Appendix B

Burland and Potts Building Damage Classification Table

Table 2.5 *Classification of visible damage to walls (after Burland et al, 1977, Boscardin and Cording, 1989; and Burland, 2001)*

Category of damage	Description of typical damage (ease of repair is underlined)	Approximate crack width (mm)	Limiting tensile strain ε_{lim} (per cent)
0 Negligible	Hairline cracks of less than about 0.1 mm are classed as negligible.	< 0.1	0.0–0.05
1 Very slight	Fine cracks that can easily be treated during normal decoration. Perhaps isolated slight fracture in building. Cracks in external brickwork visible on inspection.	< 1	0.05–0.075
2 Slight	Cracks easily filled. Redecoration probably required. Several slight fractures showing inside of building. Cracks are visible externally and some repointing may be required externally to ensure weathertightness. Doors and windows may stick slightly.	< 5	0.075–0.15
3 Moderate	The cracks require some opening up and can be patched by a mason. Recurrent cracks can be masked by suitable linings. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired.	5–15 or a number of cracks > 3	0.15–0.3
4 Severe	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Windows and frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15–25 but also depends on number of cracks	> 0.3
5 Very severe	This requires a major repair involving partial or complete rebuilding. Beams lose bearings, walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	usually > 25 but depends on number of cracks.	

Notes

1. In assessing the degree of damage, account must be taken of its location in the building or structure.
2. Crack width is only one aspect of damage and should not be used on its own as a direct measure of it.

Appendix C
Structural Calculations

CALCULATION SHEET

JOB TITLE:	JOB NUMBER / FILE:	CALCULATION NUMBER:		Form
24 HEATH DRIVE	162637			
CALCULATION:	**CALCULATION BY:**	**DATE:**	**CHECKED BY:**	
BASEMENT	CEM	29/1/18		

CALCULATIONS:

IT IS PROPOSED TO LOWER AND EXTEND THE EXISTING BASEMENT OF THE PROPERTY TO UTILISE THE FULL FOOTPRINT OF THE ORIGINAL BUILDING.

THE EXTG FOOTINGS TO THE FRONT HALF OF THE BUILDING ARE FOUNDED BELOW THE EXTG BASEMENT LEVEL, HOWEVER ONLY HALF OF THE AREA WAS USABLE SPACE WITH THE OTHER HALF BACK FILLED.

FOUNDATIONS TO THE REAR, AND NEW EXTENSION FOUNDATIONS ARE FOUND AT A HIGH LEVEL (BELOW GROUNDFLOOR)

SEE TRIAL PIT INFORMATION FROM GABRIEL GEO CONSULTING'S SI REPORT.

AS THE EXTG GROUND FLOOR IS TO REMAIN IT IS PROPOSED TO INSTALL RC 'L' UNDERPIN BENEATH THE PERIMETER MASONRY WALLS. THESE ARE DESIGNED AND WILL ACTED AS CANTILEVERS WITH A BOTTOM PROP FROM THE BASEMENT SLAB RESISTING SLIDING.

INTERNAL WALLS WILL BE UNDERPINNED WITH RC WALLS.

THE BASEMENT EXTENSION INTO THE GARDEN AREA FOR THE POOL WILL BE CONSTRUCTED WITH SECANT PILES WITH A CAPPING BEAM AND RC LINER WALL.

THE PILES WILL RESIST SOIL AND SURCHARGE IN THE PERMINENT AND TEMPORARY CONDITIONS, WITH THE RC LINER WALL RESISTING HYDROSTATIC PRESSURE IN THE PERMINANT CASE.

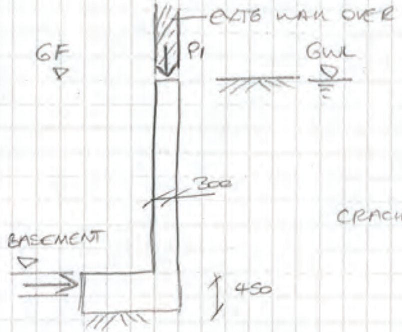
DE-WATERING IS TO BE USED DURING CONSTRUCTION OF THE RC BASEMENT. THE CONTRACTOR IS TO MITIGATE AGAINST FINE MIGRATION DURING DE-WATERING WITH THE USE OF ADEQUATE PUMP SYSTEMS AND TECHNIQUES.

CALCULATION SHEET

JOB TITLE:	JOB NUMBER / FILE:	CALCULATION NUMBER:		Form
24 HEATH DRIVE	162637			
CALCULATION:	**CALCULATION BY:**	**DATE:**	**CHECKED BY:**	
BASEMENT - RC 'L'	CEM	29/1/18		

CALCULATIONS:

WORST CASE LOADING ON TOP OF RC 'L' FROM EXTG BUILDING OVER USED FOR DESIGN PURPOSES.

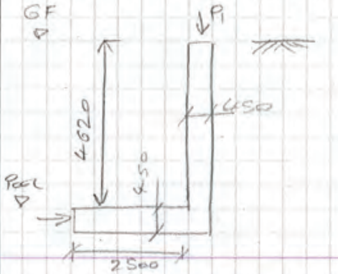


GF TO ROOF 5.1DL + 3LL
MASONRY 55 DL

TOTAL = 60 DL + 3LL
P_1 = ↑

CRACKING LIMITED TO 0.3mm

SCENARIO (1) POOL RC 'L'



COVER:

STEM : 50mm
WALL : 40mm
TOE : 50mm

SEE TEDDS OUTPUT OK

REBAR

STEM:	FRONT	H16 @ 200	(1005mm³/m)
	REAR	H16 @ 200	(1005mm³/m)
BASE:	TOP	H16 @ 200	(1005mm³/m)
	BOT	H32 @ 200	(4021.2mm³/m)
TRANSVERSE:	STEM	H16 @ 200	(1005mm³/m)
	BASE	H16 @ 200	(1005mm³/m)

FOR THERMAL CRACKING

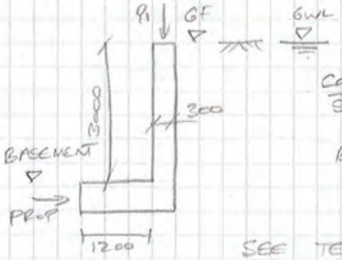
CALCULATION SHEET

JOB TITLE:	JOB NUMBER / FILE:	CALCULATION NUMBER:		Form
24 HEATH DRIVE	162637			
CALCULATION:	CALCULATION BY:	DATE:	CHECKED BY:	
BASEMENT RC 'L'	CEM	29/1/18		

CALCULATIONS:

REF | | OUTPUT

SCENARIO (2) FRONT ELEVATION RC 'L'



COVER:

STEM	FRONT	40 mm
	REAR	50 mm
BASE	TOP	40 mm
	BOT	50 mm

SEE TEDDS OUTPUT ch ✓

REBAR

STEM	FRONT	H16 @ 200 (1005 mm³/m)
	REAR	H20 @ 200 (1571 mm³/m)
BASE	TOP	H16 @ 200 (1005 mm³/m)
	BOT	H20 @ 200 (1571 mm³/m)
TRANSFER	STEM	H16 @ 200 (1005 mm³/m)
	BASE	H16 @ 200 (1005 mm³/m)

Tekla Tedds Form Structural Design 77 St John Street London EC1M 4NN	Project 24 HEATH DRIVE				Job no. 162637	
	Calcs for RC L RETAINING WALL				Start page no./Revision 1	
	Calcs by CEM	Calcs date 29/01/2018	Checked by	Checked date	Approved by	Approved date

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 2.9.03

Retaining wall details

Stem type	Cantilever
Stem height	h_{stem} = **4620** mm
Stem thickness	t_{stem} = **450** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **2500** mm
Base thickness	t_{base} = **450** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **4620** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm
Height of water	h_{water} = **4620** mm
Water density	γ_w = **9.8** kN/m^3

Retained soil properties

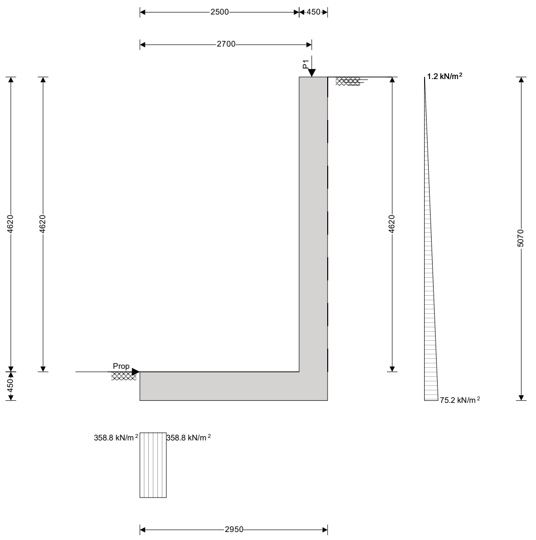
Soil type	Medium dense well graded sand
Moist density	γ_{mr} = **21** kN/m^3
Saturated density	γ_{sr} = **23** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **30** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **15** deg

Base soil properties

Soil type	Stiff clay
Soil density	γ_b = **19** kN/m^3
Characteristic cohesion	$c'_{b.k}$ = **18** kN/m^2
Characteristic adhesion	$a_{b.k}$ = **18** 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	$Surcharge_Q$ = **2.5** kN/m^2
Vertical line load at 2700 mm	P_{G1} = **60** kN/m
	P_{Q1} = **3** kN/m



General arrangement

Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem}$ = **2950** mm
Saturated soil height	$h_{sat} = h_{water} + d_{cover}$ = **4620** mm
Moist soil height	$h_{moist} = h_{ret} - h_{water}$ = **0** mm
Length of surcharge load	$l_{sur} = l_{heel}$ = **0** mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2$ = **2950** mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret}$ = **5070** mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2$ = **2535** mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem}$ = **2.079** m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2$ = **2725** mm
Area of wall base	$A_{base} = l_{base} \times t_{base}$ = **1.328** m^2
- Distance to vertical component	$x_{base} = l_{base} / 2$ = **1475** 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**

Water properties

Design water density	$\gamma_w' = \gamma_w / \gamma_\gamma$ = **9.8** kN/m^3

Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma$ = **21** kN/m^3
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma$ = **23** kN/m^3
Design effective shear resistance angle	$\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **30** deg
Design wall friction angle	$\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **15** deg

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_\gamma$ = **19** kN/m^3
Design effective shear resistance angle	$\phi'_{b.d} = \text{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **18** deg
Design wall friction angle	$\delta_{b.d} = \text{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **9** deg
Design base friction angle	$\delta_{bb.d} = \text{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **12** deg
Design effective cohesion	$c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **18** kN/m^2
Design adhesion	$a_{b.d} = a_{b.k} / \gamma_{c'}$ = **18** kN/m^2

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2)$ = **0.301**
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	$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **52** kN/m
Wall base	$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **33.2** kN/m
Line loads	$F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1}$ = **60** kN/m
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v}$ = **145.2** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff}$ = **5.5** kN/m
Saturated retained soil	$F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2$ = **66.6** kN/m
Water	$F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **170.2** kN/m
Moist retained soil	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base}))$ = **0** kN/m
Base soil	$F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2$ = **-4.5** kN/m
Total	$F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h}$ = **237.9** kN/m

Overturning moments on wall

Surcharge load	$M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h}$ = **14** kNm/m
Saturated retained soil	$M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h}$ = **112.6** kNm/m
Water	$M_{water\_OT} = F_{water\_h} \times x_{water\_h}$ = **287.7** kNm/m
Moist retained soil	$M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h}$ = **0** kNm/m
Total	$M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{water\_OT} + M_{sur\_OT}$ = **414.3** kNm/m

Restoring moments on wall

Wall stem	$M_{stem\_R} = F_{stem} \times x_{stem}$ = **141.6** kNm/m
Wall base	$M_{base\_R} = F_{base} \times x_{base}$ = **49** kNm/m
Line loads	$M_{P\_R} = (\text{abs}(\gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1})) \times p_1$ = **162** kNm/m

Total	$M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{P\_R} = \mathbf{352.6}$ kNm/m

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{0.851}$

FAIL - Overturning moment is greater than maximum restoring moment

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{70.2}$ kN/m
Wall base	$F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{44.8}$ kN/m
Line loads	$F_{P\_v} = \gamma_G \times P_{G1} + \gamma_Q \times P_{Q1} = \mathbf{85.5}$ kN/m
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v} = \mathbf{200.5}$ kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{5.5}$ kN/m
Saturated retained soil	$F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2 = \mathbf{66.6}$ kN/m
Water	$F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{170.2}$ kN/m
Moist retained soil	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) = \mathbf{0}$ kN/m
Base soil	$F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-4.5}$ kN/m
Total	$F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h} = \mathbf{237.9}$ kN/m

Moments on wall

Wall stem	$M_{stem} = F_{stem} \times x_{stem} = \mathbf{191.2}$ kNm/m
Wall base	$M_{base} = F_{base} \times x_{base} = \mathbf{66.1}$ kNm/m
Surcharge load	$M_{sur} = -F_{sur\_h} \times x_{sur\_h} = \mathbf{-14}$ kNm/m
Line loads	$M_P = (\gamma_G \times P_{G1} + \gamma_Q \times P_{Q1}) \times p_1 = \mathbf{230.9}$ kNm/m
Saturated retained soil	$M_{sat} = -F_{sat\_h} \times x_{sat\_h} = \mathbf{-112.6}$ kNm/m
Water	$M_{water} = -F_{water\_h} \times x_{water\_h} = \mathbf{-287.7}$ kNm/m
Moist retained soil	$M_{moist} = -F_{moist\_h} \times x_{moist\_h} = \mathbf{0}$ kNm/m
Total	$M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} + M_P = \mathbf{73.8}$ kNm/m

Check bearing pressure

Propping force	$F_{prop\_base} = F_{total\_h} = \mathbf{237.9}$ kN/m
Distance to reaction	$\bar{x} = M_{total} / F_{total\_v} = \mathbf{368}$ mm
Eccentricity of reaction	$e = \bar{x} - l_{base} / 2 = \mathbf{-1107}$ mm
Loaded length of base	$l_{load} = 2 \times \bar{x} = \mathbf{737}$ mm
Bearing pressure at toe	$q_{toe} = F_{total\_v} / l_{load} = \mathbf{272.1}$ kN/m^2
Bearing pressure at heel	$q_{heel} = \mathbf{0}$ kN/m^2
Effective overburden pressure	$q = \max((t_{base} + d_{cover}) \times \gamma_b' - (t_{base} + d_{cover} + h_{water}) \times \gamma_w', 0\ kN/m^2) = \mathbf{0}$ kN/m^2
Design effective overburden pressure	$q' = q / \gamma_\gamma = \mathbf{0}$ kN/m^2
Bearing resistance factors	$N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45\ deg + \phi'_{b.d} / 2))^2 = \mathbf{5.258}$
	$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{13.104}$
	$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) = \mathbf{2.767}$
Foundation shape factors	$s_q = 1$
	$s_\gamma = 1$
	$s_c = 1$
Load inclination factors	$H = F_{sur\_h} + F_{sat\_h} + F_{water\_h} + F_{moist\_h} + F_{pass\_h} - F_{prop\_base} = \mathbf{0}$ kN/m

	$V = F_{total\_v} = \mathbf{200.5}$ 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	$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_b' - \gamma_w') \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma$
	$n_f = \mathbf{245.2}$ kN/m^2
Factor of safety	$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{0.901}$

FAIL - Maximum applied bearing pressure exceeds allowable bearing pressure

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

Permanent unfavourable action	$\gamma_G = \mathbf{1.00}$
Permanent favourable action	$\gamma_{Gf} = \mathbf{1.00}$
Variable unfavourable action	$\gamma_Q = \mathbf{1.30}$
Variable favourable action	$\gamma_{Qf} = \mathbf{0.00}$

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

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

Water properties

Design water density	$\gamma_w' = \gamma_w / \gamma_\gamma = \mathbf{9.8}$ kN/m^3

Retained soil properties

Design moist density	$\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma = \mathbf{21}$ kN/m^3
Design saturated density	$\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma = \mathbf{23}$ kN/m^3
Design effective shear resistance angle	$\phi'_{r.d} = \mathrm{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{24.8}$ deg
Design wall friction angle	$\delta_{r.d} = \mathrm{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{12.1}$ deg

Base soil properties

Design soil density	$\gamma_b' = \gamma_b / \gamma_\gamma = \mathbf{19}$ kN/m^3
Design effective shear resistance angle	$\phi'_{b.d} = \mathrm{atan}(\tan(\phi'_{b.k}) / \gamma_{\phi'}) = \mathbf{14.6}$ deg
Design wall friction angle	$\delta_{b.d} = \mathrm{atan}(\tan(\delta_{b.k}) / \gamma_{\phi'}) = \mathbf{7.2}$ deg
Design base friction angle	$\delta_{bb.d} = \mathrm{atan}(\tan(\delta_{bb.k}) / \gamma_{\phi'}) = \mathbf{9.7}$ deg
Design effective cohesion	$c'_{b.d} = c'_{b.k} / \gamma_{c'} = \mathbf{14.4}$ kN/m^2
Design adhesion	$a_{b.d} = a_{b.k} / \gamma_{c'} = \mathbf{14.4}$ kN/m^2

Using Coulomb theory

Active pressure coefficient	$K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.371}$
Passive pressure coefficient	$K_P = \sin(90 - \phi'_{b.d})^2 / (\sin(90 + \delta_{b.d}) \times [1 - \sqrt{[\sin(\phi'_{b.d} + \delta_{b.d}) \times \sin(\phi'_{b.d}) / (\sin(90 + \delta_{b.d}))]}]^2) = \mathbf{1.965}$

Overturning check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{52}$ kN/m
Wall base	$F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{33.2}$ kN/m
Line loads	$F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1} = \mathbf{60}$ kN/m

Total	$F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v} = \mathbf{145.2}$ kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{6}$ kN/m
Saturated retained soil	$F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2 = \mathbf{61.5}$ kN/m
Water	$F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{126.1}$ kN/m
Moist retained soil	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) = \mathbf{0}$ kN/m
Base soil	$F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-3.8}$ kN/m
Total	$F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h} = \mathbf{189.8}$ kN/m

Overturning moments on wall

Surcharge load	$M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} = \mathbf{15.2}$ kNm/m
Saturated retained soil	$M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h} = \mathbf{103.9}$ kNm/m
Water	$M_{water\_OT} = F_{water\_h} \times x_{water\_h} = \mathbf{213.1}$ kNm/m
Moist retained soil	$M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} = \mathbf{0}$ kNm/m
Total	$M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{water\_OT} + M_{sur\_OT} = \mathbf{332.2}$ kNm/m

Restoring moments on wall

Wall stem	$M_{stem\_R} = F_{stem} \times x_{stem} = \mathbf{141.6}$ kNm/m
Wall base	$M_{base\_R} = F_{base} \times x_{base} = \mathbf{49}$ kNm/m
Line loads	$M_{P\_R} = (abs(\gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1})) \times p_1 = \mathbf{162}$ kNm/m
Total	$M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{P\_R} = \mathbf{352.6}$ kNm/m

Check stability against overturning

Factor of safety	$FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{1.062}$

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{52}$ kN/m
Wall base	$F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{33.2}$ kN/m
Line loads	$F_{P\_v} = \gamma_G \times P_{G1} + \gamma_Q \times P_{Q1} = \mathbf{63.9}$ kN/m
Total	$F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v} = \mathbf{149.1}$ kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{6}$ kN/m
Saturated retained soil	$F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2 = \mathbf{61.5}$ kN/m
Water	$F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{126.1}$ kN/m
Moist retained soil	$F_{moist\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) = \mathbf{0}$ kN/m
Base soil	$F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-3.8}$ kN/m
Total	$F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h} = \mathbf{189.8}$ kN/m

Moments on wall

Wall stem	$M_{stem} = F_{stem} \times x_{stem} = \mathbf{141.6}$ kNm/m
Wall base	$M_{base} = F_{base} \times x_{base} = \mathbf{49}$ kNm/m
Surcharge load	$M_{sur} = -F_{sur\_h} \times x_{sur\_h} = \mathbf{-15.2}$ kNm/m
Line loads	$M_P = (\gamma_G \times P_{G1} + \gamma_Q \times P_{Q1}) \times p_1 = \mathbf{172.5}$ kNm/m
Saturated retained soil	$M_{sat} = -F_{sat\_h} \times x_{sat\_h} = \mathbf{-103.9}$ kNm/m
Water	$M_{water} = -F_{water\_h} \times x_{water\_h} = \mathbf{-213.1}$ kNm/m

Moist retained soil	$M_{moist} = -F_{moist\_h} \times x_{moist\_h} = \mathbf{0}$ kNm/m
Total	$M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} + M_P = \mathbf{31}$ kNm/m

Check bearing pressure

Propping force	$F_{prop\_base} = F_{total\_h} = \mathbf{189.8}$ kN/m
Distance to reaction	$\bar{x} = M_{total} / F_{total\_v} = \mathbf{208}$ mm
Eccentricity of reaction	$e = \bar{x} - l_{base} / 2 = \mathbf{-1267}$ mm
Loaded length of base	$l_{load} = 2 \times \bar{x} = \mathbf{415}$ mm
Bearing pressure at toe	$q_{toe} = F_{total\_v} / l_{load} = \mathbf{358.8}$ kN/m²
Bearing pressure at heel	$q_{heel} = \mathbf{0}$ kN/m²
Effective overburden pressure	$q = \max((t_{base} + d_{cover}) \times \gamma_b' - (t_{base} + d_{cover} + h_{water}) \times \gamma_w', 0 \text{ kN/m}^2) = \mathbf{0}$ kN/m²
Design effective overburden pressure	$q' = q / \gamma_\gamma = \mathbf{0}$ kN/m²
Bearing resistance factors	$N_q = Exp(\pi \times \tan(\phi'_{b.d})) \times (\tan(45 \text{ deg} + \phi'_{b.d} / 2))^2 = \mathbf{3.784}$
	$N_c = (N_q - 1) \times \cot(\phi'_{b.d}) = \mathbf{10.711}$
	$N_\gamma = 2 \times (N_q - 1) \times \tan(\phi'_{b.d}) = \mathbf{1.447}$
Foundation shape factors	$s_q = \mathbf{1}$
	$s_\gamma = \mathbf{1}$
	$s_c = \mathbf{1}$
Load inclination factors	$H = F_{sur\_h} + F_{sat\_h} + F_{water\_h} + F_{moist\_h} + F_{pass\_h} - F_{prop\_base} = \mathbf{0}$ kN/m
	$V = F_{total\_v} = \mathbf{149.1}$ kN/m
	$m = \mathbf{2}$
	$i_q = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^m = \mathbf{1}$
	$i_\gamma = [1 - H / (V + l_{load} \times c'_{b.d} \times \cot(\phi'_{b.d}))]^{(m+1)} = \mathbf{1}$
	$i_c = i_q - (1 - i_q) / (N_c \times \tan(\phi'_{b.d})) = \mathbf{1}$
Net ultimate bearing capacity	$n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_b' - \gamma_w') \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma$
	$n_f = \mathbf{157}$ kN/m²
Factor of safety	$FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{0.438}$

FAIL - Maximum applied bearing pressure exceeds allowable bearing pressure

<u>RETAINING WALL DESIGN</u>

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 2.9.03

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/mm²
Characteristic compressive cube strength	$f_{ck,cube} = \mathbf{40}$ N/mm²
Mean value of compressive cylinder strength	$f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = \mathbf{40}$ N/mm²
Mean value of axial tensile strength	$f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = \mathbf{3.0}$ N/mm²
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.1}$ N/mm²
Secant modulus of elasticity of concrete	$E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = \mathbf{33346}$ N/mm²
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/mm²
Maximum aggregate size	$h_{agg} = \mathbf{20}$ mm

Tekla Tedds Form Structural Design 77 St John Street London EC1M 4NN	Project 24 HEATH DRIVE			Job no. 162637	
	Calcs for RC L RETAINING WALL			Start page no./Revision 8	
	Calcs by CEM	Calcs date 29/01/2018	Checked by	Checked date	Approved by	Approved date

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

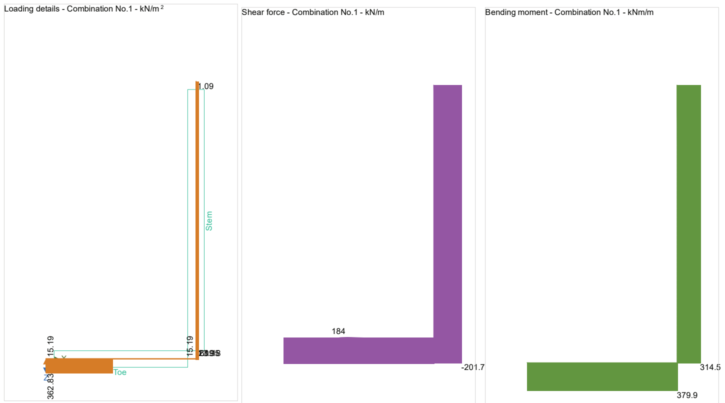
Cover to reinforcement

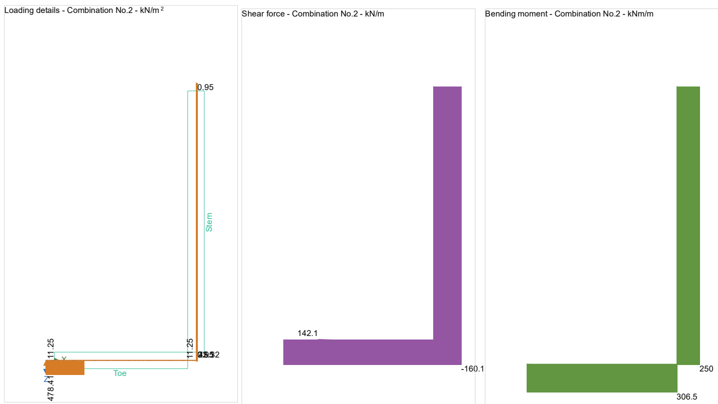
Front face of stem c_{sf} = **40** mm

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

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

Bottom face of base c_{bb} = **50** mm





Check stem design at base of stem

Depth of section h = **450** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 M = **314.5** kNm/m

Depth to tension reinforcement $d = h - c_{sr} - \phi_{sr} / 2$ = **384** mm

$K = M / (d^2 \times f_{ck})$ = **0.067**

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **360** mm

Depth of neutral axis $x = 2.5 \times (d – z)$ = **60** mm

Area of tension reinforcement required $A_{sr.req} = M / (f_{yd} \times z)$ = **2010** mm^2/m

Tension reinforcement provided 32 dia.bars @ 200 c/c

Area of tension reinforcement provided $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **4021** mm^2/m

Minimum area of reinforcement - exp.9.1N $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **604** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) $A_{sr.max} = 0.04 \times h$ = **18000** mm^2/m

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.5**

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

Deflection control - Section 7.4

Reference reinforcement ratio $\rho_0 = \sqrt{(f_{ck} / 1 N/mm^2)} / 1000$ = **0.006**

Required tension reinforcement ratio $\rho = A_{sr.req} / d$ = **0.005**

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 $K_s = \min(500 N/mm^2 / (f_{yk} \times A_{sr.req} / A_{sr.prov}), 1.5)$ = **1.5**

Limiting span to depth ratio - exp.7.16.a $\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 N/mm^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 N/mm^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b)$ = **12.4**

Actual span to depth ratio h_{stem} / d = **12**

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} = **229** kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **158.2** N/mm^2

Load duration Long term

Load duration factor k_t = **0.4**

Effective area of concrete in tension $A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **129916** mm^2/m

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

Reinforcement ratio $\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.031**

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 $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **346** 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 = **0.193** mm

w_k / w_{max} = **0.645**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force V = **201.7** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.722**

Longitudinal reinforcement ratio ρ_l = min($A_{sr.prov}$ / d, 0.02) = **0.010**

v_{min} = 0.035 $N^{1/2}$/mm × $k^{3/2}$ × $f_{ck}^{0.5}$ = **0.447** N/mm²

Design shear resistance - exp.6.2a & 6.2b $V_{Rd.c}$ = max($C_{Rd.c}$ × k × (100 N²/mm⁴ × ρ_l × f_{ck})$^{1/3}$, v_{min}) × d

$V_{Rd.c}$ = **255.8** kN/m

V / $V_{Rd.c}$ = **0.789**

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}) = **1005** mm²/m

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

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

Area of transverse reinforcement provided $A_{sx.prov}$ = π × ϕ_{sx}^2 / (4 × s_{sx}) = **1005** mm²/m

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

Check base design at toe

Depth of section h = **450** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 M = **379.9** kNm/m

Depth to tension reinforcement d = h - c_{bb} - ϕ_{bb} / 2 = **384** mm

K = M / (d² × f_{ck}) = **0.081**

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 = **354** mm

Depth of neutral axis x = 2.5 × (d – z) = **74** mm

Area of tension reinforcement required $A_{bb.req}$ = M / (f_{yd} × z) = **2465** mm²/m

Tension reinforcement provided 32 dia.bars @ 200 c/c

Area of tension reinforcement provided $A_{bb.prov}$ = π × ϕ_{bb}^2 / (4 × s_{bb}) = **4021** mm²/m

Minimum area of reinforcement - exp.9.1N $A_{bb.min}$ = max(0.26 × f_{ctm} / f_{yk}, 0.0013) × d = **604** mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3) $A_{bb.max}$ = 0.04 × h = **18000** mm²/m

max($A_{bb.req}$, $A_{bb.min}$) / $A_{bb.prov}$ = **0.613**

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} = **280.4** kNm/m

Tensile stress in reinforcement σ_s = M_{sls} / ($A_{bb.prov}$ × z) = **196.7** N/mm²

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) = **125370** mm²/m

Mean value of concrete tensile strength $f_{ct.eff}$ = f_{ctm} = **3.0** N/mm²

Reinforcement ratio $\rho_{p.eff}$ = $A_{bb.prov}$ / $A_{c.eff}$ = **0.032**

Modular ratio α_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 × c_{bb} + k_1 × k_2 × k_4 × ϕ_{bb} / $\rho_{p.eff}$ = **340** 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 = **0.258** mm

w_k / w_{max} = **0.859**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force V = **184** kN/m

$C_{Rd,c}$ = 0.18 / γ_C = **0.120**

k = min(1 + √(200 mm / d), 2) = **1.722**

Longitudinal reinforcement ratio ρ_l = min($A_{bb.prov}$ / d, 0.02) = **0.010**

v_{min} = 0.035 $N^{1/2}$/mm × $k^{3/2}$ × $f_{ck}^{0.5}$ = **0.447** N/mm²

Design shear resistance - exp.6.2a & 6.2b $V_{Rd.c}$ = max($C_{Rd.c}$ × k × (100 N²/mm⁴ × ρ_l × f_{ck})$^{1/3}$, v_{min}) × d

$V_{Rd.c}$ = **255.8** kN/m

V / $V_{Rd.c}$ = **0.720**

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

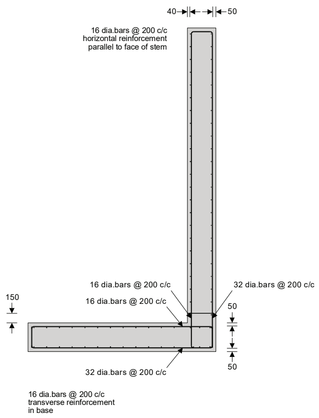
Minimum area of reinforcement – cl.9.3.1.1(2) $A_{bx.req}$ = 0.2 × $A_{bb.prov}$ = **804** mm²/m

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

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

Area of transverse reinforcement provided $A_{bx.prov}$ = π × ϕ_{bx}^2 / (4 × s_{bx}) = **1005** mm²/m

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



Reinforcement details

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 2.9.03

Retaining wall details

Stem type — Cantilever

Stem height — h_{stem} = **3000** mm

Stem thickness — t_{stem} = **300** mm

Angle to rear face of stem — α = **90** deg

Stem density — γ_{stem} = **25** kN/m^3

Toe length — l_{toe} = **1200** mm

Base thickness — t_{base} = **300** mm

Base density — γ_{base} = **25** kN/m^3

Height of retained soil — h_{ret} = **3000** mm

Angle of soil surface — β = **0** deg

Depth of cover — d_{cover} = **0** mm

Height of water — h_{water} = **3000** 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 — $\delta_{r.k}$ = **15** deg

Base soil properties

Soil type — Stiff clay

Soil density — γ_b = **19** kN/m^3

Characteristic cohesion — $c'_{b.k}$ = **18** kN/m^2

Characteristic adhesion — $a_{b.k}$ = **18** kN/m^2

Characteristic effective shear resistance angle — $\phi'_{b.k}$ = **18** deg

Characteristic wall friction angle — $\delta_{b.k}$ = **9** deg

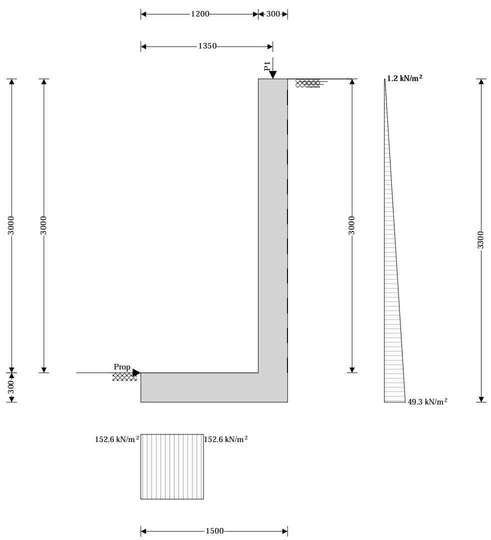
Characteristic base friction angle — $\delta_{bb.k}$ = **12** deg

Loading details

Variable surcharge load — $Surcharge_Q$ = **2.5** kN/m^2

Vertical line load at 1350 mm — P_{G1} = **60** kN/m

P_{Q1} = **3** kN/m



General arrangement

Calculate retaining wall geometry

Base length $l_{base} = l_{toe} + t_{stem} = \mathbf{1500}$ mm

Saturated soil height $h_{sat} = h_{water} + d_{cover} = \mathbf{3000}$ 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 $x_{sur\_v} = l_{base} - l_{heel} / 2 = \mathbf{1500}$ mm

Effective height of wall $h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{3300}$ mm

- Distance to horizontal component $x_{sur\_h} = h_{eff} / 2 = \mathbf{1650}$ mm

Area of wall stem $A_{stem} = h_{stem} \times t_{stem} = \mathbf{0.9}$ m^2

- Distance to vertical component $x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{1350}$ mm

Area of wall base $A_{base} = l_{base} \times t_{base} = \mathbf{0.45}$ m^2

- Distance to vertical component $x_{base} = l_{base} / 2 = \mathbf{750}$ mm

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

Permanent unfavourable action $\gamma_G = \mathbf{1.35}$

Permanent favourable action $\gamma_{Gf} = \mathbf{1.00}$

Variable unfavourable action $\gamma_Q = \mathbf{1.50}$

Variable favourable action $\gamma_{Qf} = \mathbf{0.00}$

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

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

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

Weight density $\gamma_\gamma = \mathbf{1.00}$

Water properties

Design water density $\gamma_w' = \gamma_w / \gamma_\gamma = \mathbf{9.8}$ kN/m^3

Retained soil properties

Design moist density $\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma = \mathbf{21}$ kN/m^3

Design saturated density $\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma = \mathbf{23}$ kN/m^3

Design effective shear resistance angle $\phi'_{r.d} = \text{atan}(\tan(\phi'_{r.k}) / \gamma_{\phi'}) = \mathbf{30}$ deg

Design wall friction angle $\delta_{r.d} = \text{atan}(\tan(\delta_{r.k}) / \gamma_{\phi'}) = \mathbf{15}$ deg

Base soil properties

Design soil density $\gamma_b' = \gamma_b / \gamma_\gamma = \mathbf{19}$ kN/m^3

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

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

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

Design effective cohesion $c'_{b.d} = c'_{b.k} / \gamma_{c'} = \mathbf{18}$ kN/m^2

Design adhesion $a_{b.d} = a_{b.k} / \gamma_{c'} = \mathbf{18}$ kN/m^2

Using Coulomb theory

Active pressure coefficient $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[}\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]]^2) = \mathbf{0.301}$

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

Overturning check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem} = \mathbf{22.5}$ kN/m

Wall base $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base} = \mathbf{11.2}$ kN/m

Line loads $F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1} = \mathbf{60}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v} = \mathbf{93.8}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times \text{Surcharge}_Q \times h_{eff} = \mathbf{3.6}$ kN/m

Saturated retained soil $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2 = \mathbf{28.2}$ kN/m

Water $F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{72.1}$ kN/m

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

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

Total $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h} = \mathbf{102}$ kN/m

Overturning moments on wall

Surcharge load $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} = \mathbf{5.9}$ kNm/m

Saturated retained soil $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h} = \mathbf{31.1}$ kNm/m

Water $M_{water\_OT} = F_{water\_h} \times x_{water\_h} = \mathbf{79.3}$ kNm/m

Moist retained soil $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} = \mathbf{0}$ kNm/m

Total $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{water\_OT} + M_{sur\_OT} = \mathbf{116.3}$ kNm/m

Restoring moments on wall

Wall stem $M_{stem\_R} = F_{stem} \times x_{stem} = \mathbf{30.4}$ kNm/m

Wall base $M_{base\_R} = F_{base} \times x_{base} = \mathbf{8.4}$ kNm/m

Line loads $M_{P\_R} = (\text{abs}(\gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1})) \times p_1 = \mathbf{81}$ kNm/m

Total — $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{P\_R}$ = **119.8** kNm/m

Check stability against overturning

Factor of safety — $FoS_{ot} = M_{total\_R} / M_{total\_OT}$ = **1.03**

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem — $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem}$ = **30.4** kN/m

Wall base — $F_{base} = \gamma_G \times A_{base} \times \gamma_{base}$ = **15.2** kN/m

Line loads — $F_{P\_v} = \gamma_G \times P_{G1} + \gamma_Q \times P_{Q1}$ = **85.5** kN/m

Total — $F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v}$ = **131.1** kN/m

Horizontal forces on wall

Surcharge load — $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff}$ = **3.6** kN/m

Saturated retained soil — $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2$ = **28.2** kN/m

Water — $F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2$ = **72.1** kN/m

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

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

Total — $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h}$ = **102** kN/m

Moments on wall

Wall stem — $M_{stem} = F_{stem} \times x_{stem}$ = **41** kNm/m

Wall base — $M_{base} = F_{base} \times x_{base}$ = **11.4** kNm/m

Surcharge load — $M_{sur} = -F_{sur\_h} \times x_{sur\_h}$ = **-5.9** kNm/m

Line loads — $M_P = (\gamma_G \times P_{G1} + \gamma_Q \times P_{Q1}) \times p_1$ = **115.4** kNm/m

Saturated retained soil — $M_{sat} = -F_{sat\_h} \times x_{sat\_h}$ = **-31.1** kNm/m

Water — $M_{water} = -F_{water\_h} \times x_{water\_h}$ = **-79.3** kNm/m

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

Total — $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} + M_P$ = **51.5** kNm/m

Check bearing pressure

Propping force — $F_{prop\_base} = F_{total\_h}$ = **102** kN/m

Distance to reaction — $\bar{x} = M_{total} / F_{total\_v}$ = **393** mm

Eccentricity of reaction — $e = \bar{x} - l_{base} / 2$ = **-357** mm

Loaded length of base — $l_{load} = 2 \times \bar{x}$ = **786** mm

Bearing pressure at toe — $q_{toe} = F_{total\_v} / l_{load}$ = **166.8** kN/m^2

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

Effective overburden pressure — $q = \max((t_{base} + d_{cover}) \times \gamma_b' - (t_{base} + d_{cover} + h_{water}) \times \gamma_w', 0\ kN/m^2)$ = **0** kN/m^2

Design effective overburden pressure — $q' = q / \gamma_\gamma$ = **0** kN/m^2

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

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

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

Foundation shape factors — $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

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

$V = F_{total\_v}$ = **131.1** 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 — $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_b' - \gamma_w') \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma$

n_f = **245.9** kN/m^2

Factor of safety — $FoS_{bp} = n_f / \max(q_{toe}, q_{heel})$ = **1.474**

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**

Water properties

Design water density — $\gamma_w' = \gamma_w / \gamma_\gamma$ = **9.8** kN/m^3

Retained soil properties

Design moist density — $\gamma_{mr}' = \gamma_{mr} / \gamma_\gamma$ = **21** kN/m^3

Design saturated density — $\gamma_{sr}' = \gamma_{sr} / \gamma_\gamma$ = **23** kN/m^3

Design effective shear resistance angle — $\phi'_{r.d} = atan(\tan(\phi'_{r.k}) / \gamma_{\phi'})$ = **24.8** deg

Design wall friction angle — $\delta_{r.d} = atan(\tan(\delta_{r.k}) / \gamma_{\phi'})$ = **12.1** deg

Base soil properties

Design soil density — $\gamma_b' = \gamma_b / \gamma_\gamma$ = **19** kN/m^3

Design effective shear resistance angle — $\phi'_{b.d} = atan(\tan(\phi'_{b.k}) / \gamma_{\phi'})$ = **14.6** deg

Design wall friction angle — $\delta_{b.d} = atan(\tan(\delta_{b.k}) / \gamma_{\phi'})$ = **7.2** deg

Design base friction angle — $\delta_{bb.d} = atan(\tan(\delta_{bb.k}) / \gamma_{\phi'})$ = **9.7** deg

Design effective cohesion — $c'_{b.d} = c'_{b.k} / \gamma_{c'}$ = **14.4** kN/m^2

Design adhesion — $a_{b.d} = a_{b.k} / \gamma_{c'}$ = **14.4** kN/m^2

Using Coulomb theory

Active pressure coefficient — $K_A = \sin(\alpha + \phi'_{r.d})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.d}) \times [1 + \sqrt{[\sin(\phi'_{r.d} + \delta_{r.d}) \times \sin(\phi'_{r.d} - \beta) / (\sin(\alpha - \delta_{r.d}) \times \sin(\alpha + \beta))]}]^2)$ = **0.371**

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 — $F_{stem} = \gamma_{Gf} \times A_{stem} \times \gamma_{stem}$ = **22.5** kN/m

Wall base — $F_{base} = \gamma_{Gf} \times A_{base} \times \gamma_{base}$ = **11.2** kN/m

Line loads — $F_{P\_v} = \gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1}$ = **60** kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v} = \mathbf{93.8}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{3.9}$ kN/m

Saturated retained soil $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2 = \mathbf{26.1}$ kN/m

Water $F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{53.4}$ kN/m

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

Base soil $F_{exc\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (h_{pass} + h_{base})^2 / 2 = \mathbf{-1.7}$ kN/m

Total $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{exc\_h} + F_{water\_h} + F_{sur\_h} = \mathbf{81.7}$ kN/m

Overturning moments on wall

Surcharge load $M_{sur\_OT} = F_{sur\_h} \times x_{sur\_h} = \mathbf{6.4}$ kNm/m

Saturated retained soil $M_{sat\_OT} = F_{sat\_h} \times x_{sat\_h} = \mathbf{28.7}$ kNm/m

Water $M_{water\_OT} = F_{water\_h} \times x_{water\_h} = \mathbf{58.8}$ kNm/m

Moist retained soil $M_{moist\_OT} = F_{moist\_h} \times x_{moist\_h} = \mathbf{0}$ kNm/m

Total $M_{total\_OT} = M_{sat\_OT} + M_{moist\_OT} + M_{water\_OT} + M_{sur\_OT} = \mathbf{93.8}$ kNm/m

Restoring moments on wall

Wall stem $M_{stem\_R} = F_{stem} \times x_{stem} = \mathbf{30.4}$ kNm/m

Wall base $M_{base\_R} = F_{base} \times x_{base} = \mathbf{8.4}$ kNm/m

Line loads $M_{P\_R} = (abs(\gamma_{Gf} \times P_{G1} + \gamma_{Qf} \times P_{Q1})) \times p_1 = \mathbf{81}$ kNm/m

Total $M_{total\_R} = M_{stem\_R} + M_{base\_R} + M_{P\_R} = \mathbf{119.8}$ kNm/m

Check stability against overturning

Factor of safety $FoS_{ot} = M_{total\_R} / M_{total\_OT} = \mathbf{1.277}$

PASS - Maximum restoring moment is greater than overturning moment

Bearing pressure check

Vertical forces on wall

Wall stem $F_{stem} = \gamma_G \times A_{stem} \times \gamma_{stem} = \mathbf{22.5}$ kN/m

Wall base $F_{base} = \gamma_G \times A_{base} \times \gamma_{base} = \mathbf{11.2}$ kN/m

Line loads $F_{P\_v} = \gamma_G \times P_{G1} + \gamma_Q \times P_{Q1} = \mathbf{63.9}$ kN/m

Total $F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} + F_{P\_v} = \mathbf{97.7}$ kN/m

Horizontal forces on wall

Surcharge load $F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_Q \times Surcharge_Q \times h_{eff} = \mathbf{3.9}$ kN/m

Saturated retained soil $F_{sat\_h} = \gamma_G \times K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2 = \mathbf{26.1}$ kN/m

Water $F_{water\_h} = \gamma_G \times \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2 = \mathbf{53.4}$ kN/m

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

Base soil $F_{pass\_h} = -\gamma_{Gf} \times K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2 = \mathbf{-1.7}$ kN/m

Total $F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h} = \mathbf{81.7}$ kN/m

Moments on wall

Wall stem $M_{stem} = F_{stem} \times x_{stem} = \mathbf{30.4}$ kNm/m

Wall base $M_{base} = F_{base} \times x_{base} = \mathbf{8.4}$ kNm/m

Surcharge load $M_{sur} = -F_{sur\_h} \times x_{sur\_h} = \mathbf{-6.4}$ kNm/m

Line loads $M_P = (\gamma_G \times P_{G1} + \gamma_Q \times P_{Q1}) \times p_1 = \mathbf{86.3}$ kNm/m

Saturated retained soil $M_{sat} = -F_{sat\_h} \times x_{sat\_h} = \mathbf{-28.7}$ kNm/m

Water $M_{water} = -F_{water\_h} \times x_{water\_h} = \mathbf{-58.8}$ kNm/m

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

Total $M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} + M_P = \mathbf{31.2}$ kNm/m

Check bearing pressure

Propping force $F_{prop\_base} = F_{total\_h} = \mathbf{81.7}$ kN/m

Distance to reaction $\bar{x} = M_{total} / F_{total\_v} = \mathbf{320}$ mm

Eccentricity of reaction $e = \bar{x} - l_{base} / 2 = \mathbf{-430}$ mm

Loaded length of base $l_{load} = 2 \times \bar{x} = \mathbf{640}$ mm

Bearing pressure at toe $q_{toe} = F_{total\_v} / l_{load} = \mathbf{152.6}$ kN/m²

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

Effective overburden pressure $q = \max((t_{base} + d_{cover}) \times \gamma_b' - (t_{base} + d_{cover} + h_{water}) \times \gamma_w', 0 \text{ kN/m}^2) = \mathbf{0}$ kN/m²

Design effective overburden pressure $q' = q / \gamma_\gamma = \mathbf{0}$ kN/m²

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

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

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

Foundation shape factors $s_q = 1$

$s_\gamma = 1$

$s_c = 1$

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

$V = F_{total\_v} = \mathbf{97.7}$ 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 $n_f = c'_{b.d} \times N_c \times s_c \times i_c + q' \times N_q \times s_q \times i_q + 0.5 \times (\gamma_b' - \gamma_w') \times l_{load} \times N_\gamma \times s_\gamma \times i_\gamma$

$n_f = \mathbf{158.5}$ kN/m²

Factor of safety $FoS_{bp} = n_f / \max(q_{toe}, q_{heel}) = \mathbf{1.039}$

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 2.9.03

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/mm²

Characteristic compressive cube strength $f_{ck,cube} = \mathbf{40}$ N/mm²

Mean value of compressive cylinder strength $f_{cm} = f_{ck} + 8 \text{ N/mm}^2 = \mathbf{40}$ N/mm²

Mean value of axial tensile strength $f_{ctm} = 0.3 \text{ N/mm}^2 \times (f_{ck} / 1 \text{ N/mm}^2)^{2/3} = \mathbf{3.0}$ N/mm²

5% fractile of axial tensile strength $f_{ctk,0.05} = 0.7 \times f_{ctm} = \mathbf{2.1}$ N/mm²

Secant modulus of elasticity of concrete $E_{cm} = 22 \text{ kN/mm}^2 \times (f_{cm} / 10 \text{ N/mm}^2)^{0.3} = \mathbf{33346}$ N/mm²

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/mm²

Maximum aggregate size $h_{agg} = \mathbf{20}$ 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 γ_S = **1.15**

Design yield strength of reinforcement $f_{yd} = f_{yk} / \gamma_S$ = **435** N/mm²

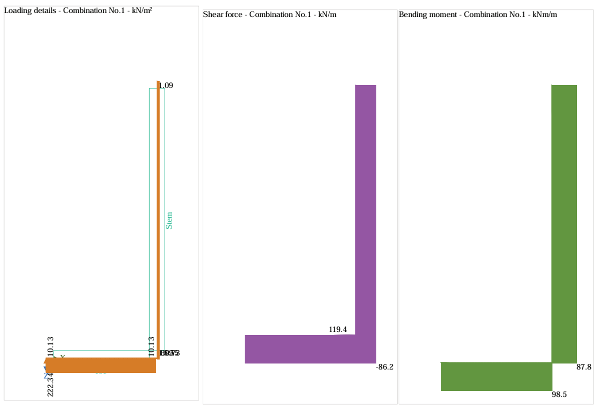
Cover to reinforcement

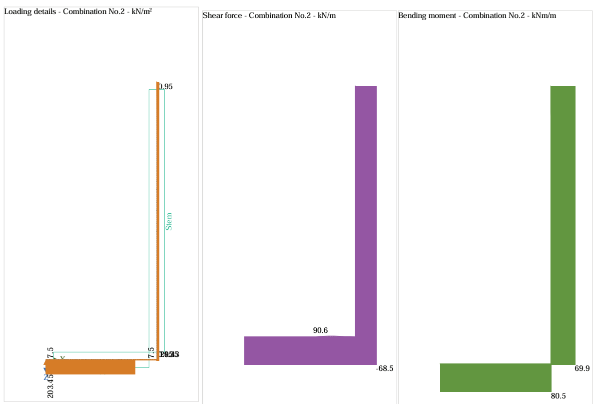
Front face of stem c_{sf} = **40** mm

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

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

Bottom face of base c_{bb} = **50** mm





Check stem design at base of stem

Depth of section h = **300** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 M = **87.8** kNm/m

Depth to tension reinforcement $d = h - c_{sr} - \phi_{sr} / 2$ = **240** mm

$K = M / (d^2 \times f_{ck})$ = **0.048**

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **228** mm

Depth of neutral axis $x = 2.5 \times (d - z)$ = **30** mm

Area of tension reinforcement required $A_{sr.req} = M / (f_{yd} \times z)$ = **886** mm²/m

Tension reinforcement provided 20 dia.bars @ 200 c/c

Area of tension reinforcement provided $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr})$ = **1571** mm²/m

Minimum area of reinforcement - exp.9.1N $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **377** mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3) $A_{sr.max} = 0.04 \times h$ = **12000** mm²/m

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov}$ = **0.564**

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

Deflection control - Section 7.4

Reference reinforcement ratio $\rho_0 = \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} / 1000$ = **0.006**

Required tension reinforcement ratio $\rho = A_{sr.req} / d$ = **0.004**

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 $\min(K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}], 40 \times K_b)$ = **16**

Actual span to depth ratio h_{stem} / d = **12.5**

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} = **63.4** kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{sr.prov} \times z)$ = **177** N/mm²

Load duration Long term

Load duration factor k_t = **0.4**

Effective area of concrete in tension $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **90000** mm²/m

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm}$ = **3.0** N/mm²

Reinforcement ratio $\rho_{p.eff} = A_{sr.prov} / A_{c.eff}$ = **0.017**

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 $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff}$ = **365** 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 = **0.194** mm

w_k / w_{max} = **0.646**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	V = **86.2** kN/m
	$C_{Rd.c}$ = 0.18 / γ_C = **0.120**
	$k = \min(1 + \sqrt{(200\ mm / d)}, 2)$ = **1.913**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{sr.prov} / d, 0.02)$ = **0.007**
	$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.524** N/mm²
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\ N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **151.9** kN/m
	$V / V_{Rd.c}$ = **0.568**

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)	$A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem})$ = **393** mm²/m
Maximum spacing of reinforcement – cl.9.6.3(2)	s_{sx_max} = **400** mm
Transverse reinforcement provided	16 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **1005** mm²/m

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

Check base design at toe

Depth of section	h = **300** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1	M = **98.5** kNm/m
Depth to tension reinforcement	$d = h - c_{bb} - \phi_{bb} / 2$ = **240** mm
	$K = M / (d^2 \times f_{ck})$ = **0.053**
	K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm	$z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **228** mm
Depth of neutral axis	$x = 2.5 \times (d – z)$ = **30** mm
Area of tension reinforcement required	$A_{bb.req} = M / (f_{yd} \times z)$ = **993** mm²/m
Tension reinforcement provided	20 dia.bars @ 200 c/c
Area of tension reinforcement provided	$A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **1571** mm²/m
Minimum area of reinforcement - exp.9.1N	$A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **377** mm²/m
Maximum area of reinforcement - cl.9.2.1.1(3)	$A_{bb.max} = 0.04 \times h$ = **12000** mm²/m
	$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov}$ = **0.632**

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} = **72.6** kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bb.prov} \times z)$ = **202.6** N/mm²
Load duration	Long term
Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h – x) / 3, h / 2)$ = **90000** mm²/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **3.0** N/mm²
Reinforcement ratio	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff}$ = **0.017**

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	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff}$ = **365** 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 = **0.23** mm
	w_k / w_{max} = **0.766**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force	V = **119.4** kN/m
	$C_{Rd.c}$ = 0.18 / γ_C = **0.120**
	$k = \min(1 + \sqrt{(200\ mm / d)}, 2)$ = **1.913**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb.prov} / d, 0.02)$ = **0.007**
	$v_{min} = 0.035\ N^{1/2}/mm \times k^{3/2} \times f_{ck}^{0.5}$ = **0.524** N/mm²
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\ N^2/mm^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **151.9** kN/m
	$V / V_{Rd.c}$ = **0.786**

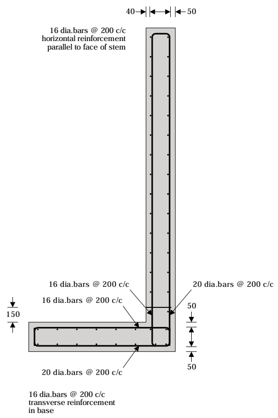
PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

Minimum area of reinforcement – cl.9.3.1.1(2)	$A_{bx.req} = 0.2 \times A_{bb.prov}$ = **314** mm²/m
Maximum spacing of reinforcement – cl.9.3.1.1(3)	s_{bx_max} = **450** mm
Transverse reinforcement provided	16 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx})$ = **1005** mm²/m

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

Form Structural Design 77 St John Street London EC1M 4NN	Project 24 HEATH DRIVE			Job no. 162637	
	Calcs for RC L RETAINING WALL			Start page no./Revision 12	
	Calcs by CEM	Calcs date 29/01/2018	Checked by	Checked date	Approved by	Approved date



Reinforcement details