Ref: 11/17802
August 2016

Basement Impact Assessment (Hydrogeological and Structural)

At

Ornan Court, 2 Ornan Road, London, NW3 4PT

For

Ornan Court Limited

VOLUME 8 of 8

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8.1 Structural Calculations

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Date 28.04.16
Eng. GO
Job No. 16.280
Sheet No. 1

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It is proposed to excavate a Basement level below the existing building. The Party wall & Front walls will be underpinned with Engineering Brick stems on reinforced concrete pad footings. The The Flank wall is to be underpinned with reinforced concrete stem and pad. The basement does not extend to the rear wall and a reinforced concrete retaining wall will be constructed in metre wide sections to support the earth beyond. Steel beam will be required to support the load bearing walls above which will be supported on steel columns which in turn will be supported on mass concrete pad foundations

LOADS	LIVE	DEAD	TOTAL
Brickwork (225)		4.8	4.8 kN/m²
(330)		7.5	7.5
Concrete Floor	1.5	2.5	5
Pitched Roof	0.75	1.35	2.1
Flat Roof	0.75	1.05	1.8
Timber Floor (Grnd)	1.5	0.7	2.2
Blanket Stud		0.5	0.5

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Beam G6-G7, span = 3.6 m

Floors Grd - 3rd $5\left(\frac{4}{2}\right) \times 4 = 40$ kN/m

Brick wall $4.8(0.85)(12.35) = 50.4$ kN/m

90 kN/m

Mmax = 146 kNm R = 220.5 kN

$\times 1.5 = 219$ kNm

Effective length = 6.4 m

Try 254 x 254 UC 89

Allowable moment = 284 kNm > 219 ∴ ok

Check Deflection

$$\delta = \frac{5}{384} \times \frac{90(3600)^4}{210000(14300 \times 10^4)} = 6.6 \text{ mm} \therefore \text{ok}$$

Beam G3-G4, span = 1.6 m

Load = 90 kN/m

Mmax = 29 kNm R = 72 kN

Use 254 x 254 UC 89:

ok by inspection

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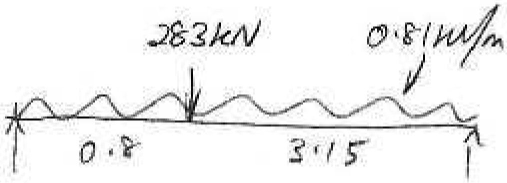
Beam B6-B7, - similar to G6-G7

Beam B6 - C6, span = 3.95m

Point load from B6-B7 & B5-B6

$= 90 \left(\frac{6.3}{2}\right) = 283\,kN$

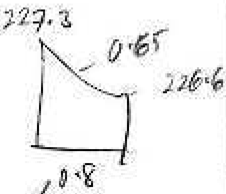
Nominal Floor $2.7(0.3) = 0.81\,kN/m$



$0.81\frac{(3.95)^2}{2} + 283(0.8) = R_B\,3.95$

$R_B = 58.9\,kN$

$R_A = 227.3\,kN$



$M_{max} = 181.6\,kNm$ $W_{eq} = 93\,kN/m$

fos x 1.5 = 272.4 KNm

Effective length = 3.15m

Try 254 x 254 UC89

Allowable moment = 316 > 272 kNm ∴ ok

Check Deflection

$d = \frac{5}{384} \times \frac{93(3950)^4}{210000(14300\times10^4)} = 10mm$ ∴ ok

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Check Columns

Load = 227 kN $M_{max} = 227(0.2) = 45.4$ kNm

Try 203 × 203 UC 46

$\frac{L}{r} = \frac{2700}{51.1} = 53$ $p_c = 131$

$D/T = 18.5$ $p_{bc} = 179$

$\frac{W}{A} = \frac{227 \times 10^3}{58.7 \times 10^2} = 38.6$

$\frac{M}{Z} = \frac{45.4 \times 10^3}{449} = 101$

$\frac{101}{179} + \frac{38.6}{131} = 0.86 < 1 \therefore$ Ok

Allowable Ground Bearing Pressure = 250 kN/m²

∴ Use 1200 × 1200

Actual GBP = $\frac{227}{1.2 \times 1.2}$ = 157 kN/m² ∴ ok

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Bay Window Support

350 Brick $7.5(0.\cancel{75})(13) = 73$ kN/m

Roof $2.1\left(\frac{0.8}{2}\right) = 0.84$

Floor $5\left(\frac{0.8}{2}\right) \times 4 = 4$

Ground Floor $2.2\left(\frac{0.8}{2}\right) = 0.88$

79 kN/m

Max span = 2.9m

Mmax = 82.8 kNm   R = 115 kN

fos × 1.5 = 124 kNm

Effective length = 2.9m

∴ Use 254×254 UC 73

Res Moment = 273 kNm > 124 ∴ ok

$\delta = \frac{5}{384} \times \frac{79(2900)^4}{210000(11400 \times 10^4)} = 3mm$ ∴ ok

Side Beams, span = 1.2m

Use 254 UC 73 ok by inspection

Column – try 152×152 UC37

$\frac{L}{r_y} = \frac{2700}{38.7} = 70$ $p_c = 115$ Mmax = 115(0.175) = 20 kNm

$D/_{T} = 14$ $p_{bc} = 167$

$W/_{A} = \frac{115 \times 10^3}{47.1 \times 10^2} = 24.4$

$M/_{Z} = \frac{20 \times 10^3}{273} = 73$ $\frac{73}{167} + \frac{24.4}{115} = 0.65 < 1$ ∴ ok

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~~Beam F4-F7, span = 6.6m~~

Timber Floor $2.7\left(\frac{6}{2}\right) = 8.1\,kN/m$

Stud Wall $0.5\,(2.7) = \underline{1.35}$

$9.45\,kN/m$

$M_{max} = 51.5\,kNm$ $\underline{R = 31\,kN}$

fact 1.5 = 77.1 kNm

Effective span = 7m

∴ Use 203 × 203 UC 60

Allowable moment : 142 kNm > 77.1 ∴ ok

$\delta = \frac{5}{384} \times \frac{9.45(6600)^4}{210000(6130 \times 10^4)} = 18\,mm$ $\frac{span}{363}$ ∴ ok

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Beams along Grid Line 4, max span = 2.9m

At Ground Floor level

Loads

Conc Floor $5\left(\frac{10.4}{2}\right) \times 3 = 78$ kN/m

Timber Floor $2.7\left(\frac{10.4}{2}\right) \times 2 = 28$

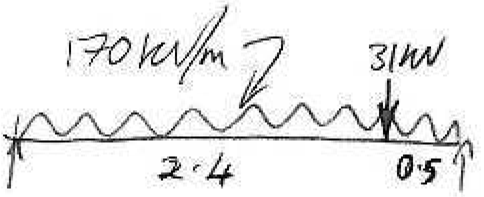
Roof $2.1\left(\frac{10.4}{2}\right) = 10.92$

225 Brick $4.8(0.85)(12.5) = 51$

Ground Floor $2.7\left(\frac{1.5}{2}\right) = 2$

170 kN/m

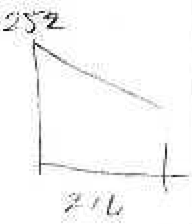
Point load from F4-F7 = 31 kN



$170\frac{(2.9)^2}{2} + 31(2.4) = R_B\, 2.9$

$R_B = 272$ kN

$R_A = 252$ kN



$M_{max} = 187$ kNm $187 \times 1.5 = 280.5$ kNm

$W_u = 178$ kN/m

Effective length = 2.5m

∴ Use 203 x 203 UC 86

Allowable moment = 259 kNm > 178 kNm

$\delta = \frac{5}{384} \times \frac{178(2900)^4}{210000(9450 \times 10^4)} = 8$mm ∴ OK

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Column F4

Load $= 272 + 170\left(\frac{1.2}{2}\right) = 374kN$

$M_{max} = 272\,(0.2) = 54.4kNm$

Try 203 × 203 UC 60

$\frac{L}{r_y} = \frac{2700}{52} = 52$ $\quad p_c = 131$

$\frac{D}{T} = 14.7$ $\quad p_{bc} = 180$

$\frac{N}{A} = \frac{374 \times 10^3}{76.4} = 48.9$

$\frac{M}{Z} = \frac{54.4 \times 10^3}{584} = 93.15$

$\frac{93.15}{180} + \frac{48.9}{131} \approx 0.89 < 1$ $\quad \therefore$ ok

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LOADS ON GRID LINE 7 (At Ground Floor level)

330 Brick $7.5(0.75)(12.5) = 70.3$ kN/m

Conc Floor $5\left(\frac{6.3}{2}\right) \times 3 = 47.25$

Timber Floor $2.7\left(\frac{6.3}{2}\right) \times 2 = 17.01$

P. Roof $2.1\left(\frac{6.3}{2}\right) = 6.6$

Mansard $1(5) = 5$

146 kN/m

Steels for temporary opening, max span = 4.15m

Mmax = 314 kNm

for × 1.5 = 471 kNm

Try 2/406 × 178 UB 60

Allowable moment = 240×2 = 480 kNm > 471 ∴ Ok

$\delta = \frac{5}{384} \times \frac{146(4150)^4}{210000(21600 \times 10^4) \times 2} = 6mm$ ∴ Ok

FOUNDATIONS ON GRID LINE 7

LOAD = 146 kN/m

BASEMENT WALL $9.6(3)(0.85) = 24.5$

171 kN/m

Use 1200 wide Footings

$GBP = \frac{171}{1.2} = 142$ kN/m² < 250 kN/m²

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LOADS ON GRID LINE A/L (At Ground Floor level)

Brick 7.5(17) = 127.5kN/m

Conc Floors 5 $\left(\frac{4}{2}\right)$ × 3 = 30

Timber Floors 2.7 $\left(\frac{4}{2}\right)$ = 5.4

163 kN/m

LOADS FROM NEIGHBOURS

30

5.4

198.4kN/m

LOADS ON GRID LINE 7 (At Ground level)

33 Brick 7.5(0.85)(12.5) = 79.6

Conc Floors 5 $\left(\frac{4}{2}\right)$ × 3 = 30

Timber Floor 2.7 $\left(\frac{4}{2}\right)$ × 2 = 10.8

P. Roof 2.1 $\left(\frac{4}{2}\right)$ = 4.2

Mansard 1(5) = 5

130 kN/m

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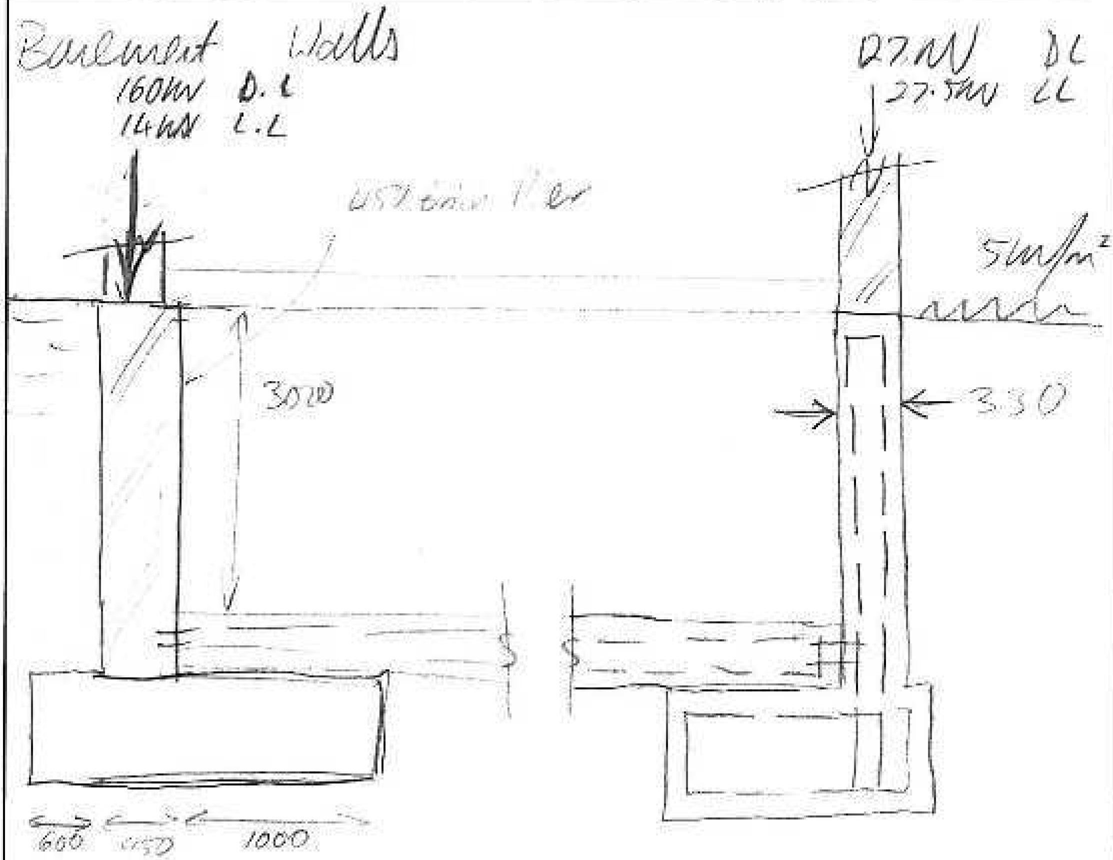
Basement Walls



WALL GRIDLINE 'A'

WALL GRIDLINE 'L'

SEE QUIKFRAME ANALYSIS

A

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 2.4.08

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **1850** mm
Prop height	h_{prop} = **1360** mm
Stem thickness	t_{stem} = **660** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **1350** mm
Base thickness	t_{base} = **600** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **1850** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm
Height of water	h_{water} = **1000** mm
Water density	γ_w = **9.8** kN/m^3

Retained soil properties

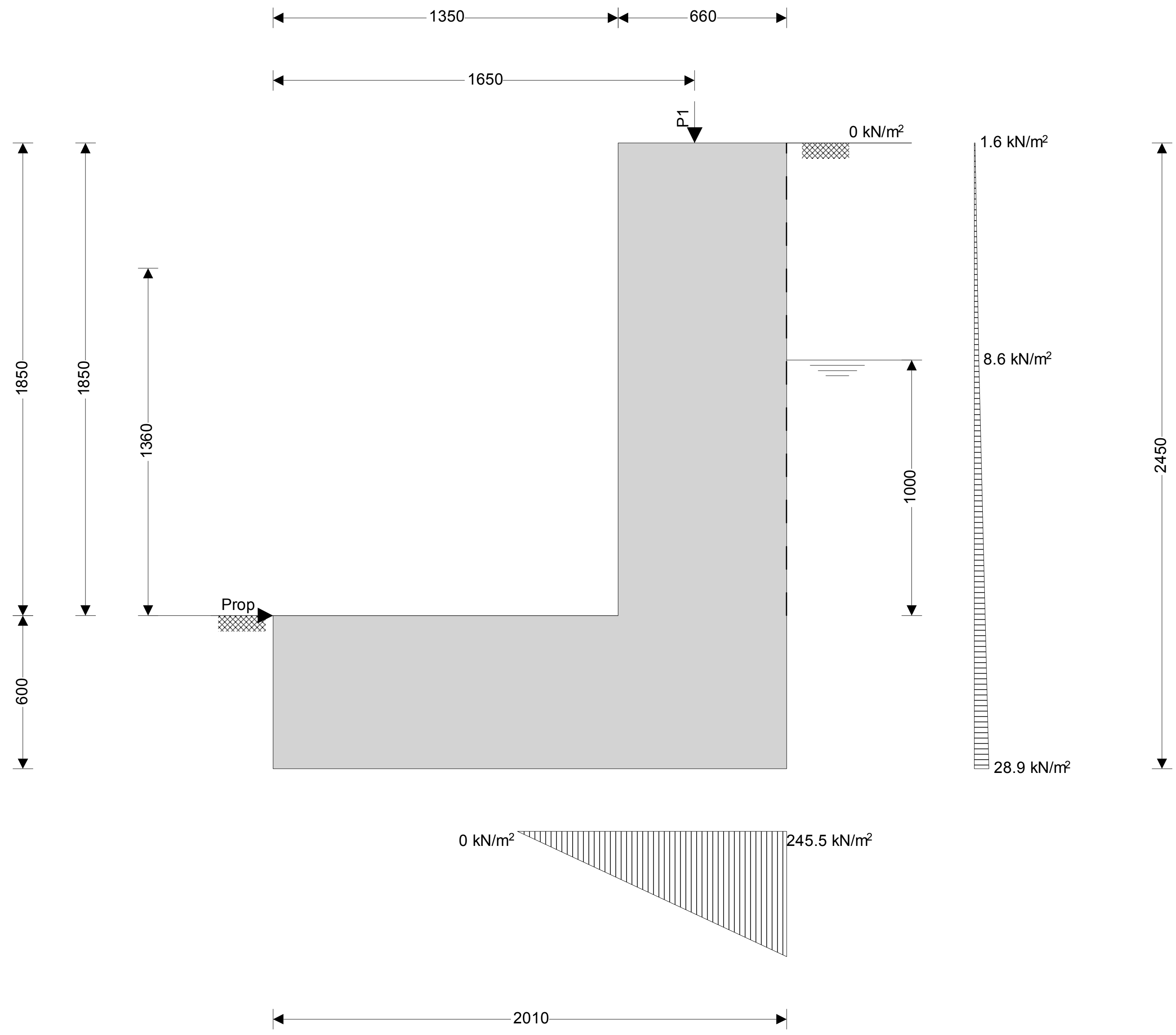
Soil type	Organic clay
Moist density	γ_{mr} = **15** kN/m^3
Saturated density	γ_{sr} = **15** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **18** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **9** deg

Base soil properties

Soil type	Organic clay
Moist density	γ_{mb} = **15** kN/m^3
Characteristic 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
Presumed bearing capacity	$P_{bearing}$ = **250** kN/m^2

Loading details

Permanent surcharge load	$Surcharge_G$ = **1** kN/m^2
Variable surcharge load	$Surcharge_Q$ = **1.5** kN/m^2
Vertical line load at 1650 mm	P_{G1} = **168** kN/m
	P_{Q1} = **30** kN/m



Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} = \mathbf{2010}$ mm
Saturated soil height	$h_{sat} = h_{water} + d_{cover} = \mathbf{1000}$ mm
Moist soil height	$h_{moist} = h_{ret} - h_{water} = \mathbf{850}$ mm
Length of surcharge load	$l_{sur} = l_{heel} = \mathbf{0}$ mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2 = \mathbf{2010}$ mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{2450}$ mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 = \mathbf{1225}$ mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} = \mathbf{1.221}$ m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{1680}$ mm
Area of wall base	$A_{base} = l_{base} \times t_{base} = \mathbf{1.206}$ m^2
- Distance to vertical component	$x_{base} = l_{base} / 2 = \mathbf{1005}$ mm

Using Coulomb theory

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

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

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{30.5}$ kN/m
Wall base	$F_{base} = A_{base} \times \gamma_{base} = \mathbf{30.2}$ kN/m
Line loads	$F_{P\_v} = P_{G1} + P_{Q1} = \mathbf{198}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v}$ = **258.7** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (Surcharge_G + Surcharge_Q) \times h_{eff}$ = **2.9** kN/m

Saturated retained soil $F_{sat\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2$ = **3.2** kN/m

Water $F_{water\_h} = \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **12.6** kN/m

Moist retained soil $F_{moist\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base}))$ = **12.3** kN/m

Total $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h}$ = **31** kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem}$ = **51.3** kNm/m

Wall base $M_{base} = F_{base} \times x_{base}$ = **30.3** kNm/m

Surcharge load $M_{sur} = -F_{sur\_h} \times x_{sur\_h}$ = **-3.6** kNm/m

Line loads $M_P = (P_{G1} + P_{Q1}) \times p_1$ = **326.7** kNm/m

Saturated retained soil $M_{sat} = -F_{sat\_h} \times x_{sat\_h}$ = **-1.7** kNm/m

Water $M_{water} = -F_{water\_h} \times x_{water\_h}$ = **-6.7** kNm/m

Moist retained soil $M_{moist} = -F_{moist\_h} \times x_{moist\_h}$ = **-12.7** kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} + M_P$ = **383.7** kNm/m

Check bearing pressure

Propping force $F_{prop\_base} = F_{total\_h}$ = **31** kN/m

Distance to reaction $\bar{x} = (M_{total} + M_{prop}) / F_{total\_v}$ = **1483** mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2$ = **478** mm

Loaded length of base $l_{load} = 2 \times (l_{base} - \bar{x})$ = **1054** mm

Bearing pressure at toe q_{toe} = **0** kN/m^2

Bearing pressure at heel $q_{heel} = F_{total\_v} / l_{load}$ = **245.5** kN/m^2

Factor of safety $FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel})$ = **1.018**

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 and EN1996-1-1:2005 incorporating Corrigenda dated February 2006 and July 2009 and the UK National Annex

Tedds calculation version 2.4.08

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

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

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

Masonry details - Section 3.1

Masonry type Clay with water absorption of < 7% - Group 1

Normalised mean compressive strength f_b = **50** N/mm^2

Characteristic flexural strength - Table NA.6 f_{xk} = **0.5** N/mm^2

Initial shear strength - Table NA.5 f_{vko} = **0.15** N/mm^2

Mortar details - Section 3.2

Mortar type General purpose - M6, prescribed mix

Compressive strength of mortar f_m = **6** N/mm^2

Ultimate limit states - Table NA.1

Class of execution control 1

Category of manufacture control 1

Partial factor for direct or flexural compression γ_{Mc} = **2.3**

Partial factor for flexural tension γ_{Mt} = **2.3**

Partial factor for shear γ_{Mv} = **2.5**

Check stem design at base of stem

Depth of section t = **660** mm

Masonry characteristics

Compressive strength constants - Table NA.4 K = **0.5**

Characteristic compressive strength - cl.3.6.1.2(1) $f_k = K \times f_b^{0.7} \times f_m^{0.3}$ = **13.234** N/mm^2

Design compressive strength $f_d = f_k / \gamma_{Mc}$ = **5.754** N/mm^2

Design flexural strength $f_{xd} = f_{xk} / \gamma_{Mt}$ = **0.217** N/mm^2

Height of masonry $h_{wt} = h_{stem}$ = **1850** mm

Compressive axial force combination 1 $F = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t + P_{G1}) + \gamma_{Qf} \times P_{Q1})$ = **198.5** kN/m

Eccentricity of axial load e = **25.4** mm

Capacity reduction factor - exp.6.4 $\Phi = 1 - 2 \times e / t$ = **0.923**

Design vertical resistance - exp.6.2 $N_{Rd} = \Phi \times t \times f_d$ = **3505.5** kN/m

Design vertical compressive stress $\sigma_d = \min(F / t, 0.15 \times N_{Rd} / t)$ = **0.301** N/mm^2

Apparent design flexural strength - exp.6.16 $f_{xd,app} = f_{xd} + \sigma_d$ = **0.518** N/mm^2

Characteristic shear strength - exp.3.5 $f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, 0.065 \times f_b)$ = **0.27** N/mm^2

Design shear strength $f_{vd} = f_{vk} / \gamma_{Mv}$ = **0.108** N/mm^2

Unreinforced masonry walls subjected to lateral loading - Section 6.3

Design bending moment combination 1 M = **14.289** kNm/m

Elastic section modulus of wall $Z = t^2 / 6$ = **72600000** mm^3/m

Moment of resistance of masonry - exp.6.15 $M_{Rd} = f_{xd,app} \times Z$ = **37.62** kNm/m

M / M_{Rd} = **0.380**

PASS - Moment of resistance exceeds applied design moment

Unreinforced masonry walls subjected to shear loading - Section 6.2

Design shear force V = **23.173** kN/m

Maximum compressive stress $\sigma_{max} = F / t + M / Z$ = **0.498** N/mm^2

Minimum compressive stress σ_{min} = F / t - M / Z = **0.104** N/mm^2

Thickness of wall in compression t_c = t = **660** mm

Design shear resistance - exp.6.13 $V_{Rd} = f_{vd} \times t_c$ = **71.364** kN/m

V / V_{Rd} = **0.325**

PASS - Design shear resistance exceeds applied design shear force

Check stem design at 460 mm

Depth of section t = **660** mm

Masonry characteristics

Compressive strength constants - Table NA.4 K = **0.5**

Characteristic compressive strength - cl.3.6.1.2(1) $f_k = K \times f_b^{0.7} \times f_m^{0.3}$ = **13.234** N/mm^2

Design compressive strength $f_d = f_k / \gamma_{Mc}$ = **5.754** N/mm^2

Design flexural strength $f_{xd} = f_{xk} / \gamma_{Mt}$ = **0.217** N/mm^2

Height of masonry $h_{wt} = h_{stem}$ - 460 mm = **1390** mm

Compressive axial force combination 1 $F = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t + P_{G1}) + \gamma_{Qf} \times P_{Q1})$ = **190.9** kN/m

Eccentricity of axial load e = **26.4** mm

Capacity reduction factor - exp.6.4 $\Phi = 1 - 2 \times e / t$ = **0.92**

Design vertical resistance - exp.6.2 $N_{Rd} = \Phi \times t \times f_d$ = **3493.8** kN/m

Design vertical compressive stress $\sigma_d = \min(F / t, 0.15 \times N_{Rd} / t)$ = **0.289** N/mm^2

Apparent design flexural strength - exp.6.16 $f_{xd,app} = f_{xd} + \sigma_d$ = **0.507** N/mm^2

Characteristic shear strength - exp.3.5 $f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, 0.065 \times f_b)$ = **0.266** N/mm^2

Design shear strength $f_{vd} = f_{vk} / \gamma_{Mv}$ = **0.106** N/mm^2

Unreinforced masonry walls subjected to lateral loading - Section 6.3

Design bending moment combination 1 M = **6.166** kNm/m

Elastic section modulus of wall $Z = t^2 / 6$ = **72600000** mm^3/m

Moment of resistance of masonry - exp.6.15 $M_{Rd} = f_{xd,app} \times Z$ = **36.785** kNm/m

M / M_{Rd} = **0.168**

PASS - Moment of resistance exceeds applied design moment

Unreinforced masonry walls subjected to shear loading - Section 6.2

Design shear force V = **12.731** kN/m

Maximum compressive stress σ_{max} = F / t + M / Z = **0.374** N/mm^2

Minimum compressive stress σ_{min} = F / t - M / Z = **0.204** N/mm^2

Thickness of wall in compression t_c = t = **660** mm

Design shear resistance - exp.6.13 $V_{Rd} = f_{vd} \times t_c$ = **70.15** kN/m

V / V_{Rd} = **0.181**

PASS - Design shear resistance exceeds applied design shear force

Check stem design at 920 mm

Depth of section t = **660** mm

Masonry characteristics

Compressive strength constants - Table NA.4 K = **0.5**

Characteristic compressive strength - cl.3.6.1.2(1) $f_k = K \times f_b^{0.7} \times f_m^{0.3}$ = **13.234** N/mm^2

Design compressive strength $f_d = f_k / \gamma_{Mc}$ = **5.754** N/mm^2

Design flexural strength $f_{xd} = f_{xk} / \gamma_{Mt}$ = **0.217** N/mm^2

Height of masonry $h_{wt} = h_{stem}$ - 920 mm = **930** mm

Compressive axial force combination 1 $F = (\gamma_{Gf} \times (\gamma_{stem} \times h_{wt} \times t + P_{G1}) + \gamma_{Qf} \times P_{Q1})$ = **183.3** kN/m

Eccentricity of axial load e = **27.5** mm

Capacity reduction factor - exp.6.4 $\Phi = 1 - 2 \times e / t =$ **0.917**

Design vertical resistance - exp.6.2 $N_{Rd} = \Phi \times t \times f_d =$ **3481.3** kN/m

Design vertical compressive stress $\sigma_d = \min(F / t, 0.15 \times N_{Rd} / t) =$ **0.278** N/mm^2

Apparent design flexural strength - exp.6.16 $f_{xd,app} = f_{xd} + \sigma_d =$ **0.495** N/mm^2

Characteristic shear strength - exp.3.5 $f_{vk} = \min(f_{vko} + 0.4 \times \sigma_d, 0.065 \times f_b) =$ **0.261** N/mm^2

Design shear strength $f_{vd} = f_{vk} / \gamma_{Mv} =$ **0.104** N/mm^2

Unreinforced masonry walls subjected to lateral loading - Section 6.3

Design bending moment combination 1 M = **2.039** kNm/m

Elastic section modulus of wall $Z = t^2 / 6 =$ **72600000** mm^3/m

Moment of resistance of masonry - exp.6.15 $M_{Rd} = f_{xd,app} \times Z =$ **35.951** kNm/m

$M / M_{Rd} =$ **0.057**

PASS - Moment of resistance exceeds applied design moment

Unreinforced masonry walls subjected to shear loading - Section 6.2

Design shear force V = **5.798** kN/m

Maximum compressive stress $\sigma_{max} = F / t + M / Z =$ **0.306** N/mm^2

Minimum compressive stress $\sigma_{min} = F / t - M / Z =$ **0.250** N/mm^2

Thickness of wall in compression $t_c = t =$ **660** mm

Design shear resistance - exp.6.13 $V_{Rd} = f_{vd} \times t_c =$ **68.935** kN/m

$V / V_{Rd} =$ **0.084**

PASS - Design shear resistance exceeds applied design shear force

Check base design at toe

Depth of section h = **600** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 M = **18.1** kNm/m

Depth to tension reinforcement $d = h - c_{bb} - \phi_{bb} / 2 =$ **519** mm

$K = M / (d^2 \times f_{ck}) =$ **0.002**

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d =$ **493** mm

Depth of neutral axis $x = 2.5 \times (d - z) =$ **65** mm

Area of tension reinforcement required $A_{bb.req} = M / (f_{yd} \times z) =$ **84** mm^2/m

Tension reinforcement provided 12 dia.bars @ 100 c/c

Area of tension reinforcement provided $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) =$ **1131** mm^2/m

Minimum area of reinforcement - exp.9.1N $A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **782** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) $A_{bb.max} = 0.04 \times h =$ **24000** mm^2/m

$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} =$ **0.691**

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 $\psi_2 =$ **0.6**

Serviceability bending moment $M_{sls} =$ **13.3** kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{bb.prov} \times z) =$ **23.8** N/mm^2

Load duration Long term

Load duration factor $k_t =$ **0.4**

Effective area of concrete in tension $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) =$ **178375** mm^2/m

Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm} = \mathbf{2.9}$ N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff} = \mathbf{0.006}$
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	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} = \mathbf{577}$ mm
Maximum crack width - exp.7.8	$w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	$w_k = \mathbf{0.041}$ mm
	$w_k / w_{max} = \mathbf{0.137}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

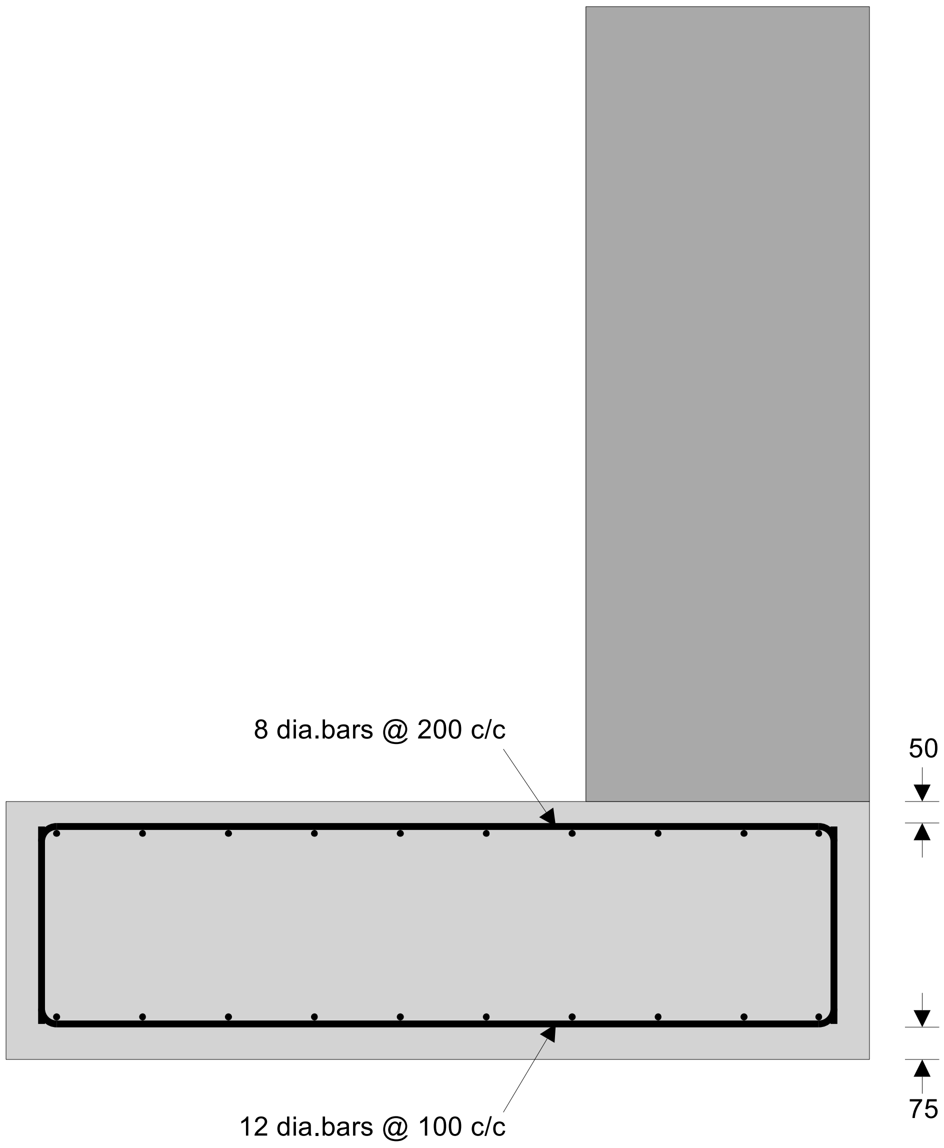
Design shear force	$V = \mathbf{92.2}$ kN/m
	$C_{Rd,c} = 0.18 / \gamma_C = \mathbf{0.120}$
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.621}$
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb.prov} / d, 0.02) = \mathbf{0.002}$
	$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.396}$ N/mm^2
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c} = \mathbf{205.3}$ kN/m
	$V / V_{Rd.c} = \mathbf{0.449}$

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)	$A_{bx.req} = 0.2 \times A_{bb.prov} = \mathbf{226}$ mm^2/m
Maximum spacing of reinforcement – cl.9.3.1.1(3)	$s_{bx\_max} = \mathbf{450}$ mm
Transverse reinforcement provided	8 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx}) = \mathbf{251}$ mm^2/m

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



8 dia.bars @ 200 c/c
transverse reinforcement
in base

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 2.4.08

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **1850** mm
Prop height	h_{prop} = **1850** mm
Stem thickness	t_{stem} = **350** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **920** mm
Heel length	l_{heel} = **480** mm
Base thickness	t_{base} = **600** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **1850** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm
Height of water	h_{water} = **1000** mm
Water density	γ_w = **9.8** kN/m^3

Retained soil properties

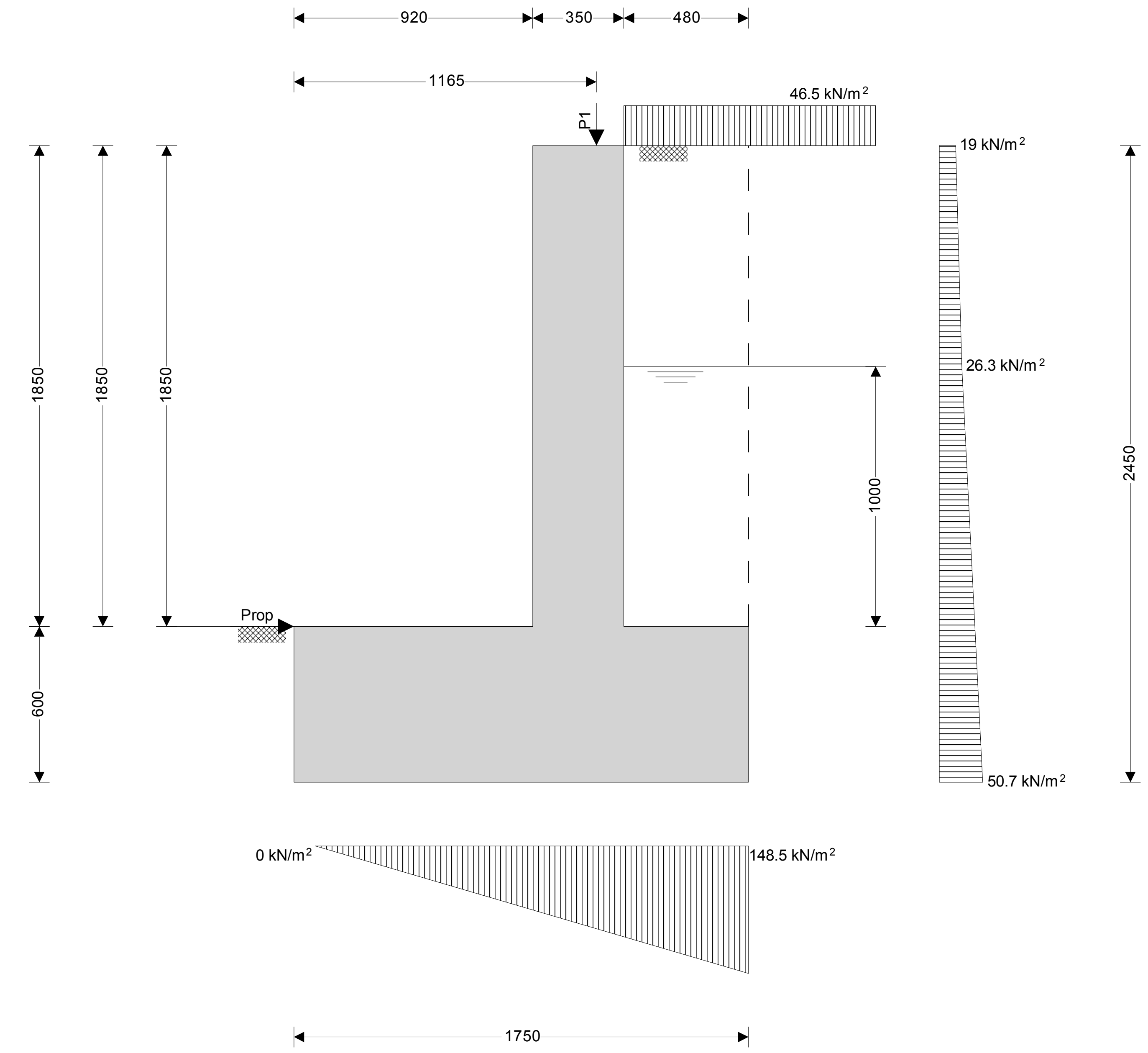
Soil type	Medium dense well graded sand
Moist density	γ_{mr} = **21** kN/m^3
Saturated density	γ_{sr} = **23** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **30** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **0** deg

Base soil properties

Soil type	Medium dense well graded sand
Moist density	γ_{mb} = **18** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **30** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **15** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **30** deg
Presumed bearing capacity	$P_{bearing}$ = **250** kN/m^2

Loading details

Permanent surcharge load	$Surcharge_G$ = **40** kN/m^2
Variable surcharge load	$Surcharge_Q$ = **5** kN/m^2
Vertical line load at 1165 mm	P_{G1} = **124** kN/m
	P_{Q1} = **40** kN/m



Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} + l_{heel} = \mathbf{1750}$ mm
Saturated soil height	$h_{sat} = h_{water} + d_{cover} = \mathbf{1000}$ mm
Moist soil height	$h_{moist} = h_{ret} - h_{water} = \mathbf{850}$ mm
Length of surcharge load	$l_{sur} = l_{heel} = \mathbf{480}$ mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2 = \mathbf{1510}$ mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{2450}$ mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 = \mathbf{1225}$ mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} = \mathbf{0.648}$ m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{1095}$ mm
Area of wall base	$A_{base} = l_{base} \times t_{base} = \mathbf{1.05}$ m^2
- Distance to vertical component	$x_{base} = l_{base} / 2 = \mathbf{875}$ mm
Area of saturated soil	$A_{sat} = h_{sat} \times l_{heel} = \mathbf{0.48}$ m^2
- Distance to vertical component	$x_{sat\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat} = \mathbf{1510}$ mm
- Distance to horizontal component	$x_{sat\_h} = (h_{sat} + h_{base}) / 3 = \mathbf{533}$ mm
Area of water	$A_{water} = h_{sat} \times l_{heel} = \mathbf{0.48}$ m^2
- Distance to vertical component	$x_{water\_v} = l_{base} - (h_{sat} \times l_{heel}^2 / 2) / A_{sat} = \mathbf{1510}$ mm
- Distance to horizontal component	$x_{water\_h} = (h_{sat} + h_{base}) / 3 = \mathbf{533}$ mm
Area of moist soil	$A_{moist} = h_{moist} \times l_{heel} = \mathbf{0.408}$ m^2
- Distance to vertical component	$x_{moist\_v} = l_{base} - (h_{moist} \times l_{heel}^2 / 2) / A_{moist} = \mathbf{1510}$ mm
- Distance to horizontal component	$x_{moist\_h} = (h_{moist} \times (t_{base} + h_{sat} + h_{moist} / 3) / 2 + (h_{sat} + t_{base})^2/2) / (h_{sat} + t_{base} + h_{moist} / 2) = \mathbf{1027}$ mm

Using Coulomb theory

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

Passive pressure coefficient $K_P = \sin(90 - \phi'_{b.k})^2 / (\sin(90 + \delta_{b.k}) \times [1 - \sqrt{[\sin(\phi'_{b.k} + \delta_{b.k}) \times \sin(\phi'_{b.k}) / (\sin(90 + \delta_{b.k}))]}]^2) = \mathbf{4.977}$

Bearing pressure check

Vertical forces on wall

Wall stem $F_{stem} = A_{stem} \times \gamma_{stem}$ = **16.2** kN/m

Wall base $F_{base} = A_{base} \times \gamma_{base}$ = **26.3** kN/m

Surcharge load $F_{sur\_v} = (Surcharge_G + Surcharge_Q) \times l_{heel}$ = **21.6** kN/m

Line loads $F_{P\_v} = P_{G1} + P_{Q1}$ = **164** kN/m

Saturated retained soil $F_{sat\_v} = A_{sat} \times (\gamma_{sr} - \gamma_w)$ = **6.3** kN/m

Water $F_{water\_v} = A_{water} \times \gamma_w$ = **4.7** kN/m

Moist retained soil $F_{moist\_v} = A_{moist} \times \gamma_{mr}$ = **8.6** kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{sat\_v} + F_{moist\_v} + F_{water\_v} + F_{sur\_v} + F_{P\_v}$ = **247.6** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times (Surcharge_G + Surcharge_Q) \times h_{eff}$ = **36.8** kN/m

Saturated retained soil $F_{sat\_h} = K_A \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2$ = **5.6** kN/m

Water $F_{water\_h} = \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **12.6** kN/m

Moist retained soil $F_{moist\_h} = K_A \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base}))$ = **12** kN/m

Total $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h}$ = **67** kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem}$ = **17.7** kNm/m

Wall base $M_{base} = F_{base} \times x_{base}$ = **23** kNm/m

Surcharge load $M_{sur} = F_{sur\_v} \times x_{sur\_v} - F_{sur\_h} \times x_{sur\_h}$ = **-12.4** kNm/m

Line loads $M_P = (P_{G1} + P_{Q1}) \times p_1$ = **191.1** kNm/m

Saturated retained soil $M_{sat} = F_{sat\_v} \times x_{sat\_v} - F_{sat\_h} \times x_{sat\_h}$ = **6.6** kNm/m

Water $M_{water} = F_{water\_v} \times x_{water\_v} - F_{water\_h} \times x_{water\_h}$ = **0.4** kNm/m

Moist retained soil $M_{moist} = F_{moist\_v} \times x_{moist\_v} - F_{moist\_h} \times x_{moist\_h}$ = **0.6** kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} + M_P$ = **226.9** kNm/m

Check bearing pressure

Propping force $F_{prop\_base} = F_{total\_h}$ = **67** kN/m

Distance to reaction $\bar{x} = (M_{total} + M_{prop}) / F_{total\_v}$ = **916** mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2$ = **41** mm

Loaded length of base $l_{load} = 2 \times (l_{base} - \bar{x})$ = **1668** mm

Bearing pressure at toe q_{toe} = **0** kN/m^2

Bearing pressure at heel $q_{heel} = F_{total\_v} / l_{load}$ = **148.5** kN/m^2

Factor of safety $FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel})$ = **1.684**

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 2.4.08

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 = **350** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	M = **46.7** kNm/m
Depth to tension reinforcement	$d = h - c_{sr} - \phi_{sr} / 2$ = **292** mm
	$K = M / (d^2 \times f_{ck})$ = **0.018**
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **277** mm
Depth of neutral axis	$x = 2.5 \times (d - z)$ = **37** mm
Area of tension reinforcement required	$A_{sr.req} = M / (f_{yd} \times z)$ = **387** mm^2/m
Tension reinforcement provided	16 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **1005** mm^2/m
Minimum area of reinforcement - exp.9.1N	$A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **440** mm^2/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{sr.max} = 0.04 \times h$ = **14000** mm^2/m
	$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.437**

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} = **33.1** kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **118.7** N/mm^2

Load duration Long term

Load duration factor k_t = **0.4**

Effective area of concrete in tension $A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **104500** mm^2/m

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

Reinforcement ratio $\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.010**

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 $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **453** 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 = **0.161** mm

w_k / w_{max} = **0.538**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force V = **59** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.828**

Longitudinal reinforcement ratio $\rho_l = \min(A_{sf.prov} / d, 0.02)$ = **0.001**

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.474** N/mm^2

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

$V_{Rd.c}$ = **138.3** kN/m

$V / V_{Rd.c}$ = **0.426**

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) $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem})$ = **350** 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 $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **393** mm^2/m

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

Check base design at toe

Depth of section h = **600** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 M = **65.8** kNm/m

Depth to tension reinforcement $d = h - c_{bb} - \phi_{bb} / 2$ = **517** mm

$K = M / (d^2 \times f_{ck})$ = **0.008**

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 – 3.53 \times K)^{0.5}, 0.95) \times d$ = **491** mm

Depth of neutral axis $x = 2.5 \times (d – z)$ = **65** mm

Area of tension reinforcement required $A_{bb.req} = M / (f_{yd} \times z)$ = **308** mm^2/m

Tension reinforcement provided 16 dia.bars @ 200 c/c

Area of tension reinforcement provided $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = \mathbf{1005}$ mm^2/m

Minimum area of reinforcement - exp.9.1N $A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{779}$ mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) $A_{bb.max} = 0.04 \times h = \mathbf{24000}$ mm^2/m

$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} = \mathbf{0.775}$

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 $M_{sls} = \mathbf{48.1}$ kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{bb.prov} \times z) = \mathbf{97.3}$ N/mm^2

Load duration Long term

Load duration factor $k_t = \mathbf{0.4}$

Effective area of concrete in tension $A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2) = \mathbf{178458}$ mm^2/m

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

Reinforcement ratio $\rho_{p.eff} = A_{bb.prov} / A_{c.eff} = \mathbf{0.006}$

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 $s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} = \mathbf{738}$ mm

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

$w_k = \mathbf{0.215}$ mm

$w_k / w_{max} = \mathbf{0.718}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force $V = \mathbf{147.7}$ kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.622}$

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

$v_{min} = 0.035$ N$^{1/2}$/mm $\times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.396}$ N/mm^2

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

$V_{Rd.c} = \mathbf{204.7}$ kN/m

$V / V_{Rd.c} = \mathbf{0.721}$

PASS - Design shear resistance exceeds design shear force

Rectangular section in shear - Section 6.2

Design shear force $V = \mathbf{38}$ kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.622}$

Longitudinal reinforcement ratio $\rho_l = \min(A_{bt.prov} / d, 0.02) = \mathbf{0.001}$

$v_{min} = 0.035$ N$^{1/2}$/mm $\times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.396}$ N/mm^2

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

$V_{Rd.c} = \mathbf{204.7}$ kN/m

$V / V_{Rd.c} = \mathbf{0.185}$

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

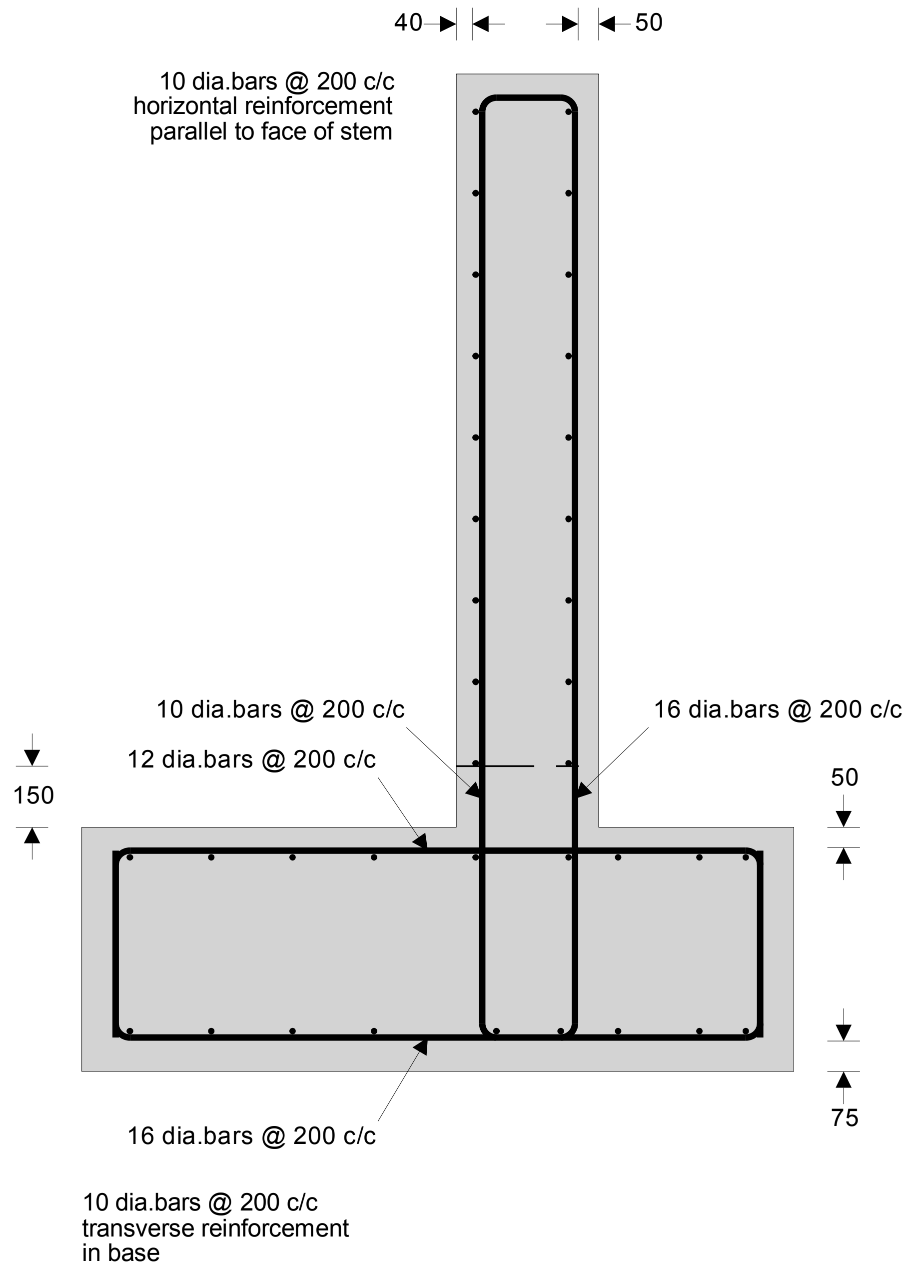
Minimum area of reinforcement – cl.9.3.1.1(2) $A_{bx.req} = 0.2 \times A_{bb.prov} = \mathbf{201}$ mm^2/m

Maximum spacing of reinforcement – cl.9.3.1.1(3) $s_{bx\_max} = \mathbf{450}$ mm

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

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

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



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 2.4.08

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **2000** mm
Prop height	h_{prop} = **2000** mm
Stem thickness	t_{stem} = **250** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **1250** mm
Base thickness	t_{base} = **350** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **1800** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm
Height of water	h_{water} = **1000** mm
Water density	γ_w = **9.8** kN/m^3

Retained soil properties

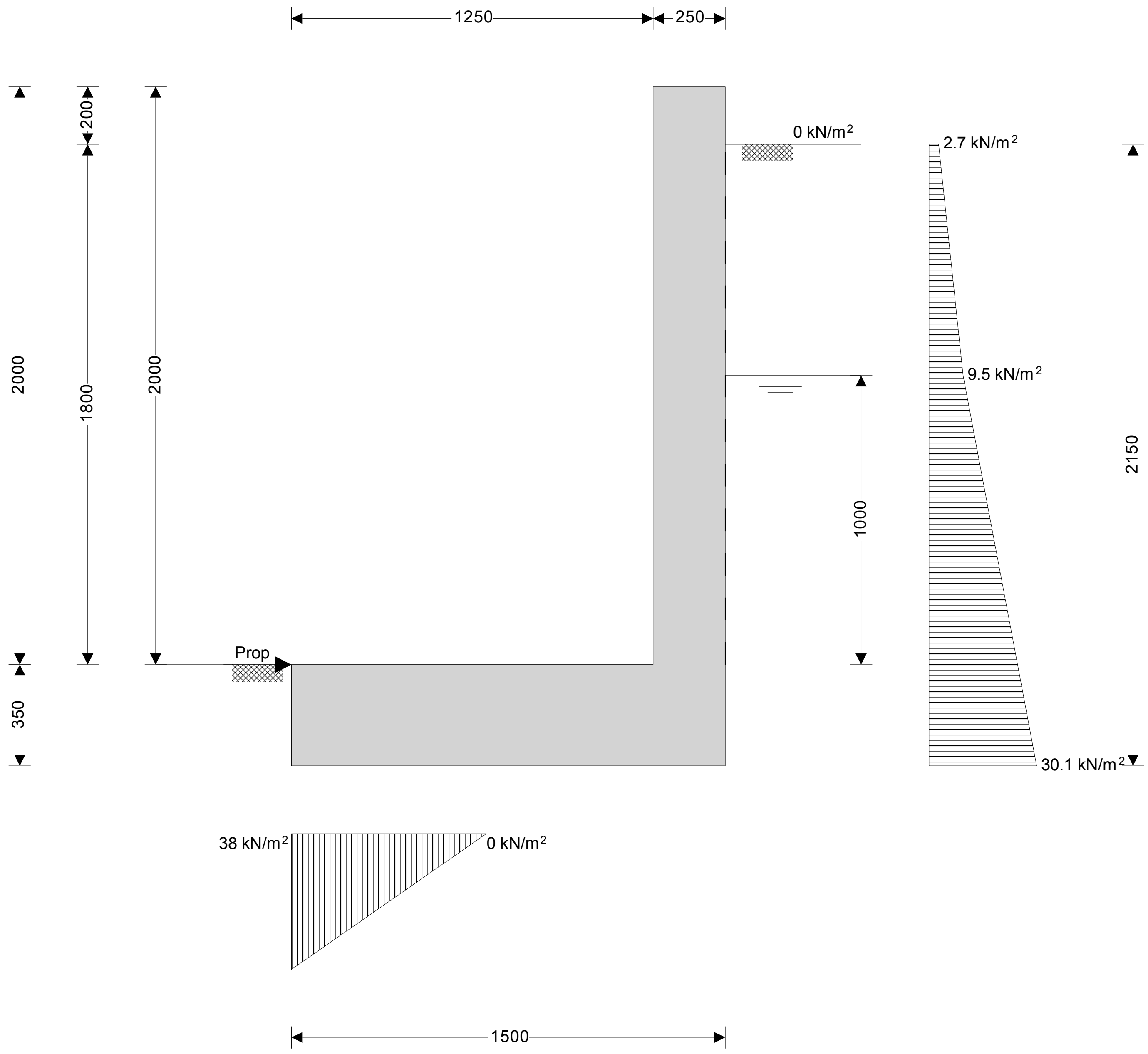
Soil type	Medium dense well graded sand
Moist density	γ_{mr} = **21** kN/m^3
Saturated density	γ_{sr} = **23** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **30** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **0** deg

Base soil properties

Soil type	Medium dense well graded sand
Moist density	γ_{mb} = **18** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **30** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **15** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **30** deg
Presumed bearing capacity	$P_{bearing}$ = **250** kN/m^2

Loading details

Variable surcharge load	$Surcharge_Q$ = **5** kN/m^2



Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} = \mathbf{1500}$ mm
Saturated soil height	$h_{sat} = h_{water} + d_{cover} = \mathbf{1000}$ mm
Moist soil height	$h_{moist} = h_{ret} - h_{water} = \mathbf{800}$ mm
Length of surcharge load	$l_{sur} = l_{heel} = \mathbf{0}$ mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2 = \mathbf{1500}$ mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{2150}$ mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 = \mathbf{1075}$ mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} = \mathbf{0.5}$ m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{1375}$ mm
Area of wall base	$A_{base} = l_{base} \times t_{base} = \mathbf{0.525}$ m^2
- Distance to vertical component	$x_{base} = l_{base} / 2 = \mathbf{750}$ mm

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r.k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.k}) \times [1 + \sqrt{[\sin(\phi'_{r.k} + \delta_{r.k}) \times \sin(\phi'_{r.k} - \beta) / (\sin(\alpha - \delta_{r.k}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.333}$
Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b.k})^2 / (\sin(90 + \delta_{b.k}) \times [1 - \sqrt{[\sin(\phi'_{b.k} + \delta_{b.k}) \times \sin(\phi'_{b.k}) / (\sin(90 + \delta_{b.k}))]}]^2) = \mathbf{4.977}$

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{12.5}$ kN/m
Wall base	$F_{base} = A_{base} \times \gamma_{base} = \mathbf{13.1}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} =$ **25.6** kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times Surcharge_Q \times h_{eff} =$ **3.6** kN/m

Saturated retained soil $F_{sat\_h} = K_A \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **4** kN/m

Water $F_{water\_h} = \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **8.9** kN/m

Moist retained soil $F_{moist\_h} = K_A \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **9.8** kN/m

Total $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h} =$ **26.3** kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem} =$ **17.2** kNm/m

Wall base $M_{base} = F_{base} \times x_{base} =$ **9.8** kNm/m

Surcharge load $M_{sur} = -F_{sur\_h} \times x_{sur\_h} =$ **-3.9** kNm/m

Saturated retained soil $M_{sat} = -F_{sat\_h} \times x_{sat\_h} =$ **-1.8** kNm/m

Water $M_{water} = -F_{water\_h} \times x_{water\_h} =$ **-4** kNm/m

Moist retained soil $M_{moist} = -F_{moist\_h} \times x_{moist\_h} =$ **-8.7** kNm/m

Total $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} =$ **8.6** kNm/m

Check bearing pressure

Propping force $F_{prop\_base} = F_{total\_h} =$ **26.3** kN/m

Distance to reaction $\bar{x} = (M_{total} + M_{prop}) / F_{total\_v} =$ **337** mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 =$ **-413** mm

Loaded length of base $l_{load} = 2 \times \bar{x} =$ **673** mm

Bearing pressure at toe $q_{toe} = F_{total\_v} / l_{load} =$ **38** kN/m²

Bearing pressure at heel $q_{heel} =$ **0** kN/m²

Factor of safety $FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) =$ **6.571**

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 2.4.08

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

Concrete strength class C30/37

Characteristic compressive cylinder strength $f_{ck} =$ **30** N/mm²

Characteristic compressive cube strength $f_{ck,cube} =$ **37** N/mm²

Mean value of compressive cylinder strength $f_{cm} = f_{ck} + 8\ N/mm^2 =$ **38** N/mm²

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/mm²

5% fractile of axial tensile strength $f_{ctk,0.05} = 0.7 \times f_{ctm} =$ **2.0** N/mm²

Secant modulus of elasticity of concrete $E_{cm} = 22\ kN/mm^2 \times (f_{cm} / 10\ N/mm^2)^{0.3} =$ **32837** N/mm²

Partial factor for concrete - Table 2.1N $\gamma_C =$ **1.50**

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

Design compressive concrete strength - exp.3.15 $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C =$ **17.0** N/mm²

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

Reinforcement details

Characteristic yield strength of reinforcement $f_{yk} =$ **500** N/mm²

Modulus of elasticity of reinforcement $E_s =$ **200000** N/mm²

Partial factor for reinforcing steel - Table 2.1N $\gamma_S =$ **1.15**

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

Cover to reinforcement

Front face of stem — $c_{sf} = \mathbf{40}$ mm

Rear face of stem — $c_{sr} = \mathbf{50}$ mm

Top face of base — $c_{bt} = \mathbf{50}$ mm

Bottom face of base — $c_{bb} = \mathbf{75}$ mm

Check stem design at base of stem

Depth of section — $h = \mathbf{250}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — $M = \mathbf{14.9}$ kNm/m

Depth to tension reinforcement — $d = h - c_{sr} - \phi_{sr} / 2 = \mathbf{192}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.013}$

$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{182}$ mm

Depth of neutral axis — $x = 2.5 \times (d - z) = \mathbf{24}$ mm

Area of tension reinforcement required — $A_{sr.req} = M / (f_{yd} \times z) = \mathbf{187}$ mm^2/m

Tension reinforcement provided — 16 dia.bars @ 200 c/c

Area of tension reinforcement provided — $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = \mathbf{1005}$ mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{289}$ mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{sr.max} = 0.04 \times h = \mathbf{10000}$ mm^2/m

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov} = \mathbf{0.288}$

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 — $M_{sls} = \mathbf{9.6}$ kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{sr.prov} \times z) = \mathbf{52.5}$ N/mm^2

Load duration — Long term

Load duration factor — $k_t = \mathbf{0.4}$

Effective area of concrete in tension — $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = \mathbf{75333}$ mm^2/m

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

Reinforcement ratio — $\rho_{p.eff} = A_{sr.prov} / A_{c.eff} = \mathbf{0.013}$

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 — $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff} = \mathbf{374}$ mm

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

$w_k = \mathbf{0.059}$ mm

$w_k / w_{max} = \mathbf{0.196}$

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — $V = \mathbf{24.7}$ kN/m

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

	$k = \min(1 + \sqrt{(200\text{ mm} / d)}, 2) = \mathbf{2.000}$
Longitudinal reinforcement ratio	$\rho_l = \min(A_{sf.prov} / d, 0.02) = \mathbf{0.002}$
	$v_{min} = 0.035\text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.542}\text{ N/mm}^2$
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c} = \mathbf{104.1}$ kN/m
	$V / V_{Rd.c} = \mathbf{0.237}$

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)	$A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem}) = \mathbf{251}\text{ mm}^2/\text{m}$
Maximum spacing of reinforcement – cl.9.6.3(2)	$s_{sx\_max} = \mathbf{400}$ mm
Transverse reinforcement provided	10 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx}) = \mathbf{393}\text{ mm}^2/\text{m}$

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

Check base design at toe

Depth of section	$h = \mathbf{350}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	$M = \mathbf{22.9}$ kNm/m
Depth to tension reinforcement	$d = h - c_{bb} - \phi_{bb} / 2 = \mathbf{269}$ mm
	$K = M / (d^2 \times f_{ck}) = \mathbf{0.011}$
	$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 – 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{256}$ mm
Depth of neutral axis	$x = 2.5 \times (d – z) = \mathbf{34}$ mm
Area of tension reinforcement required	$A_{bb.req} = M / (f_{yd} \times z) = \mathbf{206}\text{ mm}^2/\text{m}$
Tension reinforcement provided	12 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = \mathbf{565}\text{ mm}^2/\text{m}$
Minimum area of reinforcement - exp.9.1N	$A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{405}\text{ mm}^2/\text{m}$
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bb.max} = 0.04 \times h = \mathbf{14000}\text{ mm}^2/\text{m}$
	$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} = \mathbf{0.716}$

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	$M_{sls} = \mathbf{16.6}$ kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bb.prov} \times z) = \mathbf{114.6}\text{ N/mm}^2$
Load duration	Long term
Load duration factor	$k_t = \mathbf{0.4}$
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2) = \mathbf{105458}\text{ mm}^2/\text{m}$
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm} = \mathbf{2.9}\text{ N/mm}^2$
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	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} = \mathbf{635}$ 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 = **0.219** mm

w_k / w_{max} = **0.728**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force V = **19.8** kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.862**

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

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.487** N/mm²

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

$V_{Rd.c}$ = **131.1** kN/m

$V / V_{Rd.c}$ = **0.151**

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** mm²/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** mm²/m

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