RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Tedds calculation version 2.6.04

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **2500** mm
Prop height	h_{prop} = **2500** mm
Stem thickness	t_{stem} = **400** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **1300** mm
Heel length	l_{heel} = **200** mm
Base thickness	t_{base} = **400** mm
Key position	p_{key} = **1300** mm
Key depth	d_{key} = **500** mm
Key thickness	t_{key} = **400** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **2500** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm

Retained soil properties

Soil type	Organic clay
Moist density	γ_{mr} = **15** kN/m^3
Saturated density	γ_{sr} = **15** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **18** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **9** deg

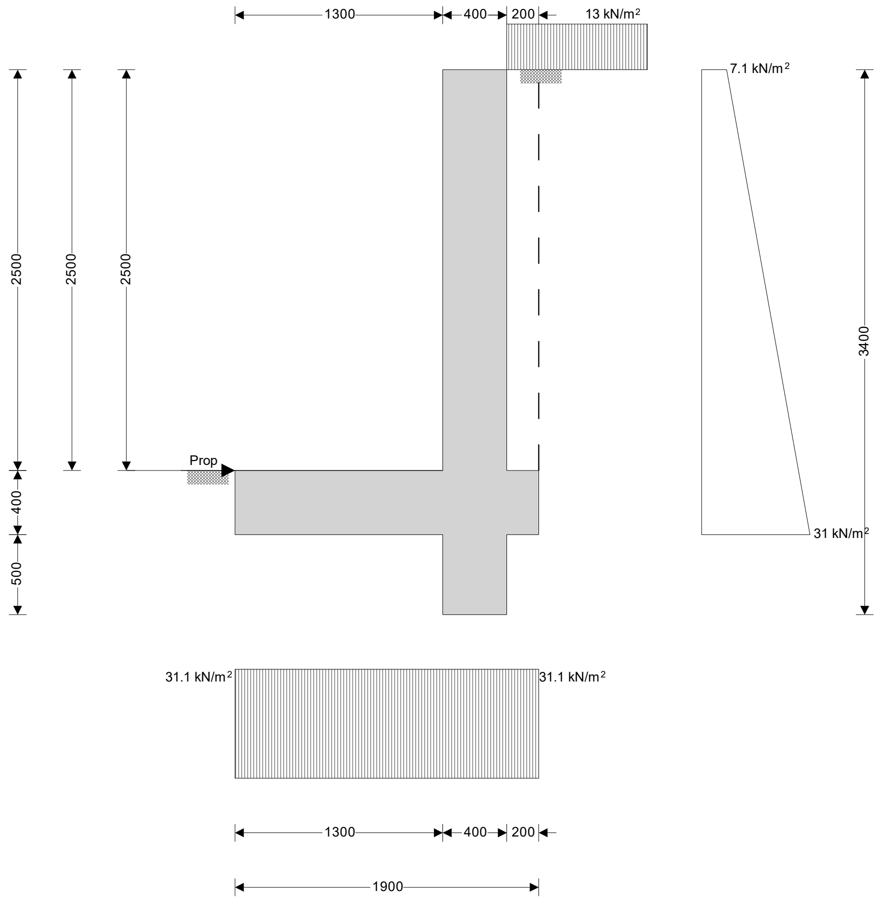
Base soil properties

Soil type	Organic clay
Moist density	γ_{mb} = **15** kN/m^3
Characteristic cohesion	$c'_{b.k}$ = **33** kN/m^2
Characteristic adhesion	$a_{b.k}$ = **25** kN/m^2
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **18** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **9** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **12** deg

Loading details

Variable surcharge load	$Surcharge_Q$ = **10** kN/m^2

Tedds RP DESIGNS 61 BARNES WALLIS COURT BARNHILL ROAD HA9 9DW WEMBLEY	Project: 163 Sumatra Road , London NW6 1PW				Job no.: 1870	
	Calcs for: Light well retaining wall				Start page no./Revision: 41	
	Calcs by: RN	Calcs date: 02/08/2019	Checked by: NH	Checked date	Approved by	Approved date



Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} + l_{heel}$ = **1900** mm
Base height	$h_{base} = t_{base} + d_{key}$ = **900** mm
Moist soil height	$h_{moist} = h_{soil}$ = **2500** mm
Length of surcharge load	$l_{sur} = l_{heel}$ = **200** mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2$ = **1800** mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret}$ = **3400** mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 - d_{key}$ = **1200** mm
- Distance to horizontal component above key	$x_{sur\_h\_a} = (h_{eff} - d_{key}) / 2$ = **1450** mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem}$ = **1** m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2$ = **1500** mm
Area of wall base	$A_{base} = l_{base} \times t_{base} + d_{key} \times t_{key}$ = **0.96** m^2
- Distance to vertical component	$x_{base} = (l_{base}^2 \times t_{base} / 2 + d_{key} \times t_{key} \times (p_{key} + t_{key} / 2)) / A_{base}$ = **1065** mm
Area of moist soil	$A_{moist} = h_{moist} \times l_{heel}$ = **0.5** m^2
- Distance to vertical component	$x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist}$ = **1800** mm
- Distance to horizontal component	$x_{moist\_h} = h_{eff} / 3 - d_{key}$ = **633** mm
- Distance to horizontal component above key	$x_{moist\_h\_a} = (h_{eff} - d_{key}) / 3$ = **967** mm

Partial factors on actions - Table A.3 - Combination 1

Permanent unfavourable action	γ_G = **1.35**

Permanent favourable action γ_{Gf} = **1.00**

Variable unfavourable action γ_{Q} = **1.50**

Variable favourable action γ_{Qf} = **0.00**

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

Angle of shearing resistance $\gamma_{\phi'}$ = **1.00**

Effective cohesion $\gamma_{c'}$ = **1.00**

Weight density γ_{γ} = **1.00**

Retained soil properties

Design effective shear resistance angle $\phi'_{r.d} = atan(tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **18** deg

Design wall friction angle $\delta_{r.d} = atan(tan(\delta_{r.k}) / \gamma_{\phi'})$ = **9** deg

Base soil properties

Design effective shear resistance angle $\phi'_{b.d} = atan(tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **18** deg

Design wall friction angle $\delta_{b.d} = atan(tan(\delta_{b.k}) / \gamma_{\phi'})$ = **9** deg

Design base friction angle $\delta_{bb.d} = atan(tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **12** deg

Design effective cohesion $c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **33** kN/m^2

Design adhesion $a_{b.d} = a_{b.k} / \gamma_{c'}$ = **25** kN/m^2

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{}[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2)$ = **0.483**

Passive pressure coefficient $K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{}[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2)$ = **2.359**

Overturning check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **25** kN/m

Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **24** kN/m

Moist retained soil $F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **7.5** kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **56.5** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times (h_{eff} - d_{key})$ = **20.8** kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2$ = **40.6** kN/m

Base soil $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **-14.2** kN/m

Total $F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h}$ = **47.2** kN/m

Overturning moments on wall

Surcharge load $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h\_a}$ = **30.1** kNm/m

Moist retained soil $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h\_a}$ = **39.3** kNm/m

Total $M_{total\_OT} = M_{moist\_OT} + M_{sur\_OT}$ = **69.4** kNm/m

Restoring moments on wall

Wall stem $M_{stem\_R} = F_{stem} \times x_{stem}$ = **37.5** kNm/m

Wall base $M_{base\_R} = F_{base} \times x_{base}$ = **25.6** kNm/m

Moist retained soil $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v}$ = **13.5** kNm/m

Total $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} = \mathbf{76.6}$ kNm/m

Check stability against overturning

Factor of safety $FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{1.104}$

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{33.8}$ kN/m

Wall base $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{32.4}$ kN/m

Surcharge load $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel} = \mathbf{3}$ kN/m

Moist retained soil $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{10.1}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v} = \mathbf{79.3}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times (h_{eff} - d_{key}) = \mathbf{20.8}$ kN/m

Moist retained soil $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2 = \mathbf{40.6}$ kN/m

Base soil $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-14.2}$ kN/m

Total $F_{total\_h} = F_{moist\_h} + F_{pass\_h} + F_{sur\_h} = \mathbf{47.2}$ kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem} = \mathbf{50.6}$ kNm/m

Wall base $M_{base} = F_{base} \times x_{base} = \mathbf{34.5}$ kNm/m

Surcharge load $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h\_a} = \mathbf{-24.7}$ kNm/m

Moist retained soil $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h\_a} = \mathbf{-21}$ kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{sur} = \mathbf{39.4}$ kNm/m

Check bearing pressure

Propping force $F_{prop\_base} = F_{total\_h} = \mathbf{47.2}$ kN/m

Distance to reaction $\bar{x} = l_{base} / 2 = \mathbf{950}$ mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{0}$ mm

Loaded length of base $l_{load} = l_{base} = \mathbf{1900}$ mm

Bearing pressure at toe $q_{toe} = F_{total\_v} / l_{base} = \mathbf{41.7}$ kN/m^2

Bearing pressure at heel $q_{heel} = F_{total\_v} / l_{base} = \mathbf{41.7}$ kN/m^2

Effective overburden pressure $q = (t_{base} + d_{cover}) \times \gamma_{mb} = \mathbf{6}$ kN/m^2

Design effective overburden pressure $q' = q / \gamma_{\gamma} = \mathbf{6}$ kN/m^2

Bearing resistance factors $N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 = \mathbf{5.258}$

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{13.104}$

$N_{\gamma} = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) = \mathbf{2.767}$

Foundation shape factors $s_q = 1$

$s_{\gamma} = 1$

$s_c = 1$

Load inclination factors $H = F_{sur\_h} + F_{moist\_h} + F_{pass\_h} - F_{prop\_base} = \mathbf{0}$ kN/m

$V = F_{total\_v} = \mathbf{79.3}$ kN/m

$m = 2$

$i_q = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^m = \mathbf{1}$

$i_{\gamma} = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^{(m + 1)} = \mathbf{1}$

	$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b.d})) = \mathbf{1}$
Net ultimate bearing capacity	$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma$ = **503.4** kN/m^2
Factor of safety	$FoS_{bp} = n_f / \max(q_{toe}, q_{heel})$ = **12.065**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

Partial factors on actions - Table A.3 - Combination 2

Permanent unfavourable action	γ_G = **1.00**
Permanent favourable action	γ_{Gf} = **1.00**
Variable unfavourable action	γ_Q = **1.30**
Variable favourable action	γ_{Qf} = **0.00**

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

Angle of shearing resistance	$\gamma_{\phi'}$ = **1.25**
Effective cohesion	$\gamma_{c'}$ = **1.25**
Weight density	γ_γ = **1.00**

Retained soil properties

Design effective shear resistance angle	$\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **14.6** deg
Design wall friction angle	$\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **7.2** deg

Base soil properties

Design effective shear resistance angle	$\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **14.6** deg
Design wall friction angle	$\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **7.2** deg
Design base friction angle	$\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **9.7** deg
Design effective cohesion	$c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **26.4** kN/m^2
Design adhesion	$a_{b.d} = a_{b.k} / \gamma_{c'}$ = **20** kN/m^2

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[}\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2)$ = **0.553**
Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[}\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]]^2)$ = **1.965**

Overturning check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **25** kN/m
Wall base	$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **24** kN/m
Moist retained soil	$F_{moist\_v} = \gamma_{Gf} \times A_{moist} \times \gamma_{mr}$ = **7.5** kN/m
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v}$ = **56.5** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times (h_{eff} - d_{key})$ = **20.7** kN/m
Moist retained soil	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2$ = **34.6** kN/m
Base soil	$F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (h_{pass} + h_{base})^2 / 2$ = **-11.8** kN/m
Total	$F_{total\_h} = F_{moist\_h} + F_{exc\_h} + F_{sur\_h}$ = **43.4** kN/m

Overturning moments on wall

Surcharge load — $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h\_a} = \mathbf{30}$ kNm/m

Moist retained soil — $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h\_a} = \mathbf{33.4}$ kNm/m

Total — $M_{total\_OT} = M_{moist\_OT} + M_{sur\_OT} = \mathbf{63.4}$ kNm/m

Restoring moments on wall

Wall stem — $M_{stem\_R} = F_{stem} \times x_{stem} = \mathbf{37.5}$ kNm/m

Wall base — $M_{base\_R} = F_{base} \times x_{base} = \mathbf{25.6}$ kNm/m

Moist retained soil — $M_{moist\_R} = F_{moist\_v} \times x_{moist\_v} = \mathbf{13.5}$ kNm/m

Total — $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{moist\_R} = \mathbf{76.6}$ kNm/m

Check stability against overturning

Factor of safety — $FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{1.207}$

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem — $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{25}$ kN/m

Wall base — $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{24}$ kN/m

Surcharge load — $F_{sur\_v} = \gamma_Q \times Surcharge_Q \times l_{heel} = \mathbf{2.6}$ kN/m

Moist retained soil — $F_{moist\_v} = \gamma_G \times A_{moist} \times \gamma_{mr} = \mathbf{7.5}$ kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{moist\_v} + F_{sur\_v} = \mathbf{59.1}$ kN/m

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times (h_{eff} - d_{key}) = \mathbf{20.7}$ kN/m

Moist retained soil — $F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times (h_{eff} - d_{key})^2 / 2 = \mathbf{34.6}$ kN/m

Base soil — $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_{mb} \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-11.8}$ kN/m

Total — $F_{total\_h} = F_{moist\_h} + F_{pass\_h} + F_{sur\_h} = \mathbf{43.4}$ kN/m

Moments on wall

Wall stem — $M_{stem} = F_{stem} \times x_{stem} = \mathbf{37.5}$ kNm/m

Wall base — $M_{base} = F_{base} \times x_{base} = \mathbf{25.6}$ kNm/m

Surcharge load — $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h\_a} = \mathbf{-25.3}$ kNm/m

Moist retained soil — $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h\_a} = \mathbf{-19.9}$ kNm/m

Total — $M_{total} = M_{stem} + M_{base} + M_{moist} + M_{sur} = \mathbf{17.8}$ kNm/m

Check bearing pressure

Propping force — $F_{prop\_base} = F_{total\_h} = \mathbf{43.4}$ kN/m

Distance to reaction — $\bar{x} = l_{base} / 2 = \mathbf{950}$ mm

Eccentricity of reaction — $e = \bar{x} - l_{base} / 2 = \mathbf{0}$ mm

Loaded length of base — $l_{load} = l_{base} = \mathbf{1900}$ mm

Bearing pressure at toe — $q_{toe} = F_{total\_v} / l_{base} = \mathbf{31.1}$ kN/m^2

Bearing pressure at heel — $q_{heel} = F_{total\_v} / l_{base} = \mathbf{31.1}$ kN/m^2

Effective overburden pressure — $q = (t_{base} + d_{cover}) \times \gamma_{mb} = \mathbf{6}$ kN/m^2

Design effective overburden pressure — $q' = q / \gamma_\gamma = \mathbf{6}$ kN/m^2

Bearing resistance factors — $N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 = \mathbf{3.784}$

$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{10.711}$

$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d})$ = **1.447**

Foundation shape factors $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

Load inclination factors $H = F_{sur\_h} + F_{moist\_h} + F_{pass\_h} - F_{prop\_base}$ = **0** kN/m

$V = F_{total\_v}$ = **59.1** kN/m

$m = 2$

$i_q = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^m$ = **1**

$i_\gamma = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^{(m + 1)}$ = **1**

$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b.d}))$ = **1**

Net ultimate bearing capacity $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times \gamma_{mb} \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma$ = **326.1** kN/m^2

Factor of safety $FoS_{bp} = n_f / \max(q_{toe}, q_{heel})$ = **10.483**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum dated January 2008 and the UK National Annex incorporating National Amendment No.1

Tedds calculation version 2.6.04

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

Concrete strength class C30/37

Characteristic compressive cylinder strength f_{ck} = **30** N/mm^2

Characteristic compressive cube strength $f_{ck,cube}$ = **37** N/mm^2

Mean value of compressive cylinder strength $f_{cm} = f_{ck} + 8$ N/mm^2 = **38** N/mm^2

Mean value of axial tensile strength $f_{ctm} = 0.3$ N/mm$^2 \times (f_{ck} / 1$ N/mm$^2)^{2/3}$ = **2.9** N/mm^2

5% fractile of axial tensile strength $f_{ctk,0.05} = 0.7 \times f_{ctm}$ = **2.0** N/mm^2

Secant modulus of elasticity of concrete $E_{cm} = 22$ kN/mm$^2 \times (f_{cm} / 10$ N/mm$^2)^{0.3}$ = **32837** N/mm^2

Partial factor for concrete - Table 2.1N γ_C = **1.50**

Compressive strength coefficient - cl.3.1.6(1) α_{cc} = **0.85**

Design compressive concrete strength - exp.3.15 $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C$ = **17.0** N/mm^2

Maximum aggregate size h_{agg} = **20** mm

Reinforcement details

Characteristic yield strength of reinforcement f_{yk} = **500** N/mm^2

Modulus of elasticity of reinforcement E_s = **200000** N/mm^2

Partial factor for reinforcing steel - Table 2.1N γ_S = **1.15**

Design yield strength of reinforcement $f_{yd} = f_{yk} / \gamma_S$ = **435** N/mm^2

Cover to reinforcement

Front face of stem c_{sf} = **40** mm

Rear face of stem c_{sr} = **50** mm

Top face of base c_{bt} = **50** mm

Bottom face of base c_{bb} = **75** mm

Check stem design at base of stem

Depth of section h = **400** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	M = **47.5** kNm/m
Depth to tension reinforcement	$d = h - c_{sr} - \phi_{sr} / 2$ = **344** mm
	$K = M / (d^2 \times f_{ck})$ = **0.013**
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **327** mm
Depth of neutral axis	$x = 2.5 \times (d - z)$ = **43** mm
Area of tension reinforcement required	$A_{sr.req} = M / (f_{yd} \times z)$ = **334** mm^2/m
Tension reinforcement provided	12 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **565** mm^2/m
Minimum area of reinforcement - exp.9.1N	$A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **518** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{sr.max} = 0.04 \times h$ = **16000** mm^2/m
	$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.916**

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

Deflection control - Section 7.4

Reference reinforcement ratio	$\rho_0 = \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} / 1000$ = **0.005**
Required tension reinforcement ratio	$\rho = A_{sr.req} / d$ = **0.001**
Required compression reinforcement ratio	$\rho' = A_{sr.2.req} / d_2$ = **0.000**
Structural system factor - Table 7.4N	K_b = **0.4**
Reinforcement factor - exp.7.17	$K_s = \min(500 \text{ N/mm}^2 / (f_{yk} \times A_{sr.req} / A_{sr.prov}), 1.5)$ = **1.5**
Limiting span to depth ratio - exp.7.16.a	$K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}]$ = **139.2**
Actual span to depth ratio	h_{stem} / d = **7.3**

PASS - Span to depth ratio is less than deflection control limit

Crack control - Section 7.3

Limiting crack width	w_{max} = **0.3** mm
Variable load factor - EN1990 – Table A1.1	ψ_2 = **0.6**
Serviceability bending moment	M_{sls} = **27.6** kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **149.3** N/mm^2
Load duration	Long term
Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **119000** mm^2/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **2.9** N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.005**
Modular ratio	$\alpha_e = E_s / E_{cm}$ = **6.091**
Bond property coefficient	k_1 = **0.8**
Strain distribution coefficient	k_2 = **0.5**
	k_3 = **3.4**
	k_4 = **0.425**
Maximum crack spacing - exp.7.11	$s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **599** mm
Maximum crack width - exp.7.8	$w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	w_k = **0.268** mm

w_k / w_{max} = **0.894**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — V = **48.1** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.762**

Longitudinal reinforcement ratio — ρ_l = min($A_{sf.prov}$ / d, 0.02) = **0.002**

v_{min} = 0.035 $N^{1/2}$/mm × $k^{3/2}$ × $f_{ck}^{0.5}$ = **0.449** N/mm^2

Design shear resistance - exp.6.2a & 6.2b — $V_{Rd.c}$ = max($C_{Rd.c}$ × k × (100 N^2/mm^4 × ρ_l × f_{ck})$^{1/3}$, v_{min}) × d

$V_{Rd.c}$ = **154.3** kN/m

V / $V_{Rd.c}$ = **0.312**

PASS - Design shear resistance exceeds design shear force

Horizontal reinforcement parallel to face of stem - Section 9.6

Minimum area of reinforcement – cl.9.6.3(1) — $A_{sx.req}$ = max(0.25 × $A_{sr.prov}$, 0.001 × t_{stem}) = **400** mm^2/m

Maximum spacing of reinforcement – cl.9.6.3(2) — s_{sx_max} = **400** mm

Transverse reinforcement provided — 10 dia.bars @ 200 c/c

Area of transverse reinforcement provided — $A_{sx.prov}$ = π × ϕ_{sx}^2 / (4 × s_{sx}) = **393** mm^2/m

FAIL - Area of reinforcement provided is less than area of reinforcement required

Check base design at toe

Depth of section — h = **400** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **23.8** kNm/m

Depth to tension reinforcement — d = h - c_{bb} - ϕ_{bb} / 2 = **319** mm

K = M / (d^2 × f_{ck}) = **0.008**

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm — z = min(0.5 + 0.5 × (1 - 3.53 × K)$^{0.5}$, 0.95) × d = **303** mm

Depth of neutral axis — x = 2.5 × (d – z) = **40** mm

Area of tension reinforcement required — $A_{bb.req}$ = M / (f_{yd} × z) = **181** mm^2/m

Tension reinforcement provided — 12 dia.bars @ 200 c/c

Area of tension reinforcement provided — $A_{bb.prov}$ = π × ϕ_{bb}^2 / (4 × s_{bb}) = **565** mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{bb.min}$ = max(0.26 × f_{ctm} / f_{yk}, 0.0013) × d = **480** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{bb.max}$ = 0.04 × h = **16000** mm^2/m

max($A_{bb.req}$, $A_{bb.min}$) / $A_{bb.prov}$ = **0.85**

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

Crack control - Section 7.3

Limiting crack width — w_{max} = **0.3** mm

Variable load factor - EN1990 – Table A1.1 — ψ_2 = **0.6**

Serviceability bending moment — M_{sls} = **17.6** kNm/m

Tensile stress in reinforcement — σ_s = M_{sls} / ($A_{bb.prov}$ × z) = **102.5** N/mm^2

Load duration — Long term

Load duration factor — k_t = **0.4**

Effective area of concrete in tension — $A_{c.eff}$ = min(2.5 × (h - d), (h – x) / 3, h / 2) = **120042** mm^2/m

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm} = \mathbf{2.9}$ N/mm^2

Reinforcement ratio $\rho_{p.eff} = A_{bb.prov} / A_{c.eff} = \mathbf{0.005}$

Modular ratio $\alpha_e = E_s / E_{cm} = \mathbf{6.091}$

Bond property coefficient $k_1 = \mathbf{0.8}$

Strain distribution coefficient $k_2 = \mathbf{0.5}$

$k_3 = \mathbf{3.4}$

$k_4 = \mathbf{0.425}$

Maximum crack spacing - exp.7.11 $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} = \mathbf{688}$ mm

Maximum crack width - exp.7.8 $w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$

$w_k = \mathbf{0.212}$ mm

$w_k / w_{max} = \mathbf{0.705}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force $V = \mathbf{36.7}$ kN/m

$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$

$k = \min(1 + \sqrt{(200\text{ mm} / d)}, 2) = \mathbf{1.792}$

Longitudinal reinforcement ratio $\rho_l = \min(A_{bb.prov} / d, 0.02) = \mathbf{0.002}$

$v_{min} = 0.035\text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.460}$ N/mm^2

Design shear resistance - exp.6.2a & 6.2b $V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$

$V_{Rd.c} = \mathbf{146.7}$ kN/m

$V / V_{Rd.c} = \mathbf{0.250}$

PASS - Design shear resistance exceeds design shear force

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 $M = \mathbf{0.7}$ kNm/m

Depth to tension reinforcement $d = h - c_{bt} - \phi_{bt} / 2 = \mathbf{344}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.000}$

$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{327}$ mm

Depth of neutral axis $x = 2.5 \times (d - z) = \mathbf{43}$ mm

Area of tension reinforcement required $A_{bt.req} = M / (f_{yd} \times z) = \mathbf{5}$ mm^2/m

Tension reinforcement provided 12 dia.bars @ 200 c/c

Area of tension reinforcement provided $A_{bt.prov} = \pi \times \phi_{bt}^2 / (4 \times s_{bt}) = \mathbf{565}$ mm^2/m

Minimum area of reinforcement - exp.9.1N $A_{bt.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{518}$ mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) $A_{bt.max} = 0.04 \times h = \mathbf{16000}$ mm^2/m

$\max(A_{bt.req}, A_{bt.min}) / A_{bt.prov} = \mathbf{0.916}$

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

Crack control - Section 7.3

Limiting crack width $w_{max} = \mathbf{0.3}$ mm

Variable load factor - EN1990 – Table A1.1 $\psi_2 = \mathbf{0.6}$

Serviceability bending moment $M_{sls} = \mathbf{0.5}$ kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{bt.prov} \times z) = \mathbf{2.5}$ N/mm^2

Load duration Long term

Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff}$ = min(2.5 × (h - d), (h – x) / 3, h / 2) = **119000** mm^2/m
Mean value of concrete tensile strength	$f_{ct.eff}$ = f_{ctm} = **2.9** N/mm^2
Reinforcement ratio	$\rho_{p.eff}$ = $A_{bt.prov}$ / $A_{c.eff}$ = **0.005**
Modular ratio	α_e = E_s / E_{cm} = **6.091**
Bond property coefficient	k_1 = **0.8**
Strain distribution coefficient	k_2 = **0.5**
	k_3 = **3.4**
	k_4 = **0.425**
Maximum crack spacing - exp.7.11	$s_{r.max}$ = k_3 × c_{bt} + k_1 × k_2 × k_4 × ϕ_{bt} / $\rho_{p.eff}$ = **599** mm
Maximum crack width - exp.7.8	w_k = $s_{r.max}$ × max(σ_s – k_t × ($f_{ct.eff}$ / $\rho_{p.eff}$) × (1 + α_e × $\rho_{p.eff}$), 0.6 × σ_s) / E_s
	w_k = **0.004** mm
	w_k / w_{max} = **0.015**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	V = **7.5** kN/m
	$C_{Rd,c}$ = 0.18 / γ_C = **0.120**
	k = min(1 + √(200 mm / d), 2) = **1.762**
Longitudinal reinforcement ratio	ρ_l = min($A_{bt.prov}$ / d, 0.02) = **0.002**
	v_{min} = 0.035 N$^{1/2}$/mm × k$^{3/2}$ × $f_{ck}$$^{0.5}$ = **0.449** N/mm^2
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c}$ = max($C_{Rd.c}$ × k × (100 N^2/mm^4 × ρ_l × f_{ck})$^{1/3}$, v_{min}) × d
	$V_{Rd.c}$ = **154.3** kN/m
	V / $V_{Rd.c}$ = **0.048**

PASS - Design shear resistance exceeds design shear force

Check key design

Depth of section	h = **400** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	M = **0.5** kNm/m
Depth to tension reinforcement	d = h - c_{bb} - ϕ_k / 2 = **319** mm
	K = M / (d^2 × f_{ck}) = **0.000**
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	z = min(0.5 + 0.5 × (1 - 3.53 × K)$^{0.5}$, 0.95) × d = **303** mm
Depth of neutral axis	x = 2.5 × (d – z) = **40** mm
Area of tension reinforcement required	$A_{k.req}$ = M / (f_{yd} × z) = **4** mm^2/m
Tension reinforcement provided	12 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{k.prov}$ = π × ϕ_k^{2} / (4 × s_k) = **565** mm^2/m
Minimum area of reinforcement - exp.9.1N	$A_{k.min}$ = max(0.26 × f_{ctm} / f_{yk}, 0.0013) × d = **480** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{k.max}$ = 0.04 × h = **16000** mm^2/m
	max($A_{k.req}$, $A_{k.min}$) / $A_{k.prov}$ = **0.85**

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

Crack control - Section 7.3

Limiting crack width	w_{max} = **0.3** mm

Variable load factor - EN1990 – Table A1.1 — ψ_2 = **0.6**

Serviceability bending moment — M_{sls} = **0.7** kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{k.prov} \times z)$ = **4.3** N/mm^2

Load duration — Long term

Load duration factor — k_t = **0.4**

Effective area of concrete in tension — $A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **120042** mm^2/m

Mean value of concrete tensile strength — $f_{ct.eff} = f_{ctm}$ = **2.9** N/mm^2

Reinforcement ratio — $\rho_{p.eff} = A_{k.prov} / A_{c.eff}$ = **0.005**

Modular ratio — $\alpha_e = E_s / E_{cm}$ = **6.091**

Bond property coefficient — k_1 = **0.8**

Strain distribution coefficient — k_2 = **0.5**

k_3 = **3.4**

k_4 = **0.425**

Maximum crack spacing - exp.7.11 — $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_k / \rho_{p.eff}$ = **688** mm

Maximum crack width - exp.7.8 — $w_k = s_{r.max} \times \max(\sigma_s – k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$

w_k = **0.009** mm

w_k / w_{max} = **0.03**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — V = **3.3** kN/m

$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.792**

Longitudinal reinforcement ratio — $\rho_l = \min(A_{k.prov} / d, 0.02)$ = **0.002**

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.460** N/mm^2

Design shear resistance - exp.6.2a & 6.2b — $V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$

$V_{Rd.c}$ = **146.7** kN/m

$V / V_{Rd.c}$ = **0.022**

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

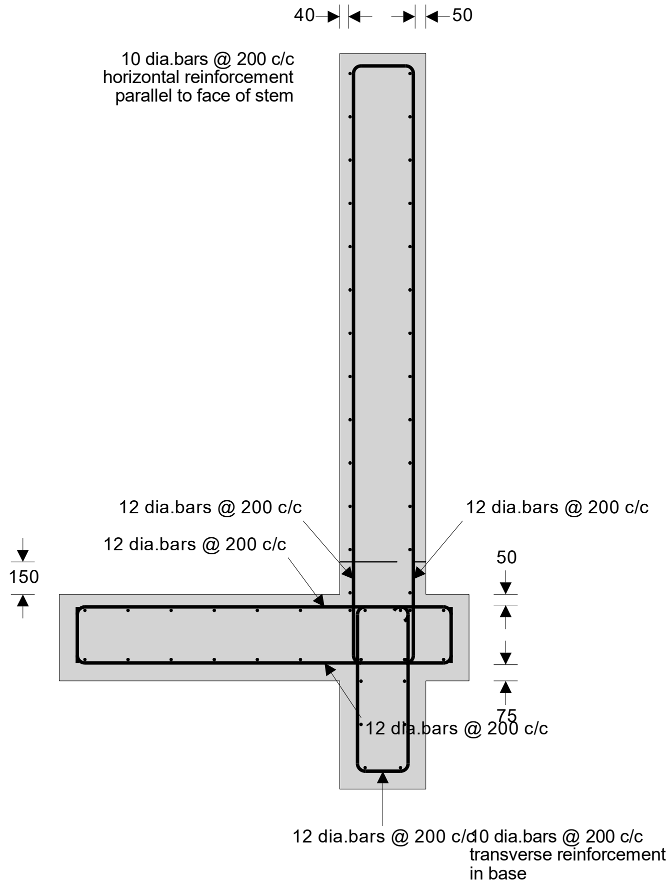
Minimum area of reinforcement – cl.9.3.1.1(2) — $A_{bx.req} = 0.2 \times A_{bb.prov}$ = **113** mm^2/m

Maximum spacing of reinforcement – cl.9.3.1.1(3) — s_{bx_max} = **450** mm

Transverse reinforcement provided — 10 dia.bars @ 200 c/c

Area of transverse reinforcement provided — $A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx})$ = **393** mm^2/m

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



40
50
10 dia.bars @ 200 c/c
horizontal reinforcement
parallel to face of stem
12 dia.bars @ 200 c/c
12 dia.bars @ 200 c/c
12 dia.bars @ 200 c/c
150
50
75
12 dia.bars @ 200 c/c
12 dia.bars @ 200 c/c
10 dia.bars @ 200 c/c
transverse reinforcement
in base