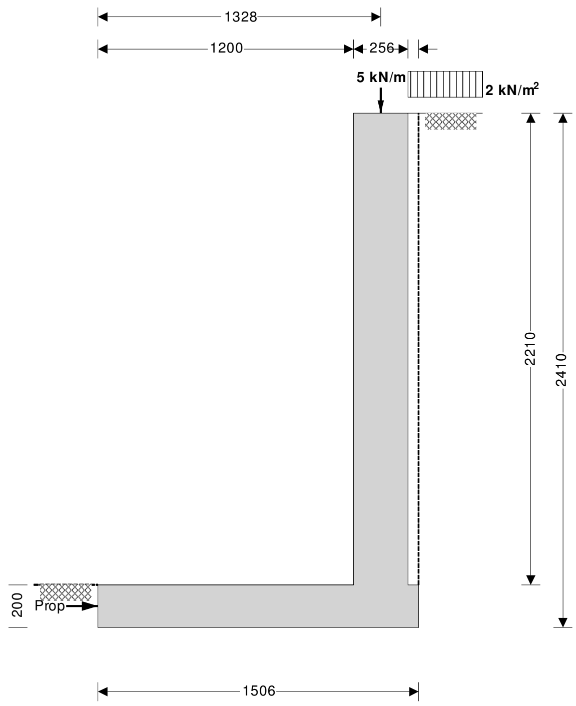
RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at base**
Height of retaining wall stem	h_{stem} = **2210** mm
Thickness of wall stem	t_{wall} = **256** mm
Length of toe	l_{toe} = **1200** mm
Length of heel	l_{heel} = **50** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **1506** mm
Thickness of base	t_{base} = **200** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **1150** mm
Thickness of downstand	t_{ds} = **200** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **2410** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **25.0** kN/m^3
Density of base construction	γ_{base} = **25.0** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **2410** mm

Retained material details

Dense, moderately graded, sub-angular, gravel

Mobilisation factor M = **1.5**

Moist density of retained material γ_m = **18.0** kN/m^3

Saturated density of retained material γ_s = **21.0** kN/m^3

Design shear strength ϕ' = **24.2** deg

Angle of wall friction δ = **0.0** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3

Design shear strength ϕ'_b = **24.2** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **120** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan Surcharge = **1.5** kN/m^2

Applied vertical dead load on wall W_{dead} = **5.2** kN/m

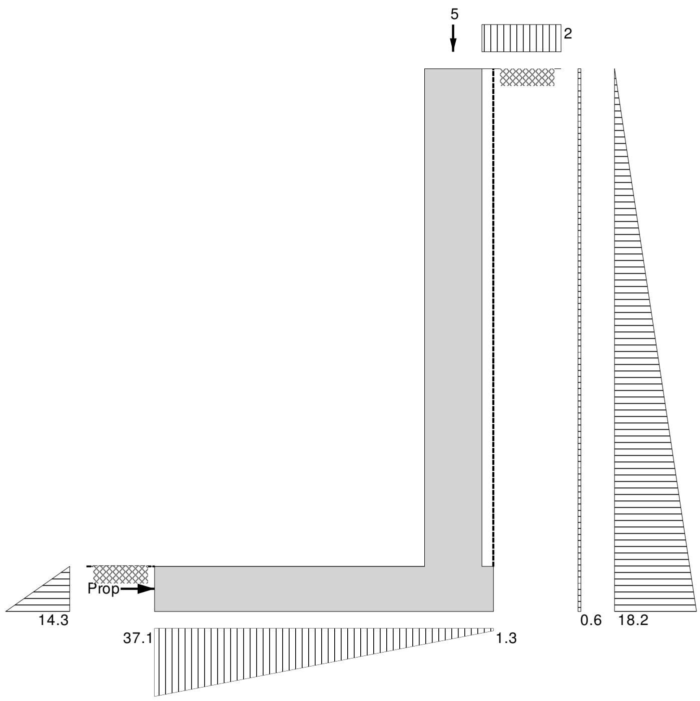
Applied vertical live load on wall W_{live} = **0.0** kN/m

Position of applied vertical load on wall l_{load} = **1328** mm

Applied horizontal dead load on wall F_{dead} = **0.0** kN/m

Applied horizontal live load on wall F_{live} = **0.0** kN/m

Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **14.1** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **7.5** kN/m

Surcharge w_{sur} = Surcharge $\times l_{heel}$ = **0.1** kN/m

Moist backfill to top of wall $w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **2** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **5.2** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + w_{sur} + w_{m\_w} + W_v$ = **28.9** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times$ Surcharge $\times h_{eff}$ = **1.5** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **21.9** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a}$ = **23.4** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **1.4** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - w_{sur}) \times \tan(\delta_b), 0\ kN/m)$

F_{prop} = **12.2** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **1.8** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **17.6** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a}$ = **19.4** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **18.8** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **5.7** kNm/m

Moist backfill $M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **2.9** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load}$ = **6.9** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{m\_r} + M_{dead}$ = **34.3** kNm/m

Check bearing pressure

Surcharge $M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **0.1** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{sur\_r}$ = **15** kNm/m

Total vertical reaction $R = W_{total}$ = **28.9** kN/m

Distance to reaction $x_{bar} = M_{total} / R$ = **519** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **234** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **37.1** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **1.3** kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **19.8** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **10.5** kN/m

Surcharge $w_{sur\_f} = \gamma_{f\_l} \times Surcharge \times l_{heel}$ = **0.1** kN/m

Moist backfill to top of wall $w_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **2.8** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **7.3** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{sur\_f} + w_{m\_w\_f} + W_{v\_f}$ = **40.5** kN/m

Factored horizontal active forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_a \times Surcharge \times h_{eff}$ = **2.4** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **30.6** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **33** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **2** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - w_{sur\_f}) \times \tan(\delta_b), 0\ kN/m)$

F_{prop_f} = **17.4** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **2.9** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **24.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f}$ = **27.5** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **26.3** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **7.9** kNm/m

Surcharge $M_{sur\_r\_f} = w_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **0.2** kNm/m

Moist backfill $M_{m\_r\_f} = (w_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + w_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **4.1** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **9.7** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{sur\_r\_f} + M_{m\_r\_f} + M_{v\_f}$ = **48.2** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **20.7** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **40.5** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **510** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **243** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **52.9** kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **0.9** kN/m²

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **34.55** kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **11.5** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2)$ = **7** kN/m²

Bearing pressure at stem / heel — $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{2.6}\ kN/m^2$

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete — $f_{cu} = \mathbf{40}\ N/mm^2$

Characteristic strength of reinforcement — $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement — $k = \mathbf{0.13}\ \%$

Cover to reinforcement in toe — $c_{toe} = \mathbf{40}\ mm$

Calculate shear for toe design

Shear from bearing pressure — $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{38.6}\ kN/m$

Shear from weight of base — $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{8.4}\ kN/m$

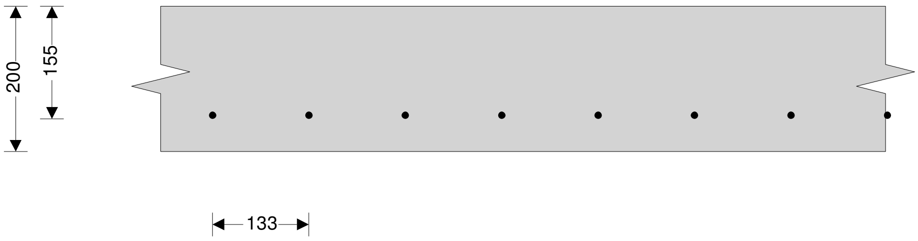
Total shear for toe design — $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{30.2}\ kN/m$

Calculate moment for toe design

Moment from bearing pressure — $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{33.2}\ kNm/m$

Moment from weight of base — $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{6.2}\ kNm/m$

Total moment for toe design — $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{27}\ kNm/m$



Check toe in bending

Width of toe — $b = \mathbf{1000}\ mm/m$

Depth of reinforcement — $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{155.0}\ mm$

Constant — $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.028}$

Compression reinforcement is not required

Lever arm — $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

$z_{toe} = \mathbf{147}\ mm$

Area of tension reinforcement required — $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{422}\ mm^2/m$

Minimum area of tension reinforcement — $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{260}\ mm^2/m$

Area of tension reinforcement required — $A_{s\_toe\_req} = \max(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{422}\ mm^2/m$

Reinforcement provided — **10 mm dia.bars @ 133 mm centres**

Area of reinforcement provided — $A_{s\_toe\_prov} = \mathbf{591}\ mm^2/m$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.195}\ N/mm^2$

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 = \mathbf{5.000}\ N/mm^2$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress — $v_{c\_toe} = \mathbf{0.679}\ N/mm^2$

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall heel (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in heel c_{heel} = **20** mm

Calculate shear for heel design

Shear from bearing pressure $V_{heel\_bear} = (p_{heel\_f} + p_{stem\_heel\_f}) \times l_{heel} / 2$ = **0.1** kN/m

Shear from weight of base $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base}$ = **0.4** kN/m

Shear from weight of moist backfill $V_{heel\_wt\_m} = w_{m\_w\_f}$ = **2.8** kN/m

Shear from surcharge $V_{heel\_sur} = w_{sur\_f}$ = **0.1** kN/m

Total shear for heel design $V_{heel} = - V_{heel\_bear} + V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_sur}$ = **3.2** kN/m

Calculate moment for heel design

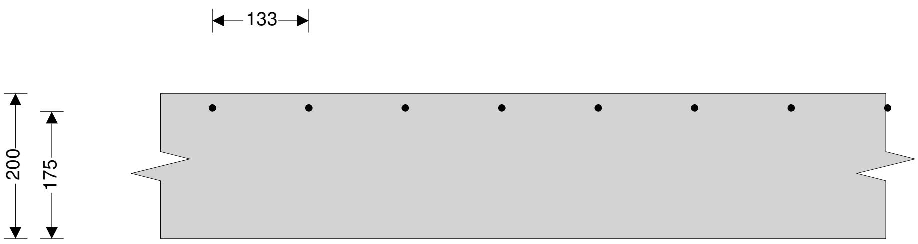
Moment from bearing pressure $M_{heel\_bear} = (2 \times p_{heel\_f} + p_{stem\_mid\_f}) \times (l_{heel} + t_{wall} / 2)^2 / 6$ = **0** kNm/m

Moment from weight of base $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2)$ = **0.1** kNm/m

Moment from weight of moist backfill $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2$ = **0.4** kNm/m

Moment from surcharge $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2$ = **0** kNm/m

Total moment for heel design $M_{heel} = - M_{heel\_bear} + M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_sur}$ = **0.5** kNm/m



Check heel in bending

Width of heel b = **1000** mm/m

Depth of reinforcement $d_{heel} = t_{base} - c_{heel} - (\phi_{heel} / 2)$ = **175.0** mm

Constant $K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu})$ = **0.000**

Compression reinforcement is not required

Lever arm $z_{heel} = \min(0.5 + \sqrt{(0.25 - (\min(K_{heel}, 0.225) / 0.9))},0.95) \times d_{heel}$

z_{heel} = **166** mm

Area of tension reinforcement required $A_{s\_heel\_des} = M_{heel} / (0.87 \times f_y \times z_{heel})$ = **7** mm^2/m

Minimum area of tension reinforcement $A_{s\_heel\_min} = k \times b \times t_{base}$ = **260** mm^2/m

Area of tension reinforcement required $A_{s\_heel\_req} = \mathrm{Max}(A_{s\_heel\_des}, A_{s\_heel\_min})$ = **260** mm^2/m

Reinforcement provided **10 mm dia.bars @ 133 mm centres**

Area of reinforcement provided $A_{s\_heel\_prov}$ = **591** mm^2/m

PASS - Reinforcement provided at the retaining wall heel is adequate

Check shear resistance at heel

Design shear stress $v_{heel} = V_{heel} / (b \times d_{heel})$ = **0.018** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \mathrm{N/mm^2})}, 5) \times 1\ \mathrm{N/mm^2}$ = **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_heel} = **0.633** N/mm^2

v_{heel} < v_{c_heel} - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **65** mm

Cover to reinforcement in wall c_{wall} = **65** mm

Factored horizontal active forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_a \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **2.2** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **25.8** kN/m

Calculate shear for stem design

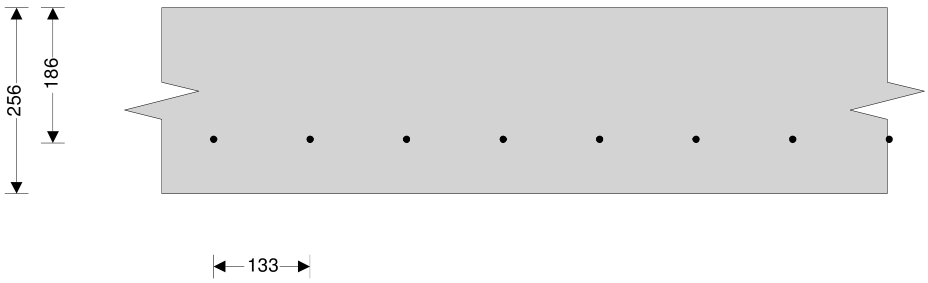
Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} - F_{prop\_f}$ = **10.5** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **2.7** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **21.5** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **24.2** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **186.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.018**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **177** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **315** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **333** mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **333** mm^2/m

Reinforcement provided **10 mm dia.bars @ 133 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **591** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.057** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000} \text{ N/mm}^2$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_stem} = \mathbf{0.611} \text{ N/mm}^2$

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas} = \mathbf{7}$

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) = \mathbf{187.9} \text{ N/mm}^2$

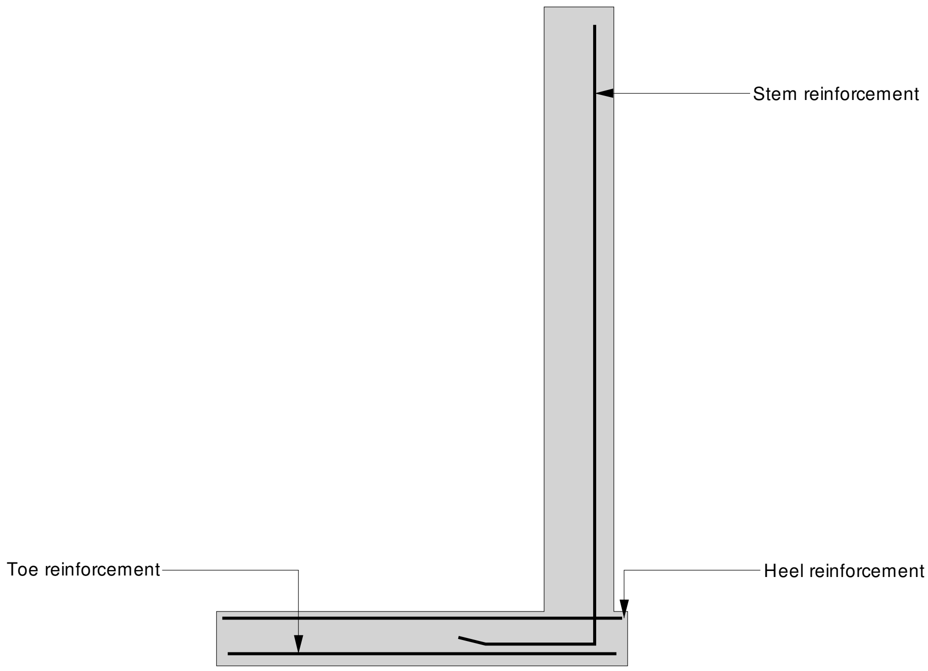
Modification factor $factor_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2) = \mathbf{2.00}$

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens} = \mathbf{14.00}$

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem} = \mathbf{11.88}$

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 10 mm dia.@ 133 mm centres - (591 mm^2/m)
Heel bars - 10 mm dia.@ 133 mm centres - (591 mm^2/m)
Stem bars - 10 mm dia.@ 133 mm centres - (591 mm^2/m)