Appendix F – Retaining Wall Calculations

CHECK VERTICAL LOAD ON UNDERPINS ALONG PARTY WALL.

EXISTING LOADINGS

MAIN WALL SW = AVERAGE 440 THK (ASSUME 80% SOLID)

w = 18 × 0.44 × 0.8 × 10.53 (HEIGHT TO EAVES)

= 66.71 KN/m.

INITIALLY FLOOR SPANNING INTO THE WALLS ARE IGNORED AS THIS IS CONSERVATIVE.

ADDITIONAL LOAD

UNDERPINS = 0.44 × 25 × 3.75m
= 41.25 KN/m.

CHECK PRESSURES

EXISTING = 66.71 / 0.8m — ASSUMED FOOTING WIDTH
= 83.39 KN/m²

PROPOSED = 66.71 + 41.25 / 1.5 — LENGTH OF UNDERPIN BASE.
= 71.97 KN/m²

∴ FOUNDATION PRESSURES ARE LOWER THAN EXISTING AND THEREFORE SETTLEMENT BENEATH WALL WILL BE LIMITED TO DISTURBANCE FROM CONSTRUCTION. ASSUME NOMINAL 3mm VERTICAL SETTLEMENT.

CALCULATE HORIZONTAL PRESSURES

THIS BASED ON 3.7 HIGH PIN WHICH IS WORST CASE IN TEMP/PERMANENT CONDITION.

GROUND CONDITIONS

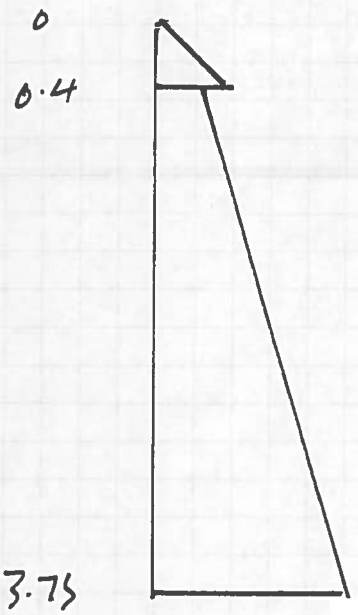
TAKEN FROM BH1 - GROUND PROFILE TYPICAL TO SLOPE.

	BGL
MADE GROUND	0 - 0.4
STIFF SILTY SANDY CLAY	0.4 – 2.45
FIRM SILTY SANDY CLAY	2.45 - 4

ACTIVE PRESSURES.

$K_a = 1 - \sin\phi' / 1 + \sin\phi'$

	ϕ'	K_a	γ_b
MG	20	0.49	17
CLAY (STIFF/FIRM)	25	0.41	19



A = 0

B = 0.49 × 17 × 0.4 = 3.332 kN/m²

C = 0.41 × 19 × 0.4 = 3.116 kN/m²

D = 0.41 × 19 × 3.75 = 29.2125 kN/m²

SURCHARGE = G_K = 10. (2m SPAN OF METAL DECK) + FINISHES c/s

Q_K = 2.5 (RESIDENTIAL LOADING)

P_S = 12.5 × 0.41 = 5.125 kN/m²

WATER ASSUME FULL DEPTH = 0 – 37.5 kN/m²

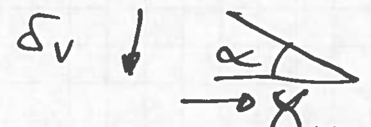
Job:	WEDDERBURN ROAD			Title:	No 4-6 PARTY WALL.			
Job No:	1220	Sheet:	3	Date:	NOV 14	Eng:	BW	Rev:

ANALYSE AS CANTILEVER BEAM USING CRACKED SECTION.
N.B. TEMPORARY PROPPING IGNORED AS THIS IS WORST CASE.

$\therefore E = 34\ kN/mm^2 \times 0.35 = 11.9\ kN/mm^2$

FROM ATTACHED CALCS HORIZONTAL MOVEMENT = 6.7m

CALCULATE VERTICAL FROM ROTATION



$\alpha = 25$

$\delta_H = 3.1mm$

$\therefore \delta_V = 3.1mm$ + NOTIONAL OF 3mm
$= ~~3~~\ 6.1\ mm.$

<u>CHECK DAMAGE CATEGORY</u>

WIDTH OF ADJACENT BUILDING/PW = 13m

$\varepsilon = 6.1\ mm / 13000 = 0.0004692$
$= 0.004692\ \%$

$\therefore$ CATEGORY 0 – NEGLIGIBLE.

CONCRETE BEAM ANALYSIS

Concrete beam dimensions:-

Beam width $b = \mathbf{1000}$ mm

Beam depth $h = \mathbf{440}$ mm

Cross-section area $A = b \times h = \mathbf{440000}$ mm^2

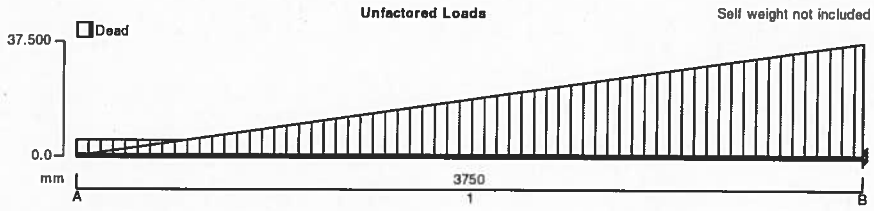
Major axis second moment of area $I_{xx} = b \times h^3 / 12 = \mathbf{7.10 \times 10^9}$ mm^4

$f_{cu} = \mathbf{30}$ N/mm^2

$E = 20$ kN/mm^2 $+ 200 \times f_{cu} = \mathbf{26.0}$ kN/mm^2

Ref BS8110:1985:Pt 2 - Eq 17

$\rho = \rho_{C.norm} = \mathbf{2400}$ kg/m^3



CONTINUOUS BEAM ANALYSIS - INPUT

BEAM DETAILS

Number of spans = **1**

Material Properties:

Modulus of elasticity = **12** kN/mm^2 Material density = **2400** kg/m^3

Support Conditions:

Support A Vertically **"Free"** Rotationally **"Free"**

Support B Vertically **"Restrained"** Rotationally **"Restrained"**

Span Definitions:

Span 1 Length = **3750** mm Cross-sectional area = **440000** mm^2 Moment of inertia = **7.10×10^9** mm^4

LOADING DETAILS

Beam Loads:

Load 1 Partial VDL Dead load **0.0** kN/m at **0.000** m to **3.3** kN/m at **0.400** m

Load 2 Partial VDL Dead load **3.3** kN/m at **0.400** m to **29.2** kN/m at **3.750** m

Load 3 UDL Dead load **5.1** kN/m

Load 4 Partial VDL Dead load **0.0** kN/m at **0.000** m to **37.5** kN/m at **3.750** m

LOAD COMBINATIONS

Load combination 1

Span 1 1×Dead

CONTINUOUS BEAM ANALYSIS - RESULTS

Support Reactions - Combination Summary

Support A Max react = **0.0** kN Min react = **0.0** kN Max mom = **0.0** kNm Min mom = **0.0** kNm

Support B Max react = **-144.7** kN Min react = **-144.7** kN Max mom = **193.3** kNm Min mom = **193.3** kNm

Beam Max/Min results - Combination Summary

Maximum shear = **0.0** kN Minimum shear F_{min} = **-144.7** kN

Maximum moment = **0.0** kNm Minimum moment = **-193.4** kNm

Maximum deflection = **6.7** mm Minimum deflection = **0.0** mm

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 2.4.09

Retaining wall details

Stem type	Propped cantilever
Stem height	h_{stem} = **3900** mm
Prop height	h_{prop} = **3900** mm
Stem thickness	t_{stem} = **440** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **1000** mm
Base thickness	t_{base} = **400** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **3750** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **150** mm
Depth of excavation	d_{exc} = **150** mm
Height of water	h_{water} = **3750** mm
Water density	γ_w = **9.8** kN/m^3

Retained soil properties

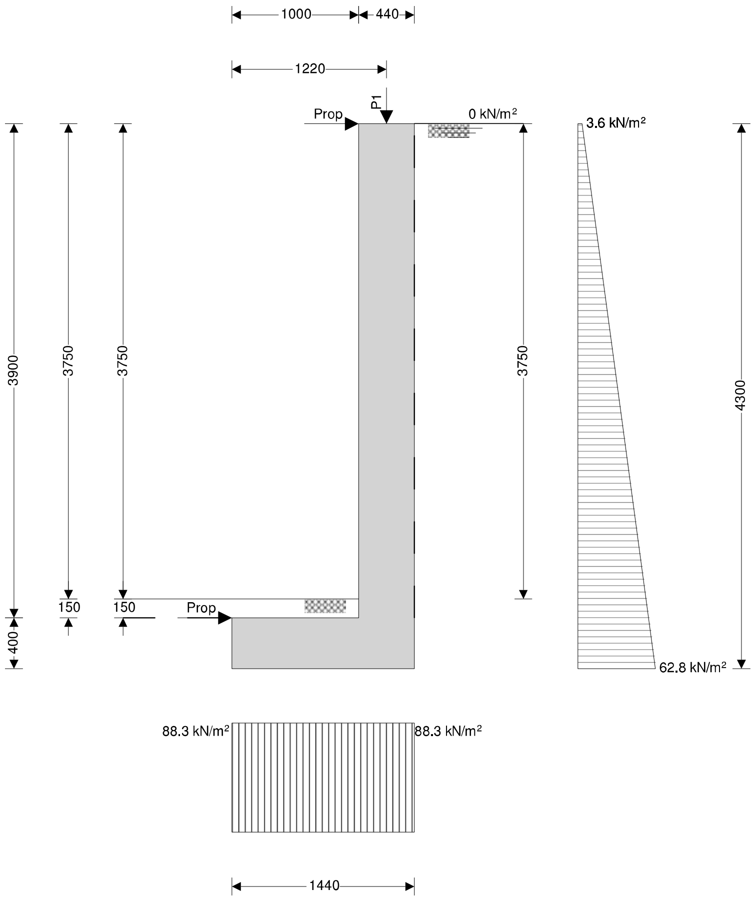
Soil type	Stiff clay
Moist density	γ_{mr} = **19** kN/m^3
Saturated density	γ_{sr} = **19** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **25** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **12.5** deg

Base soil properties

Soil type	Stiff clay
Moist density	γ_{mb} = **19** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **25** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **12.5** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **12** deg
Presumed bearing capacity	$P_{bearing}$ = **120** kN/m^2

Loading details

Permanent surcharge load	$Surcharge_G$ = **5** kN/m^2
Variable surcharge load	$Surcharge_Q$ = **2.5** kN/m^2
Vertical line load at 1220 mm	P_{G1} = **67** kN/m



Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} = \mathbf{1440}$ mm
Saturated soil height	$h_{sat} = h_{water} + d_{cover} = \mathbf{3900}$ mm
Moist soil height	$h_{moist} = h_{ret} - h_{water} = \mathbf{0}$ mm
Length of surcharge load	$l_{sur} = l_{heel} = \mathbf{0}$ mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2 = \mathbf{1440}$ mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{4300}$ mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 = \mathbf{2150}$ mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} = \mathbf{1.716}$ m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{1220}$ mm
Area of wall base	$A_{base} = l_{base} \times t_{base} = \mathbf{0.576}$ m^2
- Distance to vertical component	$x_{base} = l_{base} / 2 = \mathbf{720}$ mm
Area of base soil	$A_{pass} = d_{cover} \times l_{toe} = \mathbf{0.15}$ m^2
- Distance to vertical component	$x_{pass\_v} = l_{base} - (d_{cover} \times l_{toe} \times (l_{base} - l_{toe} / 2)) / A_{pass} = \mathbf{500}$ mm
- Distance to horizontal component	$x_{pass\_h} = (d_{cover} + h_{base}) / 3 = \mathbf{183}$ mm

Using Coulomb theory

Active pressure coefficient

$$K_A = \sin(\alpha + \phi'_{r.k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.k}) \times [1 + \sqrt{[\sin(\phi'_{r.k} + \delta_{r.k}) \times \sin(\phi'_{r.k} - \beta) / (\sin(\alpha - \delta_{r.k}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.367}$$

Passive pressure coefficient — $K_P = \sin(90 - \phi'_{b.k})^2 / (\sin(90 + \delta_{b.k}) \times [1 - \sqrt{[\sin(\phi'_{b.k} + \delta_{b.k}) \times \sin(\phi'_{b.k}) / (\sin(90 + \delta_{b.k}))]}]^2) =$ **3.552**

Bearing pressure check

Vertical forces on wall

Wall stem — $F_{stem} = A_{stem} \times \gamma_{stem} =$ **42.9** kN/m

Wall base — $F_{base} = A_{base} \times \gamma_{base} =$ **14.4** kN/m

Line loads — $F_{P\_v} = P_{G1} =$ **67** kN/m

Base soil — $F_{pass\_v} = A_{pass} \times \gamma_{mb} =$ **2.9** kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{pass\_v} + F_{water\_v} + F_{P\_v} =$ **127.2** kN/m

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (Surcharge_G + Surcharge_Q) \times h_{eff} =$ **11.6** kN/m

Saturated retained soil — $F_{sat\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr} - \gamma_w) \times (h_{sat} + h_{base})^2 / 2 =$ **30.5** kN/m

Water — $F_{water\_h} = \gamma_w \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **90.7** kN/m

Moist retained soil — $F_{moist\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_{mr} \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **0** kN/m

Total — $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{water\_h} + F_{sur\_h} =$ **132.7** kN/m

Moments on wall

Wall stem — $M_{stem} = F_{stem} \times x_{stem} =$ **52.3** kNm/m

Wall base — $M_{base} = F_{base} \times x_{base} =$ **10.4** kNm/m

Surcharge load — $M_{sur} = -F_{sur\_h} \times x_{sur\_h} =$ **-24.9** kNm/m

Line loads — $M_P = P_{G1} \times p_1 =$ **81.7** kNm/m

Saturated retained soil — $M_{sat} = -F_{sat\_h} \times x_{sat\_h} =$ **-43.7** kNm/m

Water — $M_{water} = -F_{water\_h} \times x_{water\_h} =$ **-130** kNm/m

Moist retained soil — $M_{moist} = -F_{moist\_h} \times x_{moist\_h} =$ **0** kNm/m

Base soil — $M_{pass} = F_{pass\_v} \times x_{pass\_v} =$ **1.4** kNm/m

Total — $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{pass} + M_{water} + M_{sur} + M_P =$ **-52.7** kNm/m

Check bearing pressure

Propping force to stem — $F_{prop\_stem} = \min((F_{total\_v} \times l_{base} / 2 - M_{total}) / (h_{prop} + t_{base}), F_{total\_h}) =$ **33.5** kN/m

Propping force to base — $F_{prop\_base} = F_{total\_h} - F_{prop\_stem} =$ **99.2** kN/m

Temporary works to be designed accordingley

Moment from propping force — $M_{prop} = F_{prop\_stem} \times (h_{prop} + t_{base}) =$ **144.2** kNm/m

Distance to reaction — $\bar{x} = (M_{total} + M_{prop}) / F_{total\_v} =$ **720** mm

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

Loaded length of base — $l_{load} = l_{base} =$ **1440** mm

Bearing pressure at toe — $q_{toe} = F_{total\_v} / l_{base} =$ **88.3** kN/m^2

Bearing pressure at heel $q_{heel} = F_{total\_v} / l_{base} = \mathbf{88.3}$ kN/m^2

Factor of safety $FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) = \mathbf{1.359}$

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 2.4.09

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

Concrete strength class C32/40

Characteristic compressive cylinder strength $f_{ck} = \mathbf{32}$ N/mm^2

Characteristic compressive cube strength $f_{ck,cube} = \mathbf{40}$ N/mm^2

Mean value of compressive cylinder strength $f_{cm} = f_{ck} + 8$ N/mm^2 $= \mathbf{40}$ N/mm^2

Mean value of axial tensile strength $f_{ctm} = 0.3$ N/mm$^2 \times (f_{ck} / 1$ N/mm$^2)^{2/3} = \mathbf{3.0}$ N/mm^2

5% fractile of axial tensile strength $f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.1}$ N/mm^2

Secant modulus of elasticity of concrete $E_{cm} = 22$ kN/mm$^2 \times (f_{cm} / 10$ N/mm$^2)^{0.3} = \mathbf{33346}$ N/mm^2

Partial factor for concrete - Table 2.1N $\gamma_C = \mathbf{1.50}$

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

Design compressive concrete strength - exp.3.15 $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C = \mathbf{18.1}$ N/mm^2

Maximum aggregate size $h_{agg} = \mathbf{20}$ mm

Reinforcement details

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

Modulus of elasticity of reinforcement $E_s = \mathbf{200000}$ N/mm^2

Partial factor for reinforcing steel - Table 2.1N $\gamma_S = \mathbf{1.15}$

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 1987 mm

Depth of section $h = \mathbf{440}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 $M = \mathbf{35.2}$ kNm/m

Depth to tension reinforcement $d = h - c_{sf} - \phi_{sx} - \phi_{sfM} / 2 = \mathbf{384}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.007}$

$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{365}$ mm

Depth of neutral axis	$x = 2.5 \times (d - z) = \mathbf{48}$ mm
Area of tension reinforcement required	$A_{sfM.req} = M / (f_{yd} \times z) = \mathbf{222}$ mm²/m
Tension reinforcement provided	12 dia.bars @ 150 c/c
Area of tension reinforcement provided	$A_{sfM.prov} = \pi \times \phi_{sfM}^2 / (4 \times s_{sfM}) = \mathbf{754}$ mm²/m
Minimum area of reinforcement - exp.9.1N	$A_{sfM.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{604}$ mm²/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{sfM.max} = 0.04 \times h = \mathbf{17600}$ mm²/m
	$\max(A_{sfM.req}, A_{sfM.min}) / A_{sfM.prov} = \mathbf{0.801}$

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	$M_{sls} = \mathbf{25.6}$ kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{sfM.prov} \times z) = \mathbf{93}$ N/mm²
Load duration	Long term
Load duration factor	$k_t = \mathbf{0.4}$
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = \mathbf{130667}$ mm²/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm} = \mathbf{3.0}$ N/mm²
Reinforcement ratio	$\rho_{p.eff} = A_{sfM.prov} / A_{c.eff} = \mathbf{0.006}$
Modular ratio	$\alpha_e = E_s / E_{cm} = \mathbf{5.998}$
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	$s_{r.max} = k_3 \times c_{sf} + k_1 \times k_2 \times k_4 \times \phi_{sfM} / \rho_{p.eff} = \mathbf{490}$ mm
Maximum crack width - exp.7.8	$w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	$w_k = \mathbf{0.137}$ mm
	$w_k / w_{max} = \mathbf{0.455}$

PASS - Maximum crack width is less than limiting crack width

Check stem design at base of stem

Depth of section	$h = \mathbf{440}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	$M = \mathbf{77.1}$ kNm/m
Depth to tension reinforcement	$d = h - c_{sr} - \phi_{sr} / 2 = \mathbf{382}$ mm
	$K = M / (d^2 \times f_{ck}) = \mathbf{0.017}$
	$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{363}$ mm
Depth of neutral axis	$x = 2.5 \times (d - z) = \mathbf{48}$ mm

Area of tension reinforcement required — $A_{sr.req} = M / (f_{yd} \times z) =$ **489** mm^2/m

Tension reinforcement provided — 16 dia.bars @ 150 c/c

Area of tension reinforcement provided — $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) =$ **1340** mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{sr.min} = max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d =$ **601** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{sr.max} = 0.04 \times h =$ **17600** mm^2/m

$max(A_{sr.req}, A_{sr.min}) / A_{sr.prov} =$ **0.448**

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 — $M_{sls} =$ **56.3** kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{sr.prov} \times z) =$ **115.7** N/mm^2

Load duration — Long term

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

Effective area of concrete in tension — $A_{c.eff} = min(2.5 \times (h - d), (h – x) / 3, h / 2) =$ **130750** mm^2/m

Mean value of concrete tensile strength — $f_{ct.eff} = f_{ctm} =$ **3.0** N/mm^2

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

Modular ratio — $\alpha_e = E_s / E_{cm} =$ **5.998**

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 — $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff} =$ **435** mm

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

$w_k =$ **0.151** mm

$w_k / w_{max} =$ **0.503**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — $V =$ **116.8** kN/m

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

$k = min(1 + \sqrt{(200 mm / d)}, 2) =$ **1.724**

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

$v_{min} = 0.035 N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5} =$ **0.448** N/mm^2

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

$V_{Rd.c} =$ **171.1** kN/m

$V / V_{Rd.c} =$ **0.683**

PASS - Design shear resistance exceeds design shear force

Check stem design at prop

Depth of section — $h = \mathbf{440}$ mm

Rectangular section in shear - Section 6.2

Design shear force — $V = \mathbf{32.4}$ kN/m

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

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) = \mathbf{1.724}$

Longitudinal reinforcement ratio — $\rho_l = \min(A_{sf1.prov} / d, 0.02) = \mathbf{0.001}$

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} = \mathbf{0.448}$ N/mm^2

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

$V_{Rd.c} = \mathbf{171.1}$ kN/m

$V / V_{Rd.c} = \mathbf{0.189}$

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) — $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem}) = \mathbf{440}$ mm^2/m

Maximum spacing of reinforcement – cl.9.6.3(2) — $s_{sx\_max} = \mathbf{400}$ mm

Transverse reinforcement provided — 10 dia.bars @ 150 c/c

Area of transverse reinforcement provided — $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx}) = \mathbf{524}$ mm^2/m

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

Check base design at toe

Depth of section — $h = \mathbf{400}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — $M = \mathbf{50.9}$ kNm/m

Depth to tension reinforcement — $d = h - c_{bb} - \phi_{bb} / 2 = \mathbf{319}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.016}$

$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

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

Depth of neutral axis — $x = 2.5 \times (d - z) = \mathbf{40}$ mm

Area of tension reinforcement required — $A_{bb.req} = M / (f_{yd} \times z) = \mathbf{387}$ mm^2/m

Tension reinforcement provided — 12 dia.bars @ 150 c/c

Area of tension reinforcement provided — $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb}) = \mathbf{754}$ mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{502}$ mm^2/m

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

$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov} = \mathbf{0.665}$

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 — $M_{sls} = \mathbf{37.7}$ kNm/m

Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bb.prov} \times z) =$ **165.1** 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	$f_{ct.eff} = f_{ctm} =$ **3.0** N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff} =$ **0.006**
Modular ratio	$\alpha_e = E_s / E_{cm} =$ **5.998**
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	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff} =$ **580** mm
Maximum crack width - exp.7.8	$w_k = s_{r.max} \times \max(\sigma_s – k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	$w_k =$ **0.287** mm
	$w_k / w_{max} =$ **0.957**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

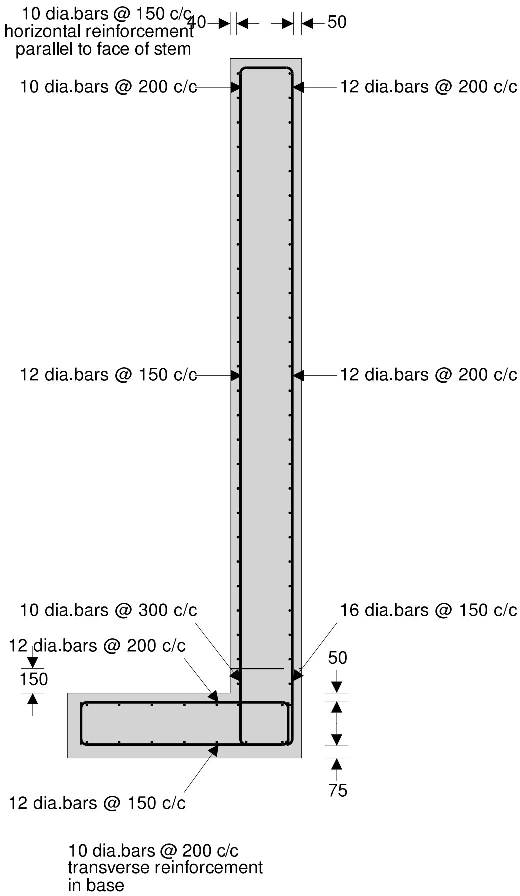
Design shear force	$V =$ **101.9** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C =$ **0.120**
	$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2) =$ **1.792**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb.prov} / d, 0.02) =$ **0.002**
	$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5} =$ **0.475** N/mm^2
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c} =$ **151.5** kN/m
	$V / V_{Rd.c} =$ **0.672**

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)	$A_{bx.req} = 0.2 \times A_{bb.prov} =$ **151** 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


10 dia.bars @ 150 c/c
horizontal reinforcement
parallel to face of stem
40
50
10 dia.bars @ 200 c/c
12 dia.bars @ 200 c/c
12 dia.bars @ 150 c/c
12 dia.bars @ 200 c/c
10 dia.bars @ 300 c/c
16 dia.bars @ 150 c/c
12 dia.bars @ 200 c/c
150
50
75
12 dia.bars @ 150 c/c
10 dia.bars @ 200 c/c
transverse reinforcement
in base