Calculations for retaining wall based on drawings prepared by Hartleys Projects Ltd series LG03
SI report shows stiff London clay to depth
surcharge load @ 10kN/m$^2$

## TIMBER FLOOR LOADING (1ST FLOOR)

**Dead load**

Boards $Floor_{1\_D1}$ = **0.15** kN/m$^2$

Joists $Floor_{1\_D2}$ = **0.15** kN/m$^2$

Ceiling $Floor_{1\_D3}$ = **0.14** kN/m$^2$

Total dead load $Floor_{1\_DL}$ = sum($Floor_{1\_D1}$,$Floor_{1\_D2}$,$Floor_{1\_D3}$) = **0.44** kN/m$^2$

**Imposed load**

Imposed load $Floor_{1\_I1}$ = **1.50** kN/m$^2$

Partitions $Floor_{1\_I2}$ = **0.00** kN/m$^2$

Total imposed load $Floor_{1\_IL}$ = sum($Floor_{1\_I1}$,$Floor_{1\_I2}$) = **1.50** kN/m$^2$

**Total 1st floor loads**

Unfactored foundation design loads $w_{floor1\_u}$ = $Floor_{1\_DL}$ + $Floor_{1\_IL}$ = **1.94** kN/m$^2$

Factored design loads $w_{floor1\_f}$ = 1.4 × $Floor_{1\_DL}$ + 1.6 × $Floor_{1\_IL}$ = **3.02** kN/m$^2$

## ROOF LOADING (FLAT TIMBER ROOF)

**Dead load**

Chippings $Roof_{D1}$ = **0.10** kN/m$^2$

Felt $Roof_{D2}$ = **0.15** kN/m$^2$

Insulation and vapour barrier $Roof_{D3}$ = **0.05** kN/m$^2$

Boarding $Roof_{D4}$ = **0.10** kN/m$^2$

Joists $Roof_{D5}$ = **0.15** kN/m$^2$

Ceiling $Roof_{D6}$ = **0.14** kN/m$^2$

Services $Roof_{D7}$ = **0.05** kN/m$^2$

Total dead load on plan

$Roof_{DL}$ = sum($Roof_{D1}$,$Roof_{D2}$,$Roof_{D3}$,$Roof_{D4}$,$Roof_{D5}$,$Roof_{D6}$,$Roof_{D7}$) = **0.74** kN/m$^2$

**Imposed load**

Roof imposed load $Roof_{IL}$ = **0.75** kN/m$^2$

**Total roof loads**

Unfactored foundation design loads $w_{roof\_u}$ = $Roof_{DL}$ + $Roof_{IL}$ = **1.49** kN/m$^2$

Factored design loads $w_{roof\_f}$ = 1.4 × $Roof_{DL}$ + 1.6 × $Roof_{IL}$ = **2.24** kN/m$^2$

## CAVITY WALL LOADING

**Dead load**

Masonry (outer leaf) $CW_{D1}$ = **2.25** kN/m$^2$

Masonry (inner leaf) $CW_{D2}$ = **0.80** kN/m$^2$

Plaster $CW_{D3}$ = **0.15** kN/m$^2$

Total dead load $CW_{DL}$ = sum($CW_{D1}$,$CW_{D2}$,$CW_{D3}$) = **3.20** kN/m$^2$

**Total cavity wall load**

Unfactored foundation design loads $w_{cw\_u}$ = $CW_{DL}$ = **3.20** kN/m$^2$

Factored design loads $w_{cw\_f}$ = 1.4 × $CW_{DL}$ = **4.48** kN/m$^2$

load to retaining wall

| | | | | | |
|---|---|---|---|---|---|
| floor | dead | 0.44x3.5 | 1.54 | live | 5.25 |
| roof | | 0.74x3.5 | 2.59 | | 2.63 |
| wall | | 3.20x3 | 9.60 | | 7.88kN/m |
| | | | 13.73kN/m | | |

## RETAINING WALL ANALYSIS & DESIGN (BS8002)

### 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 $h_{stem}$ = **3200** mm

Thickness of wall stem $t_{wall}$ = **300** mm

Length of toe $l_{toe}$ = **1350** mm

Length of heel $l_{heel}$ = **150** mm

Overall length of base $l_{base}$ = $l_{toe}$ + $l_{heel}$ + $t_{wall}$ = **1800** mm

Thickness of base $t_{base}$ = **350** mm

Depth of downstand $d_{ds}$ = **500** mm

Position of downstand $l_{ds}$ = **0** mm

Thickness of downstand $t_{ds}$ = **200** mm

Height of retaining wall $h_{wall}$ = $h_{stem}$ + $t_{base}$ + $d_{ds}$ = **4050** mm

Depth of cover in front of wall $d_{cover}$ = **200** mm

Depth of unplanned excavation $d_{exc}$ = **200** mm

Height of ground water behind wall $h_{water}$ = **1500** mm

Height of saturated fill above base $h_{sat}$ = max($h_{water}$ - $t_{base}$ - $d_{ds}$, 0 mm) = **650** mm

Density of wall construction $\gamma_{wall}$ = **23.6** kN/m$^3$

Density of base construction $\gamma_{base}$ = **23.6** kN/m$^3$

Angle of rear face of wall $\alpha$ = **90.0** deg

Angle of soil surface behind wall $\beta$ = **0.0** deg

Effective height at virtual back of wall $h_{eff}$ = $h_{wall}$ + $l_{heel}$ × tan($\beta$) = **4050** mm

**Retained material details**

Mobilisation factor M = **1.5**

Moist density of retained material $\gamma_m$ = **16.0** kN/m$^3$

Saturated density of retained material $\gamma_s$ = **20.0** kN/m$^3$

Design shear strength $\phi'$ = **24.2** deg

Angle of wall friction $\delta$ = **18.6** deg

**Base material details**

Stiff clay

Moist density $\gamma_{mb}$ = **18.0** kN/m$^3$

Design shear strength $\phi'_b$ = **24.2** deg

Design base friction $\delta_b$ = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **150** kN/m$^2$

**Using Coulomb theory**

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.369}$$

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 $K_0 = 1 - \sin(\phi') = \mathbf{0.590}$

**Loading details**

Surcharge load on plan Surcharge = **10.0** kN/m$^2$

Applied vertical dead load on wall $W_{dead}$ = **13.7** kN/m

Applied vertical live load on wall $W_{live}$ = **7.9** kN/m

Position of applied vertical load on wall $l_{load}$ = **1500** 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

**Vertical forces on wall**

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **22.7** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **14.9** kN/m

Wall downstand $w_{ds} = d_{ds} \times t_{ds} \times \gamma_{base}$ = **2.4** kN/m

Surcharge $w_{sur}$ = Surcharge $\times\, l_{heel}$ = **1.5** kN/m

Moist backfill to top of wall $w_{m\_w} = l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **6.1** kN/m

Saturated backfill $w_s = l_{heel} \times h_{sat} \times \gamma_s$ = **1.9** kN/m

Soil in front of wall $w_p = l_{toe} \times d_{cover} \times \gamma_{mb}$ = **4.9** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **21.6** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + w_{ds} + w_{sur} + w_{m\_w} + w_s + w_p + W_v$ = **75.9** kN/m

**Horizontal forces on wall**

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times$ Surcharge $\times\, h_{eff}$ = **14.2** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **18.2** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **21.4** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **4** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **11** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **68.8** kN/m

**Calculate propping force**

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **25.8** kN/m

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

$F_{prop}$ = **22.3** kN/m

**Overturning moments**

Surcharge — $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **21.6** kNm/m

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **33.7** kNm/m

Moist backfill below water table — $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **5.4** kNm/m

Soil in front of wall — $M_{p\_o} = F_p \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **5.6** kNm/m

Total overturning moment — $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_{p\_o}$ = **66.2** kNm/m

**Restoring moments**

Wall stem — $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **34** kNm/m

Wall base — $M_{base} = w_{base} \times l_{base} / 2$ = **13.4** kNm/m

Wall downstand — $M_{ds} = w_{ds} \times (l_{ds} + t_{ds} / 2)$ = **0.2** kNm/m

Moist backfill — $M_{m\_r} = (w_{m\_w} \times (l_{base} - l_{heel} / 2) + w_{m\_s} \times (l_{base} - l_{heel} / 3))$ = **10.6** kNm/m

Saturated backfill — $M_{s\_r} = w_s \times (l_{base} - l_{heel} / 2)$ = **3.4** kNm/m

Design vertical dead load — $M_{dead} = W_{dead} \times l_{load}$ = **20.6** kNm/m

Total restoring moment — $M_{rest} = M_{wall} + M_{base} + M_{ds} + M_{m\_r} + M_{s\_r} + M_{dead}$ = **82.1** kNm/m

**Check bearing pressure**

Surcharge — $M_{sur\_r} = w_{sur} \times (l_{base} - l_{heel} / 2)$ = **2.6** kNm/m

Soil in front of wall — $M_{p\_r} = w_p \times l_{toe} / 2$ = **3.3** kNm/m

Design vertical live load — $M_{live} = W_{live} \times l_{load}$ = **11.8** kNm/m

Total moment for bearing — $M_{total} = M_{rest} - M_{ot} + M_{sur\_r} + M_{p\_r} + M_{live}$ = **33.6** kNm/m

Total vertical reaction — $R = W_{total}$ = **75.9** kN/m

Distance to reaction — $x_{bar} = M_{total} / R$ = **442** mm

Eccentricity of reaction — $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **458** mm

***Reaction acts outside middle third of base***

Bearing pressure at toe — $p_{toe} = R / (1.5 \times x_{bar})$ = **114.4** kN/m$^2$

Bearing pressure at heel — $p_{heel}$ = 0 kN/m$^2$ = **0** kN/m$^2$

***PASS - Maximum bearing pressure is less than allowable bearing pressure***

**<u>RETAINING WALL DESIGN (BS 8002:1994)</u>**

TEDDS calculation version 1.2.01.06

**Ultimate limit state load factors**

Dead load factor — $\gamma_{f\_d}$ = **1.4**

Live load factor — $\gamma_{f\_l}$ = **1.6**

Earth and water pressure factor — $\gamma_{f\_e}$ = **1.4**

**Factored vertical forces on wall**

Wall stem — $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **31.7** kN/m

Wall base — $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **20.8** kN/m

Wall downstand — $w_{ds\_f} = \gamma_{f\_d} \times d_{ds} \times t_{ds} \times \gamma_{base}$ = **3.3** kN/m

Surcharge — $w_{sur\_f} = \gamma_{f\_l} \times \text{Surcharge} \times l_{heel}$ = **2.4** kN/m

| | |
|---|---|
| Moist backfill to top of wall | $w_{m\_w\_f} = \gamma_{f\_d} \times l_{heel} \times (h_{stem} - h_{sat}) \times \gamma_m$ = **8.6** kN/m |
| Saturated backfill | $w_{s\_f} = \gamma_{f\_d} \times l_{heel} \times h_{sat} \times \gamma_s$ = **2.7** kN/m |
| Soil in front of wall | $w_{p\_f} = \gamma_{f\_d} \times l_{toe} \times d_{cover} \times \gamma_{mb}$ = **6.8** kN/m |
| Applied vertical load | $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **31.8** kN/m |
| Total vertical load | $W_{total\_f} = w_{wall\_f} + w_{base\_f} + w_{ds\_f} + w_{sur\_f} + w_{m\_w\_f} + w_{s\_f} + w_{p\_f} + W_{v\_f}$ = **108.2** kN/m |

**Factored horizontal active forces on wall**

| | |
|---|---|
| Surcharge | $F_{sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times h_{eff}$ = **22.7** kN/m |
| Moist backfill above water table | $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **25.5** kN/m |
| Moist backfill below water table | $F_{m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **30** kN/m |
| Saturated backfill | $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **5.6** kN/m |
| Water | $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **15.5** kN/m |
| Total horizontal load | $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **99.2** kN/m |

**Calculate propping force**

| | |
|---|---|
| Passive resistance of soil in front of wall | $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **36.1** kN/m |
| Propping force | $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - w_{sur\_f} - w_{p\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0$ kN/m) |
| | $F_{prop\_f}$ = **34.0** kN/m |

**Factored overturning moments**

| | |
|---|---|
| Surcharge | $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.6** kNm/m |
| Moist backfill above water table | $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **47.1** kNm/m |
| Moist backfill below water table | $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **7.5** kNm/m |
| Soil in front of wall | $M_{p\_o\_f} = F_{p\_f} \times [2 \times d_{ds} - t_{base} - d_{cover} + d_{exc}] / 3$ = **7.8** kNm/m |
| Total overturning moment | $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{p\_o\_f}$ = **97** kNm/m |

**Restoring moments**

| | |
|---|---|
| Wall stem | $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **47.6** kNm/m |
| Wall base | $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **18.7** kNm/m |
| Wall downstand | $M_{ds\_f} = w_{ds\_f} \times (l_{ds} + t_{ds} / 2)$ = **0.3** kNm/m |
| Surcharge | $M_{sur\_r\_f} = w_{sur\_f} \times (l_{base} - l_{heel} / 2)$ = **4.1** kNm/m |
| Moist backfill | $M_{m\_r\_f} = (w_{m\_w\_f} \times (l_{base} - l_{heel} / 2) + w_{m\_s\_f} \times (l_{base} - l_{heel} / 3))$ = **14.8** kNm/m |
| Saturated backfill | $M_{s\_r\_f} = w_{s\_f} \times (l_{base} - l_{heel} / 2)$ = **4.7** kNm/m |
| Soil in front of wall | $M_{p\_r\_f} = w_{p\_f} \times l_{toe} / 2$ = **4.6** kNm/m |
| Design vertical load | $M_{v\_f} = W_{v\_f} \times l_{load}$ = **47.7** kNm/m |
| Total restoring moment | $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{ds\_f} + M_{sur\_r\_f} + M_{m\_r\_f} + M_{s\_r\_f} + M_{p\_r\_f} + M_{v\_f}$ = **142.6** kNm/m |

**Factored bearing pressure**

| | |
|---|---|
| Total moment for bearing | $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **45.6** kNm/m |
| Total vertical reaction | $R_f = W_{total\_f}$ = **108.2** kN/m |
| Distance to reaction | $x_{bar\_f} = M_{total\_f} / R_f$ = **421** mm |
| Eccentricity of reaction | $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **479** mm |
| | ***Reaction acts outside middle third of base*** |
| Bearing pressure at toe | $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **171.1** kN/m$^2$ |

Bearing pressure at heel $p_{heel\_f}$ = 0 kN/m² = **0** kN/m²

Rate of change of base reaction rate = $p_{toe\_f}$ / (3 × $x_{bar\_f}$) = **135.38** kN/m²/m

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

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

Bearing pressure at stem / heel $p_{stem\_heel\_f}$ = max($p_{toe\_f}$ - (rate × ($l_{toe}$ + $t_{wall}$)), 0 kN/m²) = **0** kN/m²

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

### Material properties

Characteristic strength of concrete $f_{cu}$ = **35** N/mm²

Characteristic strength of reinforcement $f_y$ = **500** N/mm²

### Base details

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

Cover to reinforcement in toe $c_{toe}$ = **40** mm

### Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear}$ = 3 × $p_{toe\_f}$ × $x_{bar\_f}$ / 2 = **108.2** kN/m

Shear from weight of base $V_{toe\_wt\_base}$ = $\gamma_{f\_d}$ × $\gamma_{base}$ × $l_{toe}$ × $t_{base}$ = **15.6** kN/m

Shear from weight of downstand $V_{toe\_wt\_ds}$ = $\gamma_{f\_d}$ × $\gamma_{base}$ × $d_{ds}$ × $t_{ds}$ = **3.3** kN/m

Shear from weight of soil $V_{toe\_wt\_soil}$ = $w_{p\_f}$ - ($\gamma_{f\_d}$ × $\gamma_m$ × $l_{toe}$ × $d_{exc}$) = **0.8** kN/m

Total shear for toe design $V_{toe}$ = $V_{toe\_bear}$ - $V_{toe\_wt\_base}$ - $V_{toe\_wt\_ds}$ - $V_{toe\_wt\_soil}$ = **88.5** kN/m

### Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear}$ = 3 × $p_{toe\_f}$ × $x_{bar\_f}$ × ($l_{toe}$ - $x_{bar\_f}$ + $t_{wall}$ / 2) / 2 = **116.7** kNm/m

Moment from weight of base $M_{toe\_wt\_base}$ = ($\gamma_{f\_d}$ × $\gamma_{base}$ × $t_{base}$ × ($l_{toe}$ + $t_{wall}$ / 2)² / 2) = **13** kNm/m

Moment from weight of downstand $M_{toe\_wt\_ds}$ = $\gamma_{f\_d}$ × $\gamma_{base}$ × $d_{ds}$ × $t_{ds}$ × ($l_{toe}$ - $l_{ds}$ + ($t_{wall}$ - $t_{ds}$) / 2) = **4.6** kNm/m

Moment from weight of soil $M_{toe\_wt\_soil}$ = ($w_{p\_f}$ - ($\gamma_{f\_d}$ × $\gamma_m$× $l_{toe}$× $d_{exc}$)) × ($l_{toe}$ + $t_{wall}$) / 2 = **0.6** kNm/m

Total moment for toe design $M_{toe}$ = $M_{toe\_bear}$ - $M_{toe\_wt\_base}$ - $M_{toe\_wt\_ds}$ - $M_{toe\_wt\_soil}$ = **98.4** kNm/m

### Check toe in bending

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

Depth of reinforcement $d_{toe}$ = $t_{base}$ – $c_{toe}$ – ($\phi_{toe}$ / 2) = **305.0** mm

Constant $K_{toe}$ = $M_{toe}$ / (b × $d_{toe}^2$ × $f_{cu}$) = **0.030**

***Compression reinforcement is not required***

Lever arm $z_{toe}$ = min(0.5 + √(0.25 - (min($K_{toe}$, 0.225) / 0.9)),0.95) × $d_{toe}$

$z_{toe}$ = **290** mm

Area of tension reinforcement required $As_{toe\_des}$ = $M_{toe}$ / (0.87 × $f_y$ × $z_{toe}$) = **781** mm²/m

Minimum area of tension reinforcement $As_{toe\_min}$ = k × b × $t_{base}$ = **455** mm²/m

Area of tension reinforcement required $As_{toe\_req}$ = Max($As_{toe\_des}$, $As_{toe\_min}$) = **781** mm²/m

Reinforcement provided **10 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $As_{toe\_prov}$ = **785** mm²/m

***PASS - Reinforcement provided at the retaining wall toe is adequate***

### Check shear resistance at toe

Design shear stress $v_{toe}$ = $V_{toe}$ / (b × $d_{toe}$) = **0.290** N/mm²

Allowable shear stress $v_{adm}$ = min(0.8 × √($f_{cu}$ / 1 N/mm²), 5) × 1 N/mm² = **4.733** N/mm²

***PASS - Design shear stress is less than maximum shear stress***

**From BS8110:Part 1:1997 – Table 3.8**

Design concrete shear stress $v_{c\_toe}$ = **0.481** 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 $f_{cu}$ = **35** 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 $c_{heel}$ = **40** mm

**Calculate shear for heel design**

Shear from weight of base $V_{heel\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{heel} \times t_{base}$ = **1.7** kN/m

Shear from weight of moist backfill $V_{heel\_wt\_m} = w_{m\_w\_f}$ = **8.6** kN/m

Shear from weight of saturated backfill $V_{heel\_wt\_s} = w_{s\_f}$ = **2.7** kN/m

Shear from surcharge $V_{heel\_sur} = w_{sur\_f}$ = **2.4** kN/m

Total shear for heel design $V_{heel} = V_{heel\_wt\_base} + V_{heel\_wt\_m} + V_{heel\_wt\_s} + V_{heel\_sur}$ = **15.4** kN/m

**Calculate moment for heel design**

Moment from weight of base $M_{heel\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{heel} + t_{wall} / 2)^2 / 2)$ = **0.5** kNm/m

Moment from weight of moist backfill $M_{heel\_wt\_m} = w_{m\_w\_f} \times (l_{heel} + t_{wall}) / 2$ = **1.9** kNm/m

Moment from weight of saturated backfill $M_{heel\_wt\_s} = w_{s\_f} \times (l_{heel} + t_{wall}) / 2$ = **0.6** kNm/m

Moment from surcharge $M_{heel\_sur} = w_{sur\_f} \times (l_{heel} + t_{wall}) / 2$ = **0.5** kNm/m

Total moment for heel design $M_{heel} = M_{heel\_wt\_base} + M_{heel\_wt\_m} + M_{heel\_wt\_s} + M_{heel\_sur}$ = **3.6** kNm/m

**Check heel in bending**

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

Depth of reinforcement $d_{heel} = t_{base} - c_{heel} - (\phi_{heel} / 2)$ = **305.0** mm

Constant $K_{heel} = M_{heel} / (b \times d_{heel}^2 \times f_{cu})$ = **0.001**

***Compression reinforcement is not required***

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

$z_{heel}$ = **290** mm

Area of tension reinforcement required $A_{s\_heel\_des} = M_{heel} / (0.87 \times f_y \times z_{heel})$ = **29** mm$^2$/m

Minimum area of tension reinforcement $A_{s\_heel\_min} = k \times b \times t_{base}$ = **455** mm$^2$/m

Area of tension reinforcement required $A_{s\_heel\_req} = \text{Max}(A_{s\_heel\_des}, A_{s\_heel\_min})$ = **455** mm$^2$/m

Reinforcement provided **B785 mesh**

Area of reinforcement provided $A_{s\_heel\_prov}$ = **785** mm$^2$/m

***PASS - Reinforcement provided at the retaining wall heel is adequate***

**Check shear resistance at heel**

Design shear stress $v_{heel} = V_{heel} / (b \times d_{heel})$ = **0.051** N/mm$^2$

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **4.733** 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 $v_{c\_heel}$ = **0.481** N/mm$^2$

***$v_{heel}$ < $v_{c\_heel}$ - No shear reinforcement required***

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

**Material properties**

Characteristic strength of concrete $f_{cu}$ = **35** $N/mm^2$

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

**Base details**

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

Cover to reinforcement in downstand $c_{ds}$ = **40** mm

**Calculate shear for downstand design**

Total shear for downstand design

$V_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times (d_{cover} + t_{base} + d_{ds} / 2)$ = **35.6** kN/m

**Calculate moment for downstand design**

Total moment for downstand design

$M_{down} = \gamma_{f\_e} \times K_p \times \cos(\delta_b) \times \gamma_m \times d_{ds} \times [(d_{cover} + t_{base}) \times (t_{base} + d_{ds}) + d_{ds} \times (t_{base} / 2 + 2 \times d_{ds} / 3)] / 2$ = **16** kNm/m

**Check downstand in bending**

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

Depth of reinforcement $d_{down} = t_{ds} - c_{ds} - (\phi_{down} / 2)$ = **155.0** mm

Constant $K_{down} = M_{down} / (b \times d_{down}^2 \times f_{cu})$ = **0.019**

***Compression reinforcement is not required***

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

$z_{down}$ = **147** mm

Area of tension reinforcement required $A_{s\_down\_des} = M_{down} / (0.87 \times f_y \times z_{down})$ = **250** $mm^2/m$

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

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

Reinforcement provided **10 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_down\_prov}$ = **785** $mm^2/m$

***PASS - Reinforcement provided at the retaining wall downstand is adequate***

**Check shear resistance at downstand**

Design shear stress $v_{down} = V_{down} / (b \times d_{down})$ = **0.229** $N/mm^2$

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **4.733** $N/mm^2$

***PASS - Design shear stress is less than maximum shear stress***

**From BS8110:Part 1:1997 – Table 3.8**

Design concrete shear stress $v_{c\_down}$ = **0.714** $N/mm^2$

***$v_{down}$ < $v_{c\_down}$ - No shear reinforcement required***

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

**Material properties**

Characteristic strength of concrete $f_{cu}$ = **35** $N/mm^2$

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

**Wall details**

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

Cover to reinforcement in stem $c_{stem}$ = **40** mm

Cover to reinforcement in wall $c_{wall}$ = **40** mm

**Factored horizontal active forces on stem**

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_a \times \cos(90 - \alpha + \delta) \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **17.9** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **25.5** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **13** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_a \times \cos(90 - \alpha + \delta) \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **1.1** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **2.9** kN/m

**Calculate shear for stem design**

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f} - F_{prop\_f}$ = **26.3** kN/m

**Calculate moment for stem design**

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **31.8** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **42.7** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2$ = **4.2** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3$ = **0.2** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3$ = **0.6** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **79.5** kNm/m

**Check wall stem in bending**

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **255.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.035**

***Compression reinforcement is not required***

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

$z_{stem}$ = **242** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **755** $mm^2/m$

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** $mm^2/m$

Area of tension reinforcement required $A_{s\_stem\_req} = \max(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **755** $mm^2/m$

Reinforcement provided **10 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **785** $mm^2/m$

***PASS - Reinforcement provided at the retaining wall stem is adequate***

**Check shear resistance at wall stem**

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.103** $N/mm^2$

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **4.733** $N/mm^2$

***PASS - Design shear stress is less than maximum shear stress***

**From BS8110:Part 1:1997 – Table 3.8**

Design concrete shear stress $v_{c\_stem}$ = **0.534** $N/mm^2$

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