$H = (y_{g4} + h_4 / 2) + (w_2 \times \sin(\epsilon)) - H_t = 3101 \text{ mm}$
Height of wall from toe to front edge of top gabion	$H_{incl} = ((y_{g4} + h_4 / 2) \times \cos(\epsilon) - (x_{g4} - (w_4 / 2)) \times \sin(\epsilon)) = 2996 \text{ mm}$
Active pressure using Coulomb theory	$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta'_{r,d})) = 1.913$
Active thrust due to soil	$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 128.7 \text{ kN/m}$
Minimum surcharge (cl.4.6.3.2)	$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 10.0 \text{ kN/m}^2$

**Horizontal forces**

Retained soil	$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta'_{r,d}) = 88.6 \text{ kN/m}$
Surcharge	$F_{surch,h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta'_{r,d}) = 40.8 \text{ kN/m}$

**Vertical forces**

Gabion weight	$F_{gabion,v,f} = \gamma_{G,f} \times W_g = 144.0 \text{ kN/m}$
Retained soil	$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta'_{r,d}) = 93.4 \text{ kN/m}$
Surcharge	$F_{surch,v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta'_{r,d}) = 43.0 \text{ kN/m}$

**Overturning stability - take moments about the toe**

Overturning moment	$M_0 = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 127.7 \text{ kNm/m}$
Restoring moment	$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times d_{v,soil} + F_{surch,v,f} \times d_{v,surch} = 689.3 \text{ kNm/m}$
Factor of safety	$FoS_M = M_R / M_0 = 5.396$
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	$T = F_{soil,h} + F_{surch,h} = 129.4 \text{ kN/m}$
Total vertical force	$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 280.4 \text{ kN/m}$
Sliding force	$F_t = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 114.5 \text{ kN/m}$
Sliding resistance	$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 160.6 \text{ kN/m}$
Factor of safety	$FoS_S = F_R / F_t = 1.402$
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 2 and 3**

**Wall geometry**

Horizontal distance to centre of gravity gabion 3	$x_{g3} = w_3 / 2 = 1500 \text{ mm}$
Vertical distance to centre of gravity gabion 3	$y_{g3} = h_3 / 2 = 500 \text{ mm}$
Weight of gabion 3	$W_{g3} = \gamma_d \times w_3 \times h_3 = 48.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 4	$x_{g4} = w_4 / 2 + s_4 = 1000 \text{ mm}$
Vertical distance to centre of gravity gabion 4	$y_{g4} = h_4 / 2 + h_3 = 1500 \text{ mm}$
Weight of gabion 4	$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$
Weight of entire gabion	$W_g = W_{g3} + W_{g4} = 80.0 \text{ kN/m}$
Horiz distance to centre of gravity entire gabion	$x_g = ((W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4})) / W_g = 1300 \text{ mm}$
Vert distance to centre of gravity entire gabion	$y_g = ((W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4})) / W_g = 900 \text{ mm}$
Correcting for wall inclination horiz dist	$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1345 \text{ mm}$
Vertical change in height due to wall inclination	$H_t = y_{g4} + h_4/2 - ((y_{g4} + h_4/2) \times \cos(\epsilon) - (x_{g4} + w_4/2) \times \sin(\epsilon)) = 107 \text{ mm}$



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**Design dimensions**

Effective angle of rear plane of wall

$$\alpha = 90 \text{ deg} - \text{Atan}((W_3 - (X_{g4} + (W_4 / 2))) / (y_{g4} + h_4 / 2)) + \varepsilon = 66.4 \text{ deg}$$

Effective face angle

$$\theta = 90 \text{ deg} - \varepsilon = 87.0 \text{ deg}$$

Effective height of wall

$$H = (y_{g4} + h_4 / 2) + (W_3 \times \sin(\varepsilon)) - H_r = 2050 \text{ mm}$$

Height of wall from toe to front edge of top gabion

$$H_{\text{incl}} = ((y_{g4} + h_4 / 2) \times \cos(\varepsilon) - (X_{g4} - (W_4 / 2)) \times \sin(\varepsilon)) = 1997 \text{ mm}$$

Active pressure using Coulomb theory

$$K_a = \sin(\alpha + \phi_{r,d}^2) / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.538$$

Active thrust due to soil

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 45.2 \text{ kN/m}$$

Minimum surcharge (cl.4.6.3.2)

$$p_{o,\text{min}} = \min(H / H_{\text{ref}}, 1) \times q_{d,\text{min}} = 6.8 \text{ kN/m}^2$$

**Horizontal forces**

Retained soil

$$F_{\text{soil}_h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = 34.9 \text{ kN/m}$$

Surcharge

$$F_{\text{surch}_h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 20.1 \text{ kN/m}$$

**Vertical forces**

Gabion weight

$$F_{\text{gabion}_v,f} = \gamma_{G,f} \times W_g = 80.0 \text{ kN/m}$$

Retained soil

$$F_{\text{soil}_v,f} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = 28.7 \text{ kN/m}$$

Surcharge

$$F_{\text{surch}_v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,\text{min}}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 13.7 \text{ kN/m}$$

**Overtuning stability - take moments about the toe**

Overtuning moment

$$M_o = F_{\text{soil}_h} \times d_{h,\text{soil}} + F_{\text{surch}_h} \times d_{h,\text{surch}} = 35.8 \text{ kNm/m}$$

Restoring moment

$$M_R = F_{\text{gabion}_v,f} \times X_g + F_{\text{soil}_v,f} \times d_{v,\text{soil}} + F_{\text{surch}_v,f} \times d_{v,\text{surch}} = 219.8 \text{ kNm/m}$$

Factor of safety

$$FoS_M = M_R / M_o = 6.136$$

Allowable factor of safety

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

*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

$$T = F_{\text{soil}_h} + F_{\text{surch}_h} = 55.0 \text{ kN/m}$$

Total vertical force

$$N = F_{\text{gabion}_v,f} + F_{\text{soil}_v,f} + F_{\text{surch}_v,f} = 122.3 \text{ kN/m}$$

Sliding force

$$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon) = 48.6 \text{ kN/m}$$

Sliding resistance

$$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bg,d}) = 70.1 \text{ kN/m}$$

Factor of safety

$$FoS_S = F_R / F_f = 1.443$$

Allowable factor of safety

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

*PASS - Design FOS for sliding exceeds min allowable FOS for sliding***Check overturning and sliding between courses 3 and 4****Wall geometry**

Horizontal distance to centre of gravity gabion 4

$$X_{g4} = W_4 / 2 = 1000 \text{ mm}$$

Vertical distance to centre of gravity gabion 4

$$y_{g4} = h_4 / 2 = 500 \text{ mm}$$

Weight of gabion 4

$$W_{g4} = \gamma_d \times W_4 \times h_4 = 32.0 \text{ kN/m}$$

Weight of entire gabion

$$W_g = W_{g4} = 32.0 \text{ kN/m}$$

Horiz distance to centre of gravity entire gabion

$$X_g = ((W_{g4} \times X_{g4})) / W_g = 1000 \text{ mm}$$

Vert distance to centre of gravity entire gabion

$$y_g = ((W_{g4} \times y_{g4})) / W_g = 500 \text{ mm}$$

Correcting for wall inclination horiz dist

$$X_g = X_g \times \cos(\varepsilon) + y_g \times \sin(\varepsilon) = 1025 \text{ mm}$$

Vertical change in height due to wall inclination

$$H_f = y_{g4} + h_4/2 - ((y_{g4} + h_4/2) \times \cos(\varepsilon) - (X_{g4} + W_4/2) \times \sin(\varepsilon)) = 106 \text{ mm}$$

**Design dimensions**

Effective angle of rear plane of wall

$$\alpha = 90 \text{ deg} + \varepsilon = 93.0 \text{ deg}$$

Effective face angle

$$\theta = 90 \text{ deg} - \varepsilon = 87.0 \text{ deg}$$

Effective height of wall

$$H = (y_{g4} + h_4 / 2) + (W_4 \times \sin(\varepsilon)) - H_r = 999 \text{ mm}$$

Height of wall from toe to front edge of top gabion

$$H_{\text{incl}} = ((y_{g4} + h_4 / 2) \times \cos(\varepsilon) - (X_{g4} - (W_4 / 2)) \times \sin(\varepsilon)) = 999 \text{ mm}$$

Active pressure using Coulomb theory

$$K_a = \sin(\alpha + \phi_{r,d}^2) / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 0.854$$

Active thrust due to soil

$$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 6.0 \text{ kN/m}$$

Minimum surcharge (cl.4.6.3.2)

$$p_{o,\text{min}} = \min(H / H_{\text{ref}}, 1) \times q_{d,\text{min}} = 3.3 \text{ kN/m}^2$$

**Horizontal forces**

Retained soil

$$F_{\text{soil}_h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = 5.8 \text{ kN/m}$$

Surcharge

$$F_{\text{surch}_h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 6.9 \text{ kN/m}$$

**Vertical forces**

Gabion weight

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

Retained soil

$$F_{\text{soil}_v,f} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = 1.3 \text{ kN/m}$$

Surcharge

$$F_{\text{surch}_v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,\text{min}}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 0.9 \text{ kN/m}$$

**Overtuning stability - take moments about the toe**

Overtuning moment

$$M_o = F_{\text{soil}_h} \times d_{h,\text{soil}} + F_{\text{surch}_h} \times d_{h,\text{surch}} = 4.0 \text{ kNm/m}$$

Restoring moment

$$M_R = F_{\text{gabion}_v,f} \times X_g + F_{\text{soil}_v,f} \times d_{v,\text{soil}} + F_{\text{surch}_v,f} \times d_{v,\text{surch}} = 37.4 \text{ kNm/m}$$

Factor of safety

$$FoS_M = M_R / M_o = 9.264$$

Allowable factor of safety

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

*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

$$T = F_{\text{soil}_h} + F_{\text{surch}_h} = 12.7 \text{ kN/m}$$

Total vertical force

$$N = F_{\text{gabion}_v,f} + F_{\text{soil}_v,f} + F_{\text{surch}_v,f} = 34.3 \text{ kN/m}$$

Sliding force

$$F_f = T \times \cos(\varepsilon) - N \times \sin(\varepsilon) = 10.9 \text{ kN/m}$$

Sliding resistance

$$F_R = (T \times \sin(\varepsilon) + N \times \cos(\varepsilon)) \times \tan(\delta_{bg,d}) = 19.5 \text{ kN/m}$$



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Factor of safety  
Allowable factor of safety

$FoS_S = F_R / F_I = 1.799$   
 $FoS_{allow} = 1.000$

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



115 Upperbrow Road, Huddersfield

ES453

## SCOPE

Design calculations for proposed works for Gabion Basket Wall for a Residential Dwelling

FROM SITE MEASUREMENTS



RELEVANT ARCHITECTURAL DRAWINGS



## RELEVANT CODES OF PRACTICE

	BRITISH STANDARDS	EUROCODES
GENERAL	Building Regulations 2010 PP7312 :2002	EN 1990 - Eurocode 0: Basis of structural design
LOADING	BS 6399 (1:1996 ; 2:1997 ; 3 1988)	EN 1991 - Eurocode 1: Actions on structures
STEELWORK	BS 5950 (1: 2000) SCI Steelwork Design Guide to BS 5950 - 6 <sup>th</sup> Edition	EN 1993 - Eurocode 3: Design of steel structures
TIMBER	BS 5268 (2:2002 ; 3:1998)	EN 1995 - Eurocode 5: Design of timber structures
MASONRY	BS 5628 (1:1992 ; 2:2000)	EN 1996 - Eurocode 6: Design of masonry structures
CONCRETE	BS 8110 (1:1997)	EN 1992 - Eurocode 2: Design of concrete structures
FOUNDATIONS	BS 8004 (1986)	

**NOT FOR BUILDERS**  
*Builders must use drawings only*



Project.

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Prepared by.

Project Ref.

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Sheet No.

01

Date

03/02/2021

LOADINGS

<u>LOADS</u>	<u>SLS</u>	<u>ULS</u>
<b>ROOF</b>		
Coverings (Tiles)	0.60	
Battens, Felt, Insulation	0.05	
Rafters / Trussed Rafters	0.15	
Ceiling Joists	0.25	
Ceiling		
DEAD	1.05	
IMPOSED	0.75	1.20
TOTAL	1.80	2.70
<b>FLAT ROOF</b>		
Chippings, 3 Layer Felt, Boards, Joists, Insulation & Ceiling	0.80	1.12
<b>FLOOR</b>		
Coverings	0.10	
Joists/PC Planks	0.15	
Ceiling	0.25	
Partitions generally		
DEAD	0.50	0.70
IMPOSED	1.50	2.40
TOTAL	2.00	3.10
<b>WALLS</b>		
Brickwork outer leaf (102 mm - fair faced)	2.00	2.80
Brickwork outer leaf (102 mm - rendered)	2.50	3.50
Brickwork inner leaf (102 mm - plastered)	2.25	3.15
Blockwork inner Leaf (100mm - plastered /1)	1.75	2.50
Blockwork partition (100mm - plastered/2)	2.10	3.00
Timber stud (75mm - plastered/2)	0.70	1.00
Lightweight stud	0.50	0.70



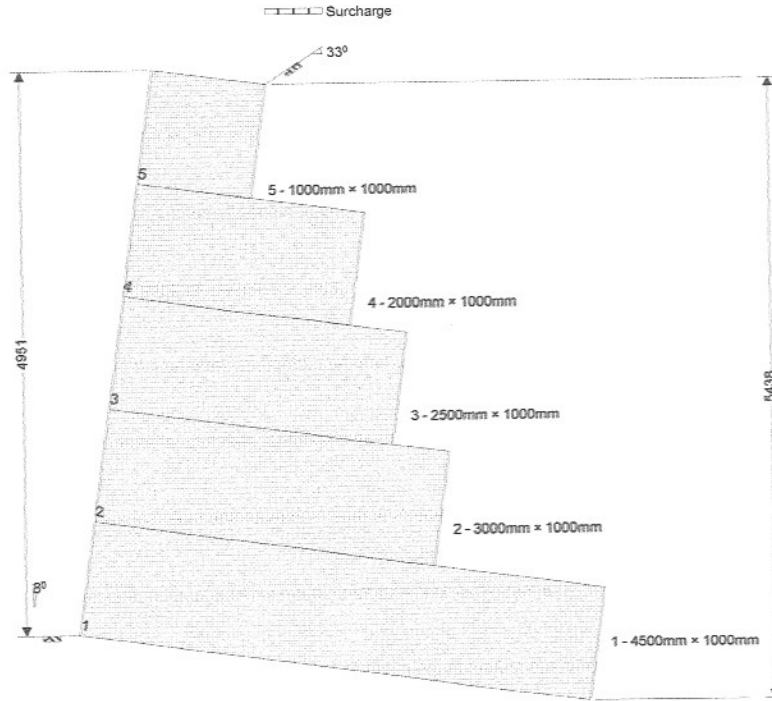
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Project 115 Upperbrow Lane, Huddersfield				Job Ref. ES453	
Section Gabion Basket Retaining Wall Design				Sheet no./rev. 02	
Calc. by SB	Date 03/02/21	Chk'd by SB	Date 03/02/21	App'd by	Date

**GABION RETAINING WALL ANALYSIS & DESIGN**

In accordance with BS8002:2015 - Code of Practice for Earth Retaining Structures and the UK National Annex

Tedds calculation version 2.0.01



**Wall geometry**

Width of gabion 1	$w_1 = 4500 \text{ mm}$
Height of gabion 1	$h_1 = 1000 \text{ mm}$
Width of gabion 2	$w_2 = 3000 \text{ mm}$
Height of gabion 2	$h_2 = 1000 \text{ mm}$
Step to front face between courses 1 and 2	$s_2 = 0 \text{ mm}$
Width of gabion 3	$w_3 = 2500 \text{ mm}$
Height of gabion 3	$h_3 = 1000 \text{ mm}$
Step to front face between courses 2 and 3	$s_3 = 0 \text{ mm}$
Width of gabion 4	$w_4 = 2000 \text{ mm}$
Height of gabion 4	$h_4 = 1000 \text{ mm}$
Step to front face between courses 3 and 4	$s_4 = 0 \text{ mm}$
Width of gabion 5	$w_5 = 1000 \text{ mm}$
Height of gabion 5	$h_5 = 1000 \text{ mm}$
Step to front face between courses 4 and 5	$s_5 = 0 \text{ mm}$
Wall inclination	$\epsilon = 8 \text{ deg}$

**Gabion properties**

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

**Loading**

Permanent surcharge	$p_{e,G} = 5 \text{ kN/m}^2$
Variable surcharge	$p_{e,Q} = 3 \text{ kN/m}^2$

**Soil properties**

Slope of retained soil	$\beta = 33.0 \text{ deg}$
Characteristic peak shearing resistance angle	$\phi'_{pk,k} = 26.0 \text{ deg}$
Characteristic saturated density of retained soil	$\gamma_{sat} = 14.0 \text{ kN/m}^3$
Coefficient for wall friction	$k_{membrane} = 0.75$
Wall friction angle	$\delta_{v,k} = 19.5 \text{ deg}$
Characteristic base friction angle	$\delta_{bb,k} = 30.0 \text{ deg}$
Bearing capacity of founding soil	$q = 200 \text{ kN/m}^2$

**Wall geometry**

Horizontal distance to centre of gravity gabion 1	$x_{g1} = w_1 / 2 = 2250 \text{ mm}$
Vertical distance to centre of gravity gabion 1	$y_{g1} = h_1 / 2 = 500 \text{ mm}$
Weight of gabion 1	$W_{g1} = \gamma_d \times w_1 \times h_1 = 72.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 2	$x_{g2} = w_2 / 2 + s_2 = 1500 \text{ mm}$
Vertical distance to centre of gravity gabion 2	$y_{g2} = h_2 / 2 + h_1 = 1500 \text{ mm}$



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Weight of gabion 2  
Horizontal distance to centre of gravity gabion 3  
Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$W_{g2} = \gamma_d \times w_2 \times h_2 = 48.0 \text{ kN/m}$$

$$x_{g3} = w_3 / 2 + s_2 + s_3 = 1250 \text{ mm}$$

$$y_{g3} = h_3 / 2 + h_1 + h_2 = 2500 \text{ mm}$$

$$W_{g3} = \gamma_d \times w_3 \times h_3 = 40.0 \text{ kN/m}$$

$$x_{g4} = w_4 / 2 + s_2 + s_3 + s_4 = 1000 \text{ mm}$$

$$y_{g4} = h_4 / 2 + h_1 + h_2 + h_3 = 3500 \text{ mm}$$

$$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$$

$$x_{g5} = w_5 / 2 + s_2 + s_3 + s_4 + s_5 = 500 \text{ mm}$$

$$y_{g5} = h_5 / 2 + h_1 + h_2 + h_3 + h_4 = 4500 \text{ mm}$$

$$W_{g5} = \gamma_d \times w_5 \times h_5 = 16.0 \text{ kN/m}$$

$$W_g = W_{g1} + W_{g2} + W_{g3} + W_{g4} + W_{g5} = 208.0 \text{ kN/m}$$

$$x_g = ((W_{g1} \times x_{g1}) + (W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4}) + (W_{g5} \times x_{g5})) / W_g = 1558 \text{ mm}$$

$$y_g = ((W_{g1} \times y_{g1}) + (W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4}) + (W_{g5} \times y_{g5})) / W_g = 1885 \text{ mm}$$

$$x_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1805 \text{ mm}$$

$$H_r = y_{g5} + h_5 / 2 - ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} + w_5 / 2) \times \sin(\epsilon)) = 188 \text{ mm}$$

#### Design dimensions

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((w_1 - (x_{g5} + (w_5 / 2))) / (y_{g5} + h_5 / 2)) + \epsilon = 63.0 \text{ deg}$$

$$\theta = 90\text{deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_1 \times \sin(\epsilon)) - H_r = 5438 \text{ mm}$$

$$H_{incl} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 4951 \text{ mm}$$

$$K_a = \sin(\alpha + \phi'_{r,k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,k})) = 1.829$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{sr} \times H^2 = 378.6 \text{ kN/m}$$

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 10.0 \text{ kN/m}^2$$

#### Pressure at base

##### Horizontal forces

Retained soil  
Height of soil thrust resolved vertically  
Surcharge  
Height of surcharge thrust resolved vertically

$$F_{soil,h,q} = P_{a,soil} \times \cos(90 - \alpha + \delta_{r,k}) = 260.7 \text{ kN/m}$$

$$d_{h,soil} = H / 3 - w_1 \times \sin(\epsilon) = 1187 \text{ mm}$$

$$F_{surch,h,q} = \max((p_{o,G} + p_{o,Q}), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,k}) = 68.5 \text{ kN/m}$$

$$d_{h,surch} = H / 2 - w_1 \times \sin(\epsilon) = 2093 \text{ mm}$$

##### Vertical forces

Gabion weight  
Retained soil  
Horizontal dist to where soil thrust acts  
Surcharge  
Horizontal dist to where surcharge thrust acts  
Total horizontal unfactored force  
Total vertical unfactored force  
Force normal to base  
Total unfactored overturning force  
Total unfactored restoring force  
Eccentricity

$$F_{gabion,v,q} = W_g = 208.0 \text{ kN/m}$$

$$F_{soil,v,q} = P_{a,soil} \times \sin(90 - \alpha + \delta_{r,k}) = 274.6 \text{ kN/m}$$

$$d_{v,soil} = w_1 \times \cos(\epsilon) - (H / 3) / \tan(\alpha) = 3533 \text{ mm}$$

$$F_{surch,v,q} = \max((p_{o,G} + p_{o,Q}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,k}) = 72.1 \text{ kN/m}$$

$$d_{v,surch} = w_1 \times \cos(\epsilon) - (H / 2) / \tan(\alpha) = 3071 \text{ mm}$$

$$T_q = F_{soil,h,q} + F_{surch,h,q} = 329.1 \text{ kN/m}$$

$$N_q = F_{gabion,v,q} + F_{soil,v,q} + F_{surch,v,q} = 554.7 \text{ kN/m}$$

$$N_s = N_q \times \cos(\epsilon) + T_q \times \sin(\epsilon) = 595.2 \text{ kN/m}$$

$$M_{o,q} = F_{soil,h,q} \times d_{h,soil} + F_{surch,h,q} \times d_{h,surch} = 452.6 \text{ kNm/m}$$

$$M_{R,q} = F_{gabion,v,q} \times x_g + F_{soil,v,q} \times d_{v,soil} + F_{surch,v,q} \times d_{v,surch} = 1567.1 \text{ kNm/m}$$

$$e = w_1 / 2 - (M_{R,q} - M_{o,q}) / N_s = 377 \text{ mm}$$

Reaction acts within middle third of base

Pressure at toe  
Pressure at heel  
Factor of safety  
Allowable factor of safety

$$\sigma_{toe} = N_s / w_1 \times (1 + (6 \times e / w_1)) = 198.8 \text{ kN/m}^2$$

$$\sigma_{heel} = N_s / w_1 \times (1 - (6 \times e / w_1)) = 65.7 \text{ kN/m}^2$$

$$FoS_Q = q / \max(\sigma_{toe}, \sigma_{heel}) = 1.006$$

$$FoS_{Q,allow} = 1.000$$

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  
Permanent favourable action  
Variable unfavourable action  
Variable favourable action

$$\gamma_G = 1.35$$

$$\gamma_{G,f} = 1.00$$

$$\gamma_Q = 1.50$$

$$\gamma_{Q,f} = 0.00$$

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

Angle of shearing resistance  
Weight density

$$\gamma_{\phi} = 1.00$$

$$\gamma_{\gamma} = 1.00$$

##### Design soil properties

Design effective shearing resistance angle  
Design saturated density of retained soil  
Design wall friction angle (cl.5.4.2.1)  
Design base friction angle  
Design friction between gabions  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\phi'_{r,d} = \text{Atan}(\tan(\phi'_{r,k}) / \gamma_{\phi}) = 26.0 \text{ deg}$$

$$\gamma_{s,d} = \gamma_{sr} / \gamma_{\gamma} = 14.0 \text{ kN/m}^3$$

$$\delta_{r,d} = \min(\text{atan}(\tan(\delta_{r,k}) / \gamma_{\phi}), \phi'_{r,d} \times K_{\text{membrane}}) = 19.5 \text{ deg}$$

$$\delta_{bb,d} = \text{Atan}(\tan(\delta_{bb,k}) / \gamma_{\phi}) = 30.0 \text{ deg}$$

$$\delta_{bg,d} = \text{Atan}(\tan(\delta_{bg,k}) / \gamma_{\phi}) = 35.0 \text{ deg}$$

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.829$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 378.6 \text{ kN/m}$$

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 10.0 \text{ kN/m}^2$$



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#### Horizontal forces

Retained soil  
Surcharge

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 351.9 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{0,G} \times \gamma_G + p_{0,Q} \times \gamma_Q), p_{0,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 71.9 \text{ kN/m}$$

#### Vertical forces

Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,f} = \gamma_G \times W_g = 208.0 \text{ kN/m}$$

$$F_{soil,v,f} = \gamma_G \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 274.6 \text{ kN/m}$$

$$F_{surch,v,f} = \max((p_{0,G} \times \gamma_G + p_{0,Q} \times \gamma_Q), p_{0,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 72.1 \text{ kN/m}$$

#### Overtuning stability - take moments about the toe

Overtuning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 568.0 \text{ kNm/m}$$

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times d_{v,soil} + F_{surch,v,f} \times d_{v,surch} = 1567.1 \text{ kNm/m}$$

$$FoSM = M_R / M_o = 2.759$$

$$FoSM_{allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil,h} + F_{surch,h} = 423.8 \text{ kN/m}$$

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 554.7 \text{ kN/m}$$

$$F_I = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 342.5 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bb,d}) = 351.2 \text{ kN/m}$$

$$FoSS = F_R / F_I = 1.026$$

$$FoSS_{allow} = 1.000$$

**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  
Vertical distance to centre of gravity gabion 2  
Weight of gabion 2  
Horizontal distance to centre of gravity gabion 3  
Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g2} = W_2 / 2 = 1500 \text{ mm}$$

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

$$W_{g2} = \gamma_d \times W_2 \times h_2 = 48.0 \text{ kN/m}$$

$$x_{g3} = W_3 / 2 + s_3 = 1250 \text{ mm}$$

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

$$W_{g3} = \gamma_d \times W_3 \times h_3 = 40.0 \text{ kN/m}$$

$$x_{g4} = W_4 / 2 + s_3 + s_4 = 1000 \text{ mm}$$

$$y_{g4} = h_4 / 2 + h_2 + h_3 = 2500 \text{ mm}$$

$$W_{g4} = \gamma_d \times W_4 \times h_4 = 32.0 \text{ kN/m}$$

$$x_{g5} = W_5 / 2 + s_3 + s_4 + s_5 = 500 \text{ mm}$$

$$y_{g5} = h_5 / 2 + h_2 + h_3 + h_4 = 3500 \text{ mm}$$

$$W_{g5} = \gamma_d \times W_5 \times h_5 = 16.0 \text{ kN/m}$$

$$W_g = W_{g2} + W_{g3} + W_{g4} + W_{g5} = 136.0 \text{ kN/m}$$

$$x_g = ((W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4}) + (W_{g5} \times x_{g5})) / W_g = 1191 \text{ mm}$$

$$y_g = ((W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4}) + (W_{g5} \times y_{g5})) / W_g = 1618 \text{ mm}$$

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1405 \text{ mm}$$

$$H_r = y_{g5} + h_2 / 2 - ((y_{g5} + h_2 / 2) \times \cos(\epsilon) - (x_{g5} + w_2) \times \sin(\epsilon)) = 178 \text{ mm}$$

##### Design dimensions

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((w_2 - (x_{g5} + (w_5 / 2))) / (y_{g5} + h_5 / 2)) / (y_{g5} + h_5 / 2) + \epsilon = 71.4 \text{ deg}$$

$$\theta = 90\text{deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_2 \times \sin(\epsilon)) - H_r = 4239 \text{ mm}$$

$$H_{ind} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 3961 \text{ mm}$$

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.390$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 174.8 \text{ kN/m}$$

$$p_{0,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 10.0 \text{ kN/m}^2$$

##### Horizontal forces

Retained soil  
Surcharge

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 185.8 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{0,G} \times \gamma_G + p_{0,Q} \times \gamma_Q), p_{0,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 48.7 \text{ kN/m}$$

##### Vertical forces

Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,f} = \gamma_G \times W_g = 136.0 \text{ kN/m}$$

$$F_{soil,v,f} = \gamma_G \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 107.8 \text{ kN/m}$$

$$F_{surch,v,f} = \max((p_{0,G} \times \gamma_G + p_{0,Q} \times \gamma_Q), p_{0,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 36.3 \text{ kN/m}$$

##### Overtuning stability - take moments about the toe

Overtuning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 267.9 \text{ kNm/m}$$

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times d_{v,soil} + F_{surch,v,f} \times d_{v,surch} = 542.2 \text{ kNm/m}$$

$$FoSM = M_R / M_o = 2.024$$

$$FoSM_{allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance

$$T = F_{soil,h} + F_{surch,h} = 234.5 \text{ kN/m}$$

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 280.1 \text{ kN/m}$$

$$F_I = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 193.3 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 217.1 \text{ kN/m}$$



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Factor of safety  
Allowable factor of safety

$$FoS_S = F_R / F_I = 1.123$$

$$FoS_{S\_allow} = 1.000$$

**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  
Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g3} = w_3 / 2 = 1250 \text{ mm}$$

$$y_{g3} = h_3 / 2 = 500 \text{ mm}$$

$$W_{g3} = \gamma_d \times w_3 \times h_3 = 40.0 \text{ kN/m}$$

$$x_{g4} = w_4 / 2 + s_4 = 1000 \text{ mm}$$

$$y_{g4} = h_4 / 2 + h_3 = 1500 \text{ mm}$$

$$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$$

$$x_{g5} = w_5 / 2 + s_4 + s_5 = 500 \text{ mm}$$

$$y_{g5} = h_5 / 2 + h_3 + h_4 = 2500 \text{ mm}$$

$$W_{g5} = \gamma_d \times w_5 \times h_5 = 16.0 \text{ kN/m}$$

$$W_g = W_{g3} + W_{g4} + W_{g5} = 88.0 \text{ kN/m}$$

$$x_g = ((W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4}) + (W_{g5} \times x_{g5})) / W_g = 1023 \text{ mm}$$

$$y_g = ((W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4}) + (W_{g5} \times y_{g5})) / W_g = 1227 \text{ mm}$$

$$x_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1184 \text{ mm}$$

$$H_r = y_{g5} + h_5/2 - ((y_{g5} + h_5/2) \times \cos(\epsilon) - (x_{g5} + w_5/2) \times \sin(\epsilon)) = 168 \text{ mm}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((w_3 - (x_{g5} + (w_5 / 2))) / (y_{g5} + h_5 / 2)) + \epsilon = 71.4 \text{ deg}$$

$$\theta = 90\text{deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_3 \times \sin(\epsilon)) - H_r = 3180 \text{ mm}$$

$$H_{incl} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 2971 \text{ mm}$$

$$K_a = \sin(\alpha + \phi_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.390$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 98.3 \text{ kN/m}$$

$$p_{o,min} = \min(H / H_{ret}, 1) \times q_{d,min} = 10.0 \text{ kN/m}^2$$

**Horizontal forces**

Retained soil  
Surcharge

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 104.5 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 36.5 \text{ kN/m}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,f} = \gamma_{G,f} \times W_g = 88.0 \text{ kN/m}$$

$$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 60.6 \text{ kN/m}$$

$$F_{surch,v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 27.2 \text{ kN/m}$$

**Overturning stability - take moments about the toe**

Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 119.8 \text{ kNm/m}$$

$$M_R = F_{gabion,v,f} \times x_g + F_{soil,v,f} \times b_{v,soil} + F_{surch,v,f} \times b_{v,surch} = 285.6 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 2.384$$

$$FoS_{M\_allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil,h} + F_{surch,h} = 141.1 \text{ kN/m}$$

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 175.9 \text{ kN/m}$$

$$F_I = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 115.2 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 135.7 \text{ kN/m}$$

$$FoS_S = F_R / F_I = 1.178$$

$$FoS_{S\_allow} = 1.000$$

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

**Check overturning and sliding between courses 3 and 4**

**Wall geometry**

Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g4} = w_4 / 2 = 1000 \text{ mm}$$

$$y_{g4} = h_4 / 2 = 500 \text{ mm}$$

$$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$$

$$x_{g5} = w_5 / 2 + s_5 = 500 \text{ mm}$$

$$y_{g5} = h_5 / 2 + h_4 = 1500 \text{ mm}$$

$$W_{g5} = \gamma_d \times w_5 \times h_5 = 16.0 \text{ kN/m}$$

$$W_g = W_{g4} + W_{g5} = 48.0 \text{ kN/m}$$

$$x_g = ((W_{g4} \times x_{g4}) + (W_{g5} \times x_{g5})) / W_g = 833 \text{ mm}$$

$$y_g = ((W_{g4} \times y_{g4}) + (W_{g5} \times y_{g5})) / W_g = 833 \text{ mm}$$

$$x_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 941 \text{ mm}$$

$$H_r = y_{g5} + h_5/2 - ((y_{g5} + h_5/2) \times \cos(\epsilon) - (x_{g5} + w_5/2) \times \sin(\epsilon)) = 159 \text{ mm}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion

$$\alpha = 90\text{deg} - \text{Atan}((w_4 - (x_{g5} + (w_5 / 2))) / (y_{g5} + h_5 / 2)) + \epsilon = 71.4 \text{ deg}$$

$$\theta = 90\text{deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_4 \times \sin(\epsilon)) - H_r = 2120 \text{ mm}$$

$$H_{incl} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 1981 \text{ mm}$$



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Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$K_a = \sin(\alpha + \phi_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.390$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 43.7 \text{ kN/m}$$

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 7.1 \text{ kN/m}^2$$

**Horizontal forces**

Retained soil  
Surcharge

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 46.5 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 24.4 \text{ kN/m}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,f} = \gamma_{G,f} \times W_g = 48.0 \text{ kN/m}$$

$$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 27.0 \text{ kN/m}$$

$$F_{surch,v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 12.8 \text{ kN/m}$$

**Overtuning stability - take moments about the toe**

Overtuning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 38.9 \text{ kNm/m}$$

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times b_{v,soil} + F_{surch,v,f} \times b_{v,surch} = 113.0 \text{ kNm/m}$$

$$FoSM = M_R / M_o = 2.903$$

$$FoSM_{allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil,h} + F_{surch,h} = 70.8 \text{ kN/m}$$

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 87.8 \text{ kN/m}$$

$$F_I = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 57.9 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{og,d}) = 67.8 \text{ kN/m}$$

$$FoS_S = F_R / F_I = 1.170$$

$$FoS_{S,allow} = 1.000$$

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

**Check overturning and sliding between courses 4 and 5**

**Wall geometry**

Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g5} = w_5 / 2 = 500 \text{ mm}$$

$$y_{g5} = h_5 / 2 = 500 \text{ mm}$$

$$W_{g5} = \gamma_4 \times w_5 \times h_5 = 16.0 \text{ kN/m}$$

$$W_g = W_{g5} = 16.0 \text{ kN/m}$$

$$x_g = ((W_{g5} \times x_{g5})) / W_g = 500 \text{ mm}$$

$$y_g = ((W_{g5} \times y_{g5})) / W_g = 500 \text{ mm}$$

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 565 \text{ mm}$$

$$H_r = y_{g5} + h_5/2 - ((y_{g5} + h_5/2) \times \cos(\epsilon) - (x_{g5} + w_5/2) \times \sin(\epsilon)) = 149 \text{ mm}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90 \text{ deg} + \epsilon = 98.0 \text{ deg}$$

$$\theta = 90 \text{ deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_5 \times \sin(\epsilon)) - H_r = 990 \text{ mm}$$

$$H_{incl} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 990 \text{ mm}$$

$$K_a = \sin(\alpha + \phi_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 0.715$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 4.9 \text{ kN/m}$$

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 3.3 \text{ kN/m}^2$$

**Horizontal forces**

Retained soil  
Surcharge

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 6.5 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 7.3 \text{ kN/m}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,f} = \gamma_{G,f} \times W_g = 16.0 \text{ kN/m}$$

$$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 1.0 \text{ kN/m}$$

$$F_{surch,v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 0.7 \text{ kN/m}$$

**Overtuning stability - take moments about the toe**

Overtuning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 3.8 \text{ kNm/m}$$

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times b_{v,soil} + F_{surch,v,f} \times b_{v,surch} = 10.8 \text{ kNm/m}$$

$$FoSM = M_R / M_o = 2.816$$

$$FoSM_{allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil,h} + F_{surch,h} = 13.8 \text{ kN/m}$$

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 17.7 \text{ kN/m}$$

$$F_I = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 11.2 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{og,d}) = 13.6 \text{ kN/m}$$

$$FoS_S = F_R / F_I = 1.216$$

$$FoS_{S,allow} = 1.000$$

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



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### Design approach 1

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

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

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

Angle of shearing resistance	$\gamma_\phi = 1.25$
Weight density	$\gamma_r = 1.00$

#### Design soil properties

Design effective shearing resistance angle	$\phi_{r,d} = \text{Atan}(\tan(\phi_{pk,k}) / \gamma_\phi) = 21.3 \text{ deg}$
Design saturated density of retained soil	$\gamma_{s,d} = \gamma_{sr} / \gamma_r = 14.0 \text{ kN/m}^3$
Design wall friction angle (cl.5.4.2.1)	$\delta_{r,d} = \min(\text{atan}(\tan(\delta_{r,k}) / \gamma_\phi), \phi_{r,d} \times K_{\text{membrane}}) = 15.8 \text{ deg}$
Design base friction angle	$\delta_{bb,d} = \text{Atan}(\tan(\delta_{bb,k}) / \gamma_\phi) = 24.8 \text{ deg}$
Design friction between gabions	$\delta_{bg,d} = \text{Atan}(\tan(\delta_{bg,k}) / \gamma_\phi) = 29.3 \text{ deg}$

#### Wall geometry

Horizontal distance to centre of gravity gabion 1	$X_{g1} = W_1 / 2 = 2250 \text{ mm}$
Vertical distance to centre of gravity gabion 1	$Y_{g1} = h_1 / 2 = 500 \text{ mm}$
Weight of gabion 1	$W_{g1} = \gamma_d \times W_1 \times h_1 = 72.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 2	$X_{g2} = W_2 / 2 + S_2 = 1500 \text{ mm}$
Vertical distance to centre of gravity gabion 2	$Y_{g2} = h_2 / 2 + h_1 = 1500 \text{ mm}$
Weight of gabion 2	$W_{g2} = \gamma_d \times W_2 \times h_2 = 48.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 3	$X_{g3} = W_3 / 2 + S_2 + S_3 = 1250 \text{ mm}$
Vertical distance to centre of gravity gabion 3	$Y_{g3} = h_3 / 2 + h_1 + h_2 = 2500 \text{ mm}$
Weight of gabion 3	$W_{g3} = \gamma_d \times W_3 \times h_3 = 40.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 4	$X_{g4} = W_4 / 2 + S_2 + S_3 + S_4 = 1000 \text{ mm}$
Vertical distance to centre of gravity gabion 4	$Y_{g4} = h_4 / 2 + h_1 + h_2 + h_3 = 3500 \text{ mm}$
Weight of gabion 4	$W_{g4} = \gamma_d \times W_4 \times h_4 = 32.0 \text{ kN/m}$
Horizontal distance to centre of gravity gabion 5	$X_{g5} = W_5 / 2 + S_2 + S_3 + S_4 + S_5 = 500 \text{ mm}$
Vertical distance to centre of gravity gabion 5	$Y_{g5} = h_5 / 2 + h_1 + h_2 + h_3 + h_4 = 4500 \text{ mm}$
Weight of gabion 5	$W_{g5} = \gamma_d \times W_5 \times h_5 = 16.0 \text{ kN/m}$
Weight of entire gabion	$W_g = W_{g1} + W_{g2} + W_{g3} + W_{g4} + W_{g5} = 208.0 \text{ kN/m}$
Horiz distance to centre of gravity entire gabion	$X_g = ((W_{g1} \times X_{g1}) + (W_{g2} \times X_{g2}) + (W_{g3} \times X_{g3}) + (W_{g4} \times X_{g4}) + (W_{g5} \times X_{g5})) / W_g = 1558 \text{ mm}$
Vert distance to centre of gravity entire gabion	$Y_g = ((W_{g1} \times Y_{g1}) + (W_{g2} \times Y_{g2}) + (W_{g3} \times Y_{g3}) + (W_{g4} \times Y_{g4}) + (W_{g5} \times Y_{g5})) / W_g = 1885 \text{ mm}$
Correcting for wall inclination horiz dist	$X_g = X_g \times \cos(\epsilon) + Y_g \times \sin(\epsilon) = 1805 \text{ mm}$
Vertical change in height due to wall inclination	$H_r = Y_{g5} + h_5/2 - ((Y_{g5} + h_5/2) \times \cos(\epsilon) - (X_{g5} + W_5/2) \times \sin(\epsilon)) = 188 \text{ mm}$

#### Design dimensions

Effective angle of rear plane of wall	$\alpha = 90\text{deg} - \text{Atan}((W_1 - (X_{g5} + (W_5 / 2))) / (Y_{g5} + h_5 / 2)) + \epsilon = 63.0 \text{ deg}$
Effective face angle	$\theta = 90\text{deg} - \epsilon = 82.0 \text{ deg}$
Effective height of wall	$H = (Y_{g5} + h_5 / 2) + (W_1 \times \sin(\epsilon)) - H_r = 5438 \text{ mm}$
Height of wall from toe to front edge of top gabion	$H_{\text{net}} = ((Y_{g5} + h_5 / 2) \times \cos(\epsilon) - (X_{g5} - (W_5 / 2)) \times \sin(\epsilon)) = 4951 \text{ mm}$
Active pressure using Coulomb theory	$K_a = \sin(\alpha + \phi_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.700$
Active thrust due to soil	$P_{a,\text{soil}} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 352.0 \text{ kN/m}$
Minimum surcharge (cl.4.6.3.2)	$P_{o,\text{min}} = \min(H / H_{\text{ret}}, 1) \times Q_{d,\text{min}} = 10.0 \text{ kN/m}^2$

#### Horizontal forces

Retained soil	$F_{\text{soil},h} = \gamma_G \times P_{a,\text{soil}} \times \cos(90 - \alpha + \delta_{r,d}) = 258.2 \text{ kN/m}$
Surcharge	$F_{\text{surch},h} = \max((P_{o,q} \times \gamma_G + P_{o,q} \times \gamma_Q), P_{o,\text{min}}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 67.8 \text{ kN/m}$

#### Vertical forces

Gabion weight	$F_{\text{gabion},v,f} = \gamma_{G,f} \times W_g = 208.0 \text{ kN/m}$
Retained soil	$F_{\text{soil},v,f} = \gamma_{G,f} \times P_{a,\text{soil}} \times \sin(90 - \alpha + \delta_{r,d}) = 239.2 \text{ kN/m}$
Surcharge	$F_{\text{surch},v,f} = \max((P_{o,q} \times \gamma_{G,f} + P_{o,q} \times \gamma_{Q,f}), P_{o,\text{min}}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 62.8 \text{ kN/m}$

#### Overturning stability - take moments about the toe

Overturning moment	$M_o = F_{\text{soil},h} \times d_{n,\text{soil}} + F_{\text{surch},h} \times d_{n,\text{surch}} = 448.3 \text{ kNm/m}$
Restoring moment	$M_R = F_{\text{gabion},v,f} \times X_g + F_{\text{soil},v,f} \times b_{v,\text{soil}} + F_{\text{surch},v,f} \times b_{v,\text{surch}} = 1413.3 \text{ kNm/m}$
Factor of safety	$FoS_M = M_R / M_o = 3.152$
Allowable factor of safety	$FoS_{M,\text{allow}} = 1.000$

**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	$T = F_{\text{soil},h} + F_{\text{surch},h} = 326.0 \text{ kN/m}$
Total vertical force	$N = F_{\text{gabion},v,f} + F_{\text{soil},v,f} + F_{\text{surch},v,f} = 510.0 \text{ kN/m}$
Sliding force	$F_r = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 251.9 \text{ kN/m}$
Sliding resistance	$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bb,d}) = 254.2 \text{ kN/m}$
Factor of safety	$FoS_S = F_R / F_r = 1.009$
Allowable factor of safety	$FoS_{S,\text{allow}} = 1.000$

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



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**Check overturning and sliding between courses 1 and 2**

**Wall geometry**

Horizontal distance to centre of gravity gabion 2  
Vertical distance to centre of gravity gabion 2  
Weight of gabion 2  
Horizontal distance to centre of gravity gabion 3  
Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$\begin{aligned}
 x_{g2} &= w_2 / 2 = 1500 \text{ mm} \\
 y_{g2} &= h_2 / 2 = 500 \text{ mm} \\
 W_{g2} &= \gamma_d \times w_2 \times h_2 = 48.0 \text{ kN/m} \\
 x_{g3} &= w_3 / 2 + s_3 = 1250 \text{ mm} \\
 y_{g3} &= h_3 / 2 + h_2 = 1500 \text{ mm} \\
 W_{g3} &= \gamma_d \times w_3 \times h_3 = 40.0 \text{ kN/m} \\
 x_{g4} &= w_4 / 2 + s_3 + s_4 = 1000 \text{ mm} \\
 y_{g4} &= h_4 / 2 + h_2 + h_3 = 2500 \text{ mm} \\
 W_{g4} &= \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m} \\
 x_{g5} &= w_5 / 2 + s_3 + s_4 + s_5 = 500 \text{ mm} \\
 y_{g5} &= h_5 / 2 + h_2 + h_3 + h_4 = 3500 \text{ mm} \\
 W_{g5} &= \gamma_d \times w_5 \times h_5 = 16.0 \text{ kN/m} \\
 W_g &= W_{g2} + W_{g3} + W_{g4} + W_{g5} = 136.0 \text{ kN/m} \\
 x_g &= ((W_{g2} \times x_{g2}) + (W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4}) + (W_{g5} \times x_{g5})) / W_g = 1191 \text{ mm} \\
 y_g &= ((W_{g2} \times y_{g2}) + (W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4}) + (W_{g5} \times y_{g5})) / W_g = 1618 \text{ mm} \\
 X_g &= x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1405 \text{ mm} \\
 H_r &= y_{g5} + h_5/2 - ((y_{g5} + h_5/2) \times \cos(\epsilon) - (x_{g5} + w_5/2) \times \sin(\epsilon)) = 178 \text{ mm}
 \end{aligned}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\begin{aligned}
 \alpha &= 90\text{deg} - \text{Atan}((w_2 - (x_{g5} + (w_5 / 2))) / (y_{g5} + h_5 / 2)) + \epsilon = 71.4 \text{ deg} \\
 \theta &= 90\text{deg} - \epsilon = 82.0 \text{ deg} \\
 H &= (y_{g5} + h_5 / 2) + (w_2 \times \sin(\epsilon)) - H_r = 4239 \text{ mm} \\
 H_{incl} &= ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 3961 \text{ mm} \\
 K_a &= \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.345 \\
 P_{a,soil} &= 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 169.2 \text{ kN/m} \\
 p_{o,min} &= \min(H / H_{ref}, 1) \times q_{d,min} = 10.0 \text{ kN/m}^2
 \end{aligned}$$

**Horizontal forces**

Retained soil  
Surcharge

$$\begin{aligned}
 F_{soil,h} &= \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 139.7 \text{ kN/m} \\
 F_{surch,h} &= \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 47.1 \text{ kN/m}
 \end{aligned}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

$$\begin{aligned}
 F_{gabion,v,t} &= \gamma_{G,t} \times W_g = 136.0 \text{ kN/m} \\
 F_{soil,v,t} &= \gamma_{G,t} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 95.6 \text{ kN/m} \\
 F_{surch,v,t} &= \max((p_{o,G} \times \gamma_{G,t} + p_{o,Q} \times \gamma_{Q,t}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 32.2 \text{ kN/m}
 \end{aligned}$$

**Overturning stability - take moments about the toe**

Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$\begin{aligned}
 M_o &= F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 219.2 \text{ kNm/m} \\
 M_R &= F_{gabion,v,t} \times X_g + F_{soil,v,t} \times b_{v,soil} + F_{surch,v,t} \times b_{v,surch} = 502.4 \text{ kNm/m} \\
 FoSM &= M_R / M_o = 2.292 \\
 FoSM_{allow} &= 1.000
 \end{aligned}$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$\begin{aligned}
 T &= F_{soil,h} + F_{surch,h} = 186.7 \text{ kN/m} \\
 N &= F_{gabion,v,t} + F_{soil,v,t} + F_{surch,v,t} = 263.8 \text{ kN/m} \\
 F_r &= T \times \cos(\epsilon) - N \times \sin(\epsilon) = 148.2 \text{ kN/m} \\
 F_R &= (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{sp,d}) = 160.9 \text{ kN/m} \\
 FoS_S &= F_r / F_t = 1.085 \\
 FoS_S_{allow} &= 1.000
 \end{aligned}$$

**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  
Vertical distance to centre of gravity gabion 3  
Weight of gabion 3  
Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$\begin{aligned}
 x_{g3} &= w_3 / 2 = 1250 \text{ mm} \\
 y_{g3} &= h_3 / 2 = 500 \text{ mm} \\
 W_{g3} &= \gamma_d \times w_3 \times h_3 = 40.0 \text{ kN/m} \\
 x_{g4} &= w_4 / 2 + s_4 = 1000 \text{ mm} \\
 y_{g4} &= h_4 / 2 + h_3 = 1500 \text{ mm} \\
 W_{g4} &= \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m} \\
 x_{g5} &= w_5 / 2 + s_4 + s_5 = 500 \text{ mm} \\
 y_{g5} &= h_5 / 2 + h_3 + h_4 = 2500 \text{ mm} \\
 W_{g5} &= \gamma_d \times w_5 \times h_5 = 16.0 \text{ kN/m} \\
 W_g &= W_{g3} + W_{g4} + W_{g5} = 88.0 \text{ kN/m} \\
 x_g &= ((W_{g3} \times x_{g3}) + (W_{g4} \times x_{g4}) + (W_{g5} \times x_{g5})) / W_g = 1023 \text{ mm} \\
 y_g &= ((W_{g3} \times y_{g3}) + (W_{g4} \times y_{g4}) + (W_{g5} \times y_{g5})) / W_g = 1227 \text{ mm} \\
 X_g &= x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 1184 \text{ mm} \\
 H_r &= y_{g5} + h_5/2 - ((y_{g5} + h_5/2) \times \cos(\epsilon) - (x_{g5} + w_5/2) \times \sin(\epsilon)) = 168 \text{ mm}
 \end{aligned}$$

**Design dimensions**

Effective angle of rear plane of wall

$$\alpha = 90\text{deg} - \text{Atan}((w_3 - (x_{g5} + (w_5 / 2))) / (y_{g5} + h_5 / 2)) + \epsilon = 71.4 \text{ deg}$$



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Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\theta = 90\text{deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_3 \times \sin(\epsilon)) - H_r = 3180 \text{ mm}$$

$$H_{incl} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 2971 \text{ mm}$$

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.345$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 95.2 \text{ kN/m}$$

$$P_{o,min} = \min(H / H_{ref}, 1) \times Q_{d,min} = 10.0 \text{ kN/m}^2$$

**Horizontal forces**  
Retained soil  
Surcharge

$$F_{soil,h} = \gamma_c \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 78.6 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 35.3 \text{ kN/m}$$

**Vertical forces**  
Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,f} = \gamma_{G,f} \times W_g = 88.0 \text{ kN/m}$$

$$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 53.8 \text{ kN/m}$$

$$F_{surch,v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 24.2 \text{ kN/m}$$

**Overturning stability - take moments about the toe**  
Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 99.8 \text{ kNm/m}$$

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times b_{v,soil} + F_{surch,v,f} \times b_{v,surch} = 265.0 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 2.656$$

$$FoS_{M,allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil,h} + F_{surch,h} = 113.9 \text{ kN/m}$$

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 165.9 \text{ kN/m}$$

$$F_r = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 89.7 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 100.9 \text{ kN/m}$$

$$FoS_S = F_r / F_t = 1.125$$

$$FoS_{S,allow} = 1.000$$

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

**Check overturning and sliding between courses 3 and 4**

**Wall geometry**

Horizontal distance to centre of gravity gabion 4  
Vertical distance to centre of gravity gabion 4  
Weight of gabion 4  
Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g4} = w_4 / 2 = 1000 \text{ mm}$$

$$y_{g4} = h_4 / 2 = 500 \text{ mm}$$

$$W_{g4} = \gamma_d \times w_4 \times h_4 = 32.0 \text{ kN/m}$$

$$x_{g5} = w_5 / 2 + s_5 = 500 \text{ mm}$$

$$y_{g5} = h_5 / 2 + h_4 = 1500 \text{ mm}$$

$$W_{g5} = \gamma_d \times w_5 \times h_5 = 16.0 \text{ kN/m}$$

$$W_g = W_{g4} + W_{g5} = 48.0 \text{ kN/m}$$

$$x_g = ((W_{g4} \times x_{g4}) + (W_{g5} \times x_{g5})) / W_g = 833 \text{ mm}$$

$$y_g = ((W_{g4} \times y_{g4}) + (W_{g5} \times y_{g5})) / W_g = 833 \text{ mm}$$

$$X_g = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 941 \text{ mm}$$

$$H_t = y_{g5} + h_5/2 - ((y_{g5} + h_5/2) \times \cos(\epsilon) - (x_{g5} + w_5/2) \times \sin(\epsilon)) = 159 \text{ mm}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90\text{deg} - \text{Atan}((w_4 - (x_{g5} + (w_5 / 2))) / (y_{g5} + h_5 / 2)) + \epsilon = 71.4 \text{ deg}$$

$$\theta = 90\text{deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_4 \times \sin(\epsilon)) - H_r = 2120 \text{ mm}$$

$$H_{incl} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 1981 \text{ mm}$$

$$K_a = \sin(\alpha + \phi'_{r,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 1.345$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 42.3 \text{ kN/m}$$

$$P_{o,min} = \min(H / H_{ref}, 1) \times Q_{d,min} = 7.1 \text{ kN/m}^2$$

**Horizontal forces**  
Retained soil  
Surcharge

$$F_{soil,h} = \gamma_c \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 34.9 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{o,G} \times \gamma_G + p_{o,Q} \times \gamma_Q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 19.4 \text{ kN/m}$$

**Vertical forces**  
Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,f} = \gamma_{G,f} \times W_g = 48.0 \text{ kN/m}$$

$$F_{soil,v,f} = \gamma_{G,f} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 23.9 \text{ kN/m}$$

$$F_{surch,v,f} = \max((p_{o,G} \times \gamma_{G,f} + p_{o,Q} \times \gamma_{Q,f}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 11.4 \text{ kN/m}$$

**Overturning stability - take moments about the toe**  
Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 30.1 \text{ kNm/m}$$

$$M_R = F_{gabion,v,f} \times X_g + F_{soil,v,f} \times b_{v,soil} + F_{surch,v,f} \times b_{v,surch} = 105.3 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 3.496$$

$$FoS_{M,allow} = 1.000$$

**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  
Total vertical force  
Sliding force

$$T = F_{soil,h} + F_{surch,h} = 54.3 \text{ kN/m}$$

$$N = F_{gabion,v,f} + F_{soil,v,f} + F_{surch,v,f} = 83.3 \text{ kN/m}$$

$$F_r = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 42.2 \text{ kN/m}$$



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Project <b>115 Upperbrow Lane, Huddersfield</b>				Job Ref. <b>ES453</b>	
Section <b>Gabion Basket Retaining Wall Design</b>				Sheet no./rev. <b>10</b>	
Calc. by <b>SB</b>	Date <b>03/02/21</b>	Chk'd by <b>SB</b>	Date <b>03/02/21</b>	App'd by	Date

Sliding resistance  
Factor of safety  
Allowable factor of safety

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 50.4 \text{ kN/m}$$

$$FoS_S = F_R / F_t = 1.195$$

$$FoS_{S,allow} = 1.000$$

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

**Check overturning and sliding between courses 4 and 5**

**Wall geometry**

Horizontal distance to centre of gravity gabion 5  
Vertical distance to centre of gravity gabion 5  
Weight of gabion 5  
Weight of entire gabion  
Horiz distance to centre of gravity entire gabion  
Vert distance to centre of gravity entire gabion  
Correcting for wall inclination horiz dist  
Vertical change in height due to wall inclination

$$x_{g5} = w_5 / 2 = 500 \text{ mm}$$

$$y_{g5} = h_5 / 2 = 500 \text{ mm}$$

$$W_{g5} = \gamma_d \times w_5 \times h_5 = 16.0 \text{ kN/m}$$

$$W_g = W_{g5} = 16.0 \text{ kN/m}$$

$$x_g = ((W_{g5} \times x_{g5})) / W_g = 500 \text{ mm}$$

$$y_g = ((W_{g5} \times y_{g5})) / W_g = 500 \text{ mm}$$

$$x_d = x_g \times \cos(\epsilon) + y_g \times \sin(\epsilon) = 565 \text{ mm}$$

$$H_r = y_{g5} + h_5/2 - ((y_{g5} + h_5/2) \times \cos(\epsilon) - (x_{g5} + w_5/2) \times \sin(\epsilon)) = 149 \text{ mm}$$

**Design dimensions**

Effective angle of rear plane of wall  
Effective face angle  
Effective height of wall  
Height of wall from toe to front edge of top gabion  
Active pressure using Coulomb theory  
Active thrust due to soil  
Minimum surcharge (cl.4.6.3.2)

$$\alpha = 90 \text{ deg} + \epsilon = 98.0 \text{ deg}$$

$$\theta = 90 \text{ deg} - \epsilon = 82.0 \text{ deg}$$

$$H = (y_{g5} + h_5 / 2) + (w_5 \times \sin(\epsilon)) - H_r = 990 \text{ mm}$$

$$H_{incl} = ((y_{g5} + h_5 / 2) \times \cos(\epsilon) - (x_{g5} - (w_5 / 2)) \times \sin(\epsilon)) = 990 \text{ mm}$$

$$K_a = \sin(\alpha + \phi'_{s,d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r,d})) = 0.783$$

$$P_{a,soil} = 0.5 \times K_a \times \gamma_{s,d} \times H^2 = 5.4 \text{ kN/m}$$

$$p_{o,min} = \min(H / H_{ref}, 1) \times q_{d,min} = 3.3 \text{ kN/m}^2$$

**Horizontal forces**

Retained soil  
Surcharge

$$F_{soil,h} = \gamma_G \times P_{a,soil} \times \cos(90 - \alpha + \delta_{r,d}) = 5.3 \text{ kN/m}$$

$$F_{surch,h} = \max((p_{o,G} \times \gamma_G + p_{o,q} \times \gamma_q), p_{o,min}) \times K_a \times H \times \cos(90 - \alpha + \delta_{r,d}) = 6.3 \text{ kN/m}$$

**Vertical forces**

Gabion weight  
Retained soil  
Surcharge

$$F_{gabion,v,t} = \gamma_{G,t} \times W_g = 16.0 \text{ kN/m}$$

$$F_{soil,v,t} = \gamma_{G,t} \times P_{a,soil} \times \sin(90 - \alpha + \delta_{r,d}) = 0.7 \text{ kN/m}$$

$$F_{surch,v,t} = \max((p_{o,G} \times \gamma_{G,t} + p_{o,q} \times \gamma_{q,t}), p_{o,min}) \times K_a \times H \times \sin(90 - \alpha + \delta_{r,d}) = 0.5 \text{ kN/m}$$

**Overturning stability - take moments about the toe**

Overturning moment  
Restoring moment  
Factor of safety  
Allowable factor of safety

$$M_o = F_{soil,h} \times d_{h,soil} + F_{surch,h} \times d_{h,surch} = 3.3 \text{ kNm/m}$$

$$M_R = F_{gabion,v,t} \times X_g + F_{soil,v,t} \times d_{v,soil} + F_{surch,v,t} \times d_{v,surch} = 10.4 \text{ kNm/m}$$

$$FoS_M = M_R / M_o = 3.165$$

$$FoS_{M,allow} = 1.000$$

**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  
Total vertical force  
Sliding force  
Sliding resistance  
Factor of safety  
Allowable factor of safety

$$T = F_{soil,h} + F_{surch,h} = 11.7 \text{ kN/m}$$

$$N = F_{gabion,v,t} + F_{soil,v,t} + F_{surch,v,t} = 17.3 \text{ kN/m}$$

$$F_t = T \times \cos(\epsilon) - N \times \sin(\epsilon) = 9.1 \text{ kN/m}$$

$$F_R = (T \times \sin(\epsilon) + N \times \cos(\epsilon)) \times \tan(\delta_{bg,d}) = 10.5 \text{ kN/m}$$

$$FoS_S = F_R / F_t = 1.147$$

$$FoS_{S,allow} = 1.000$$

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

**NOTES**

CDM REGULATIONS 2015

1) Principal Contractor to provide client with Construction Phase Health and Safety File prior to works commencing on site.

**GENERAL**

2) This drawing should be read in conjunction with all relevant drawings and specifications issued by Elysium Structures, the Architect and other specialists.

3) Unless agreed otherwise, the client or contractor shall be responsible for securing the local authority or approved inspector any required commencement notice eg. building notice, full plans.

4) This drawing is not to be sealed from.

Prior to the fabrication of any built in elements, all existing dimensions are to be checked on site and any discrepancy brought to the attention of the engineer immediately.

5) Unless stated otherwise, all dimensions shown are in millimetres (mm)

6) Gabions are to be installed in accordance with manufacturers instructions and faced with wire matching the Gabion Mesh.

7) Internal bracing wires are to be provided to exposed faces. Wires to match gabion mesh. Wires to be provided at 1/3 and 2/3 gabion height for 1m high Gabions and 1/2 height for 0.5m high Gabions.

8) Gabion infill stones shall be hard and durable and 150mm nominal size but not less than 100mm and not greater than 200mm

9) Gabion infill stone to be angular and placed flat to minimize voids and provide a dense stable structure. Gabions to be filled by machine. Stones to the front shall be selected and placed by hand to provide a neat finish.

10) Gabions to be welded mesh 76.2 x 76.2 x 3.4 or 5mm wire. Galvan corrosion protection coating. 3mm Diameter wire for walls up to 3m high. Baskets higher than 3m to have 4mm diameter wire.

11) Formation to be proof rolled with a dead weight roller min. weight 2 tonnes to identify any soft spots which are to be excavated and filled with Type 1 granular sub base material and compacted in layers of 150mm thickness.

12) Backfill material shall comprise a well graded granular material max. particle size 40mm, uniformity coefficient greater than 10 and at a moisture content to ensure a dense stable compacted state SHW 0N.

13) The size of compaction plant used within a 2m distance from the rear of the retaining wall shall have a dead load not greater than 1000kg.

14) UDL Surcharge is taken as: domestic pedestrian (1.5kN/m2). Vehicle traffic areas with vehicle weight less than 3 tonnes (2.5kN/m2) and vehicle traffic areas with weight less than 16 tonnes (3.0kN/m2).

15) Gabion retaining walls are flexible structure. The design of adjacent vehicle trafficked areas should be prepared accordingly.

16) Global Stability - Subject to embankment wall arrangement and in situ walls, the overall stability of the embankment wall arrangement i.e global stability should be checked to ensure satisfactory stability.

17) Rows can be stepped back e.g. 150mm or finished with a flush face as shown.

18) For installations where ground water seepage is encountered from retaining soils or where the wall is subject to flooding consideration, should be given to the incorporation of a geotextile filter membrane as Terrain T1000 or similar to the rear of the wall.

CONTACT ENGINEER IN CASE OF QUERIES

Rev D - 22nd Aug 2022 - As built Retaining Wall Structure



**ELYSIUM STRUCTURES**  
07450482148  
info@elysiumstructures.co.uk

project <b>115 Upperbrow Road, Huddersfield</b>		client <b>BI</b>	
scale <b>1:50</b>	drawn by <b>SB</b>	checked by <b>SB</b>	date <b>Jan 2021</b>
drawing title <b>Gabion Basket Layout</b>		rev <b>D</b>	draw no <b>ES453 - 01</b>

**FOUNDATION SOILS**  
COHESIONLESS I.E SANDS, GRAVELS - INSITU STATE NOT LESS THAN LOOSE. I.E CAN'T BE EXCAVATED WITH A SPADE, 50mm PEG EASILY DRIVEN.

**COHESIVE SOILS I.E. MIN FIRM CLAYS - PLASTICITY INDEX NOT GREATER THAN 23%**

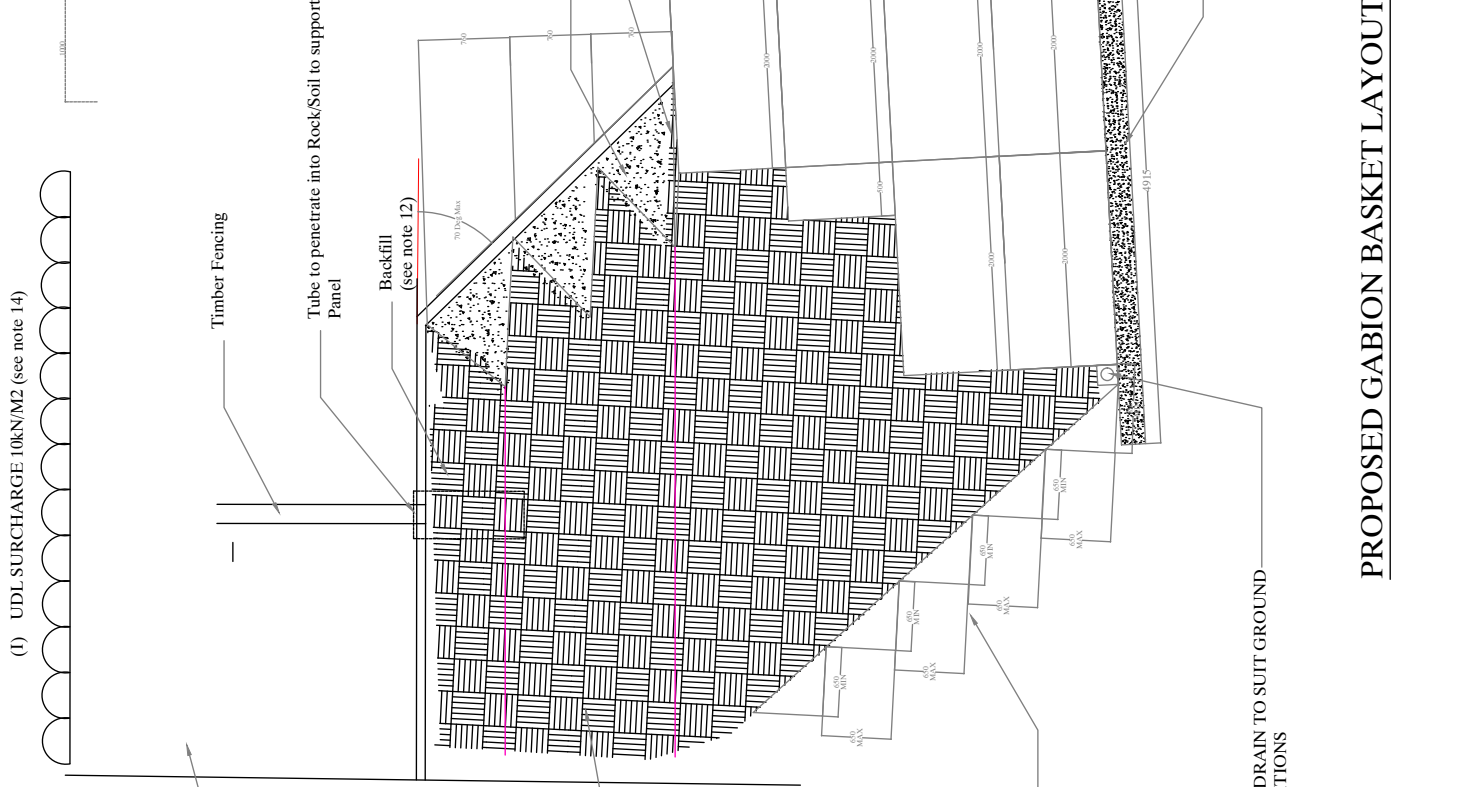
**MAXIMUM IMPOSED FOUNDATION PRESSURES**  
SLS - 200 kN/m2  
ULS - 318 kN/m2

**CONTRACTOR NOTES:**

-HEIGHT OF RETAINING WALL TO BE CONFIRMED ONSITE PRIOR TO ORDERING OF MATERIALS.

-RETAINING WALL TO BE BUILT FROM GROUND UP WITH ACCEPTABLE TEMPORARY PROPPING TO EMBANKMENT.

-TERRAMESH WALL TO BE BUILT FROM 4M HEIGHT IN ACCORDANCE WITH MANUFACTURERS INSTRUCTIONS



BASE BENEATH THE WALLS TO COMPRISE OFF 300MM REINFORCED CONCRETE BASE WITH A393 MESH TOP AND BOTTOM TO FORM A DENSE STABLE MASS.  
(HARDCORE NOT SUITABLE DUE TO HIGH WATER TABLE AND POTENTIAL FOR HEAVE)

**PROPOSED GABION BASKET LAYOUT**

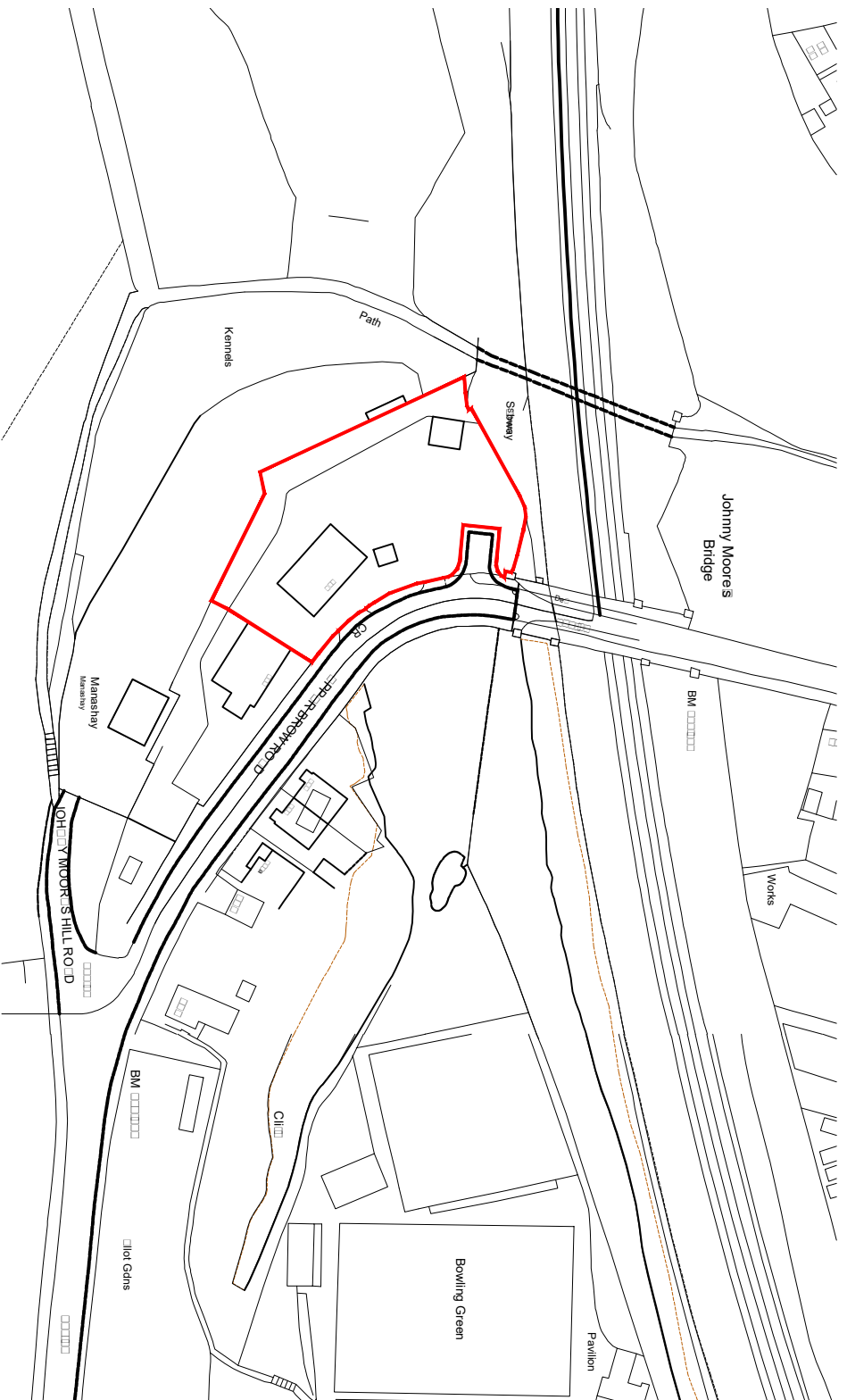
(II) SLOPE  
LOAD COMBINATIONS TO BE SUBJECT TO SEPARATE CONSIDERATIONS

see note 18 for Ground water seepage protection

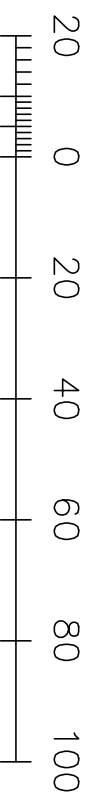
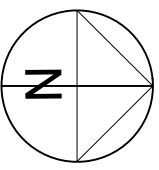
SAFE TEMPORARY BATTER TO SUIT GROUND CONDITIONS. TYPICALLY 45 DEGREES UPON WHICH STANDARD DESIGNS ARE BASED, WALL DESIGN TO BE REVIEWED FOR OTHER TEMPORARY BATTER SLOPES.

LAND DRAIN TO SUIT GROUND CONDITIONS





**1** LOCATION PLAN  
Scale: 1:1250



Metres

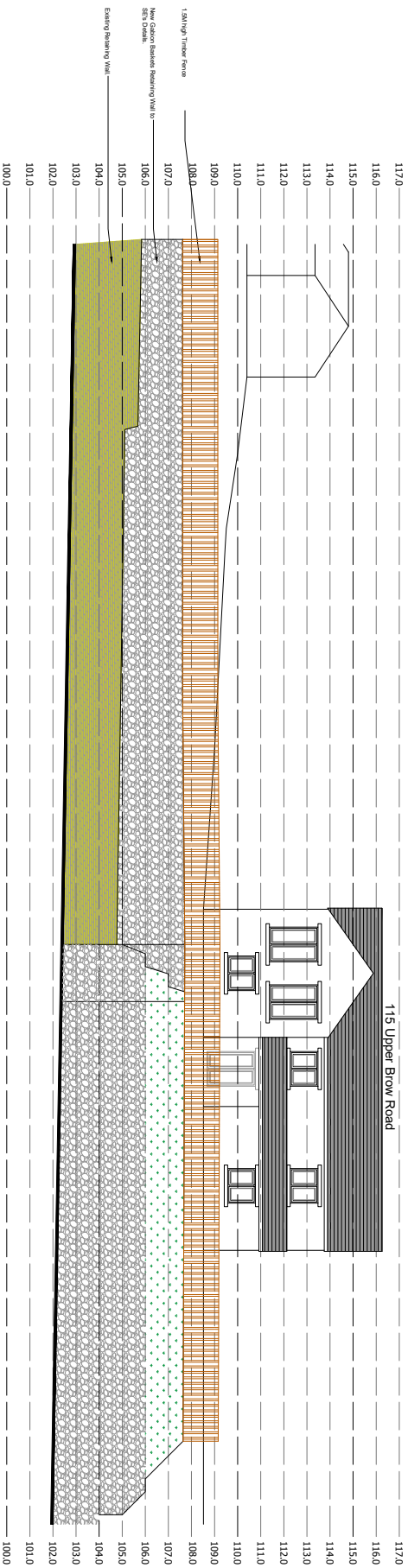
Only figured dimensions should be used.  
Scaled dimensions should be checked with the Architect.  
This drawing together with the design, is the property and copyright of the Architect and must not be reproduced without written permission

DO NOT SCALE THIS DRAWING	rev	description	drwn	atn	date

Client <b>MRS R BIBI</b>		Project <b>PPR BROW ROAD</b>		Description <b>LOCATION PLAN</b>	
Project <input type="checkbox"/>	Drawing <input type="checkbox"/>	Rev <input type="checkbox"/>	Scale <input type="checkbox"/>	Date Drawn <input type="checkbox"/>	Drawn By <input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
				Authorised By <input type="checkbox"/>	Planning <input checked="" type="checkbox"/> Building Regs <input type="checkbox"/> Tender <input type="checkbox"/> Construction <input type="checkbox"/> Co <input type="checkbox"/> Rent <input type="checkbox"/> In <input type="checkbox"/>
				<b>JC</b>	

**NOUVEN**  
DESIGNERS & ARCHITECTS

acumenarchitects.co.uk      01484 546 000  
Headrow House, Old Leeds Road, Huddersfield, HD1 1SG



1 PROPOSED REAR ELEVATION  
 SCALE: 1:100

CONTRACT SCALE OFF THE DRAWING			
1:100	1:200	1:500	1:1000

CLIENT		MRS R BIBI	
PROJECT		115 UPPER BROW ROAD HUDDERSFIELD	
PROJECT NO	CLIENT REF	NO	REV
2709	(100)03	A	
DATE			
DATE ORDERED	DATE BY	APPROVED BY	
1:100 @ A1	15/07/21		
PROPOSED REAR ELEVATION			

# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 001



Photo 002



Photo 003



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 004



Photo 005



Photo 006



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 007



Photo 008



Photo 009



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 010



Photo 011



Photo 012



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 013



Photo 014



Photo 015



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 016



Photo 017



Photo 018



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 019



Photo 020



Photo 021



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 022



Photo 023



Photo 024



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 025



Photo 026



Photo 027



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 028



Photo 029



Photo 030



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 031



Photo 032



Photo 033



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 034



Photo 035



Photo 036



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 037



Photo 038



Photo 039



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 040



Photo 041



Photo 042



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 043



Photo 044



Photo 045



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 046



Photo 047



Photo 048



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 049



Photo 050



Photo 051



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 052



Photo 053



Photo 054



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 055



Photo 056



Photo 057



# Photographic record of

115 Upper Brow Road, HD1 4UP (Drone Survey) Survey dated 13 October 2021

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Photo 058



Photo 059



Photo 060



# Photographic record of

RafeenBi, 115 Upper Brow Road, HD1 4UP Survey [during construction]

Photo IMG P100



Photo IMG P101



Photo IMG P102



# Photographic record of

RafeenBi, 115 Upper Brow Road, HD1 4UP Survey [during construction]

Photo IMG P104



Photo IMG P105



Photo IMG P106

