CALCULATIONS

FOR

38 FROGNAL LANE

PRELIMINARY LOAD RUNDOWNS AND RETAINING WALL THICKNESSES.

Rev. P2

TAK STRUCTURES

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Design Philosophy & Superstructure

- New build RC framed house.
- Building is to be 4-storeys.
- Basement is to be formed using a contiguous piled wall.
- Ground floor slab will be a transfer slab.
- RC frame will be clad with masonry.
- Internal partitions will be timber stud.

Foundation

- All internal columns and lift shaft will be supported upon piles with pile caps.

Stability

- Stability in both directions will be provided by the RC lift shaft.

Disproportionate collapse

- Disproportionate collapse has been considered to building consequence class 1.

British Standard

Imposed Loads	BS6399
Steelwork	BS5950
Timber	BS5268
Masonry	BS5628
Concrete	BS8110

Loading Data

Concrete slab load excl. concrete		kN/m²	Dead	Live
Dead:	Finishes	0.10		
	75mm screed	1.65		
	Ceiling & services	0.50		
		Total =	**2.25**	

Normal reinforced concrete		kN/m³	Dead	Live
Dead:	Normal RC	25.00		
		Total =	**25.00**	

Live:	Allow 2.50kN/m² for residential loading case.			**2.50**
	(Load includes 1.00kN/m² partitions load)			

Sloped roof w/o attic		kN/m²	Dead	Live
Dead:	Tiles	0.75		
	Battens	0.05		
	Rafter	0.20		
	Insulation	0.05		
		Total / cos30 =	**1.25**	
Live:	Allow 0.75kN/m²			**0.75**

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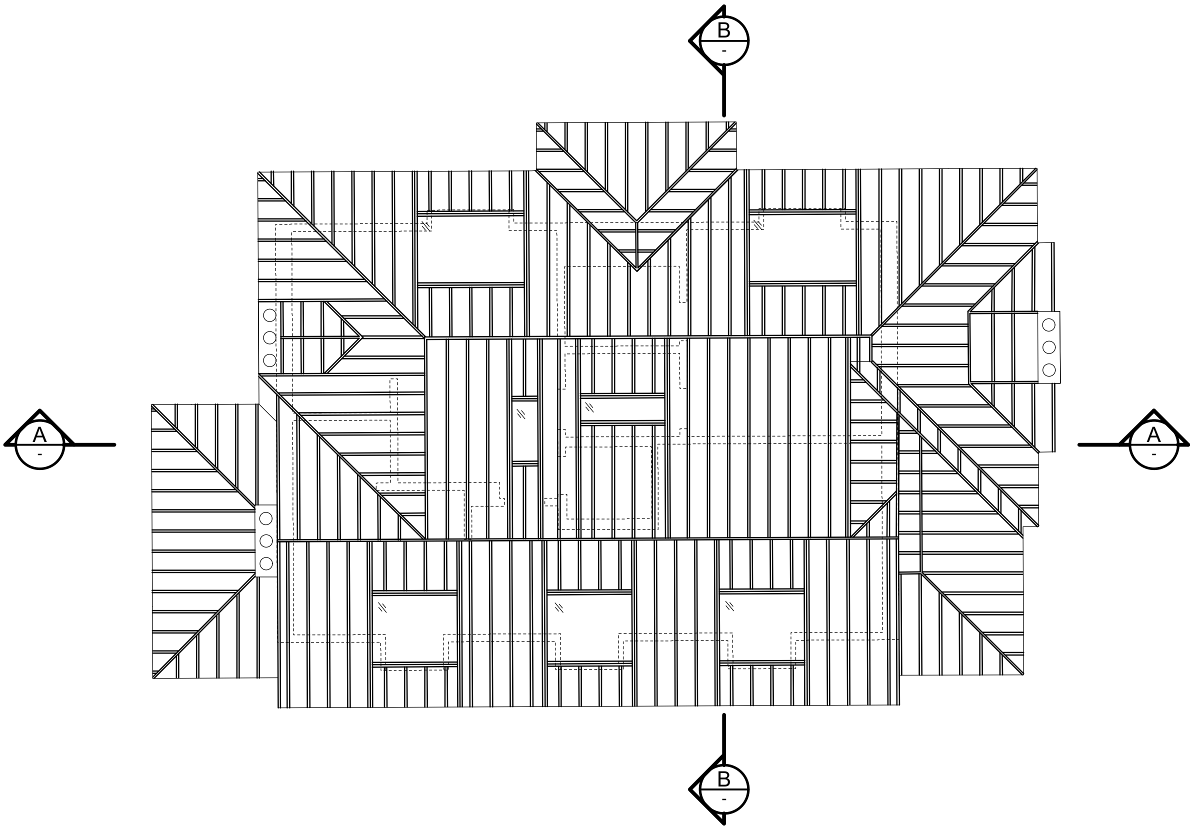
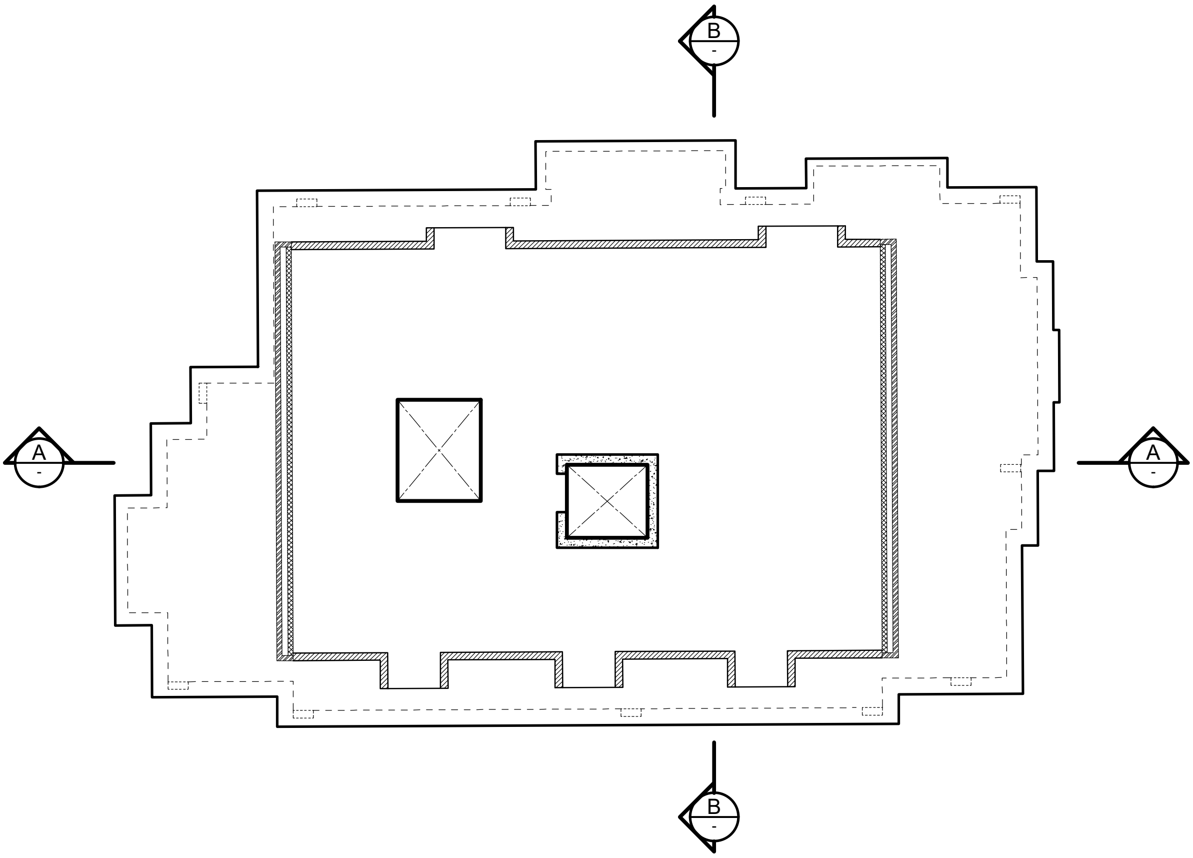
Flat Roof		kN/m²	Dead	Live
Dead:	Finishes	0.70		
	Ceiling & services	0.20		
	Joists	0.20		
		Total =	**1.10**	
Live:	Allow 0.75kN/m²			**0.75**

Ext. cavity wall w/ 100mm blockwork		kN/m²	Dead	Live
Dead:	103mm brickwork	2.30		
	100mm blockwork	2.00		
	Plaster	0.15		
		Total =	**4.45**	

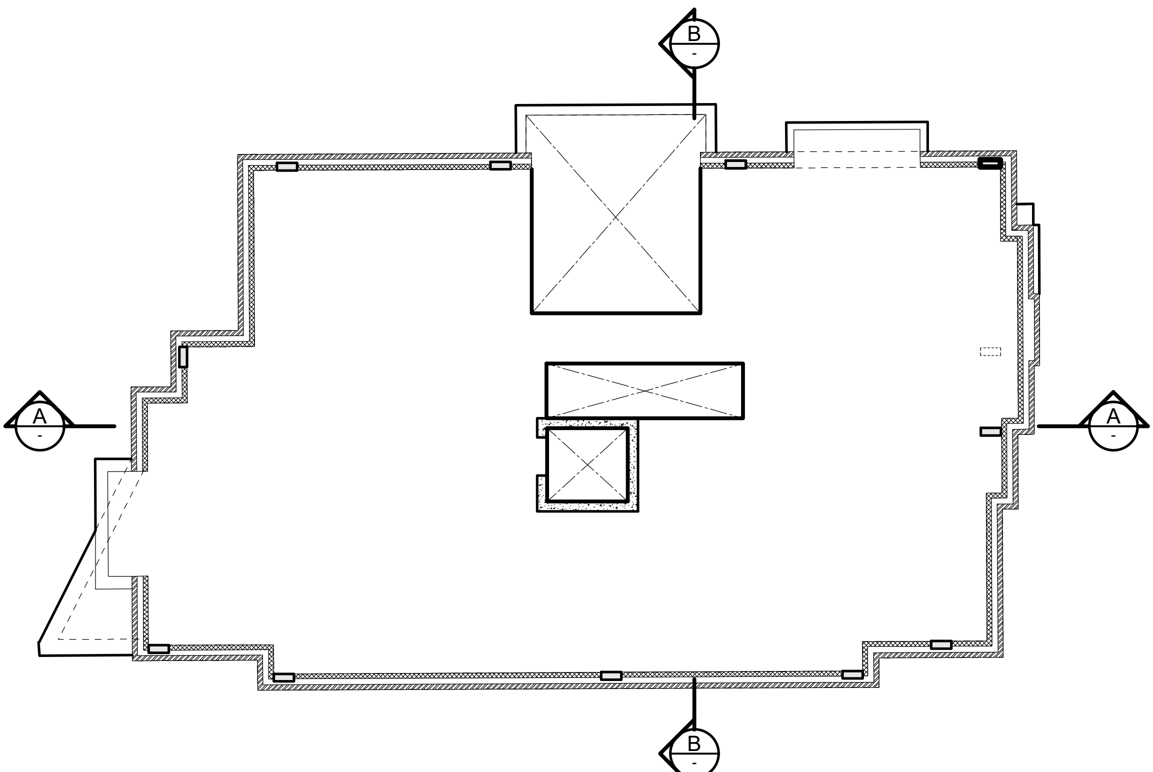


PLAN ON ROOF
(NOT TO SCALE)

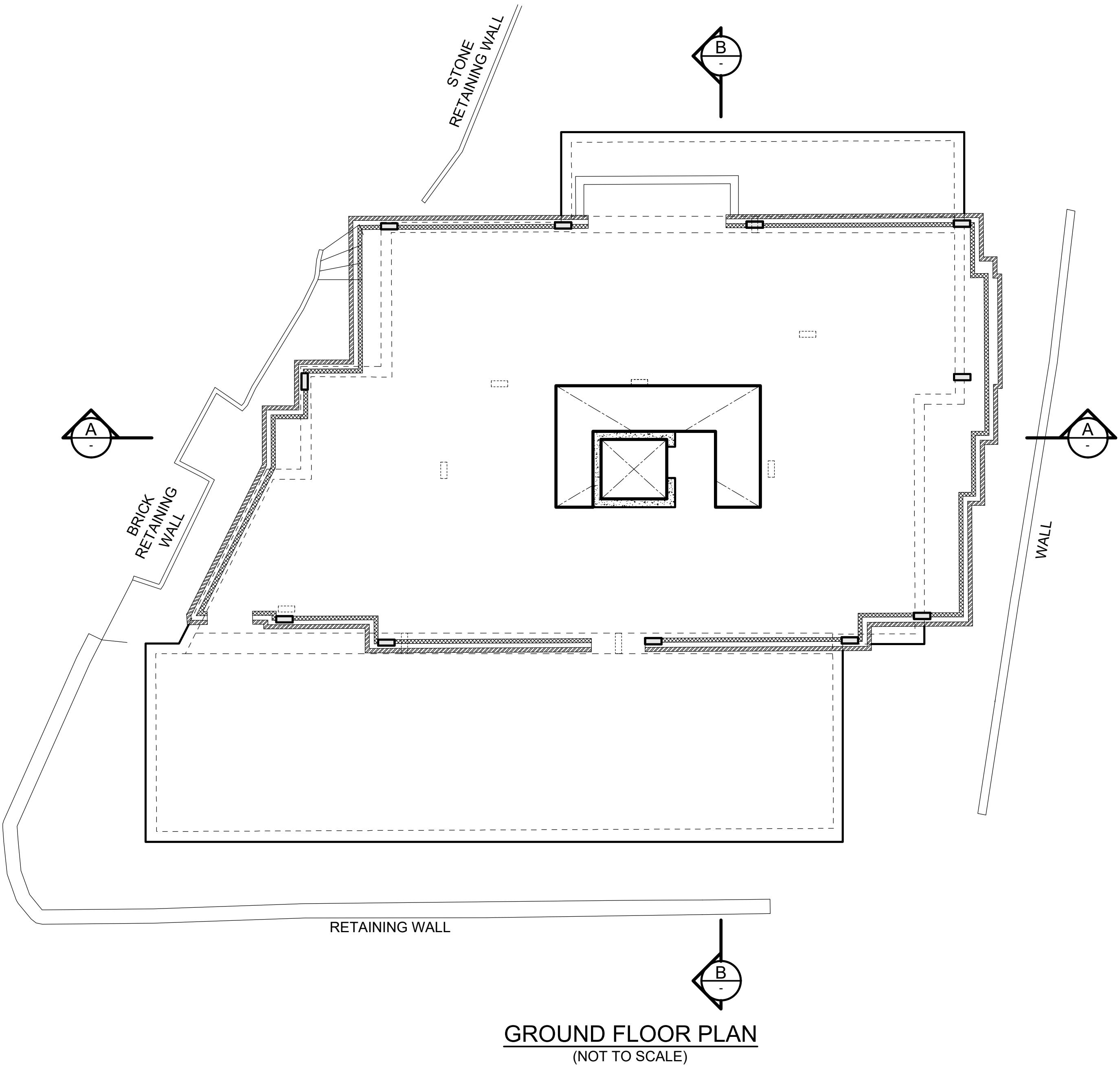


SECOND FLOOR PLAN

(NOT TO SCALE)

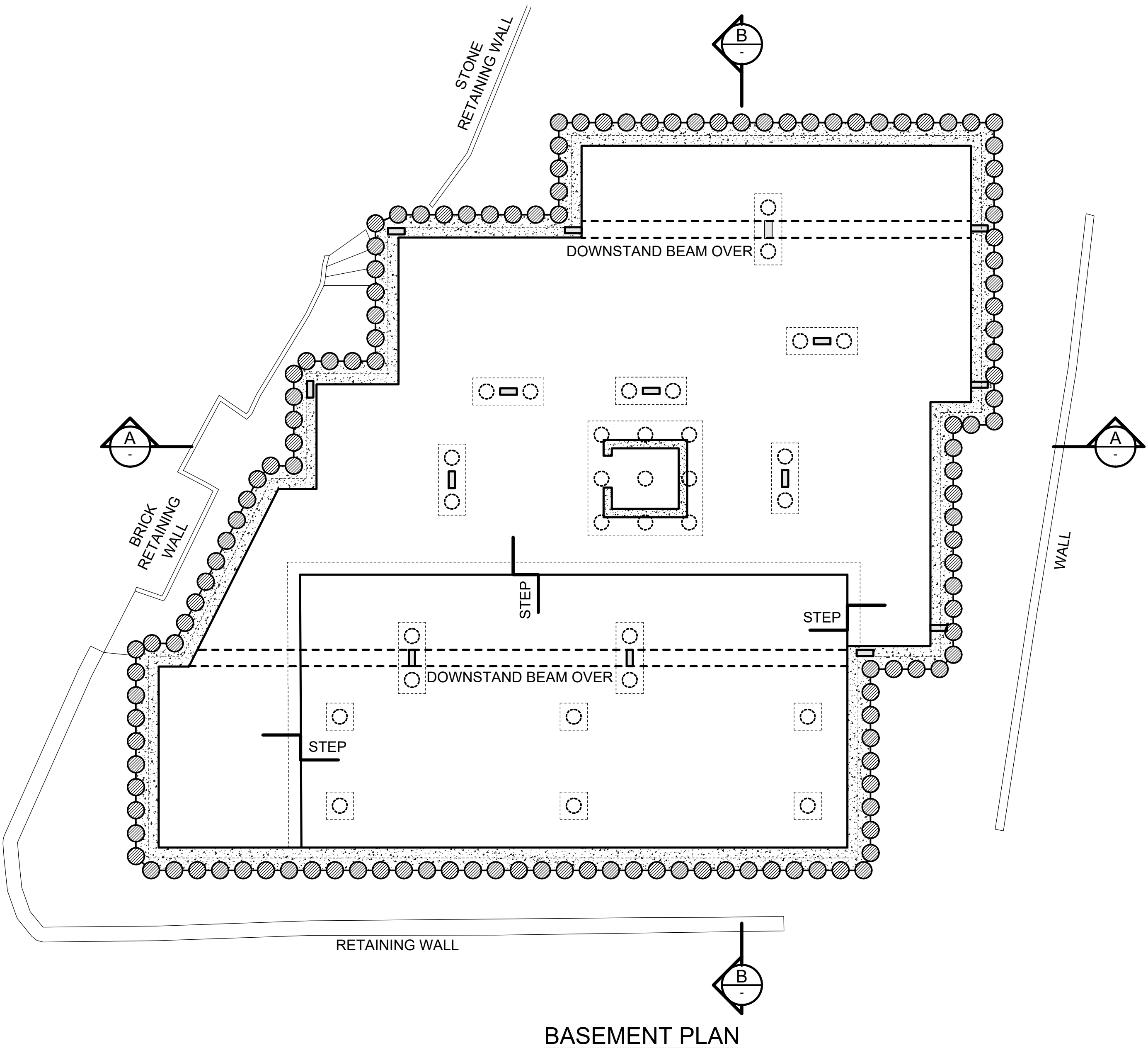


FIRST FLOOR PLAN
(NOT TO SCALE)



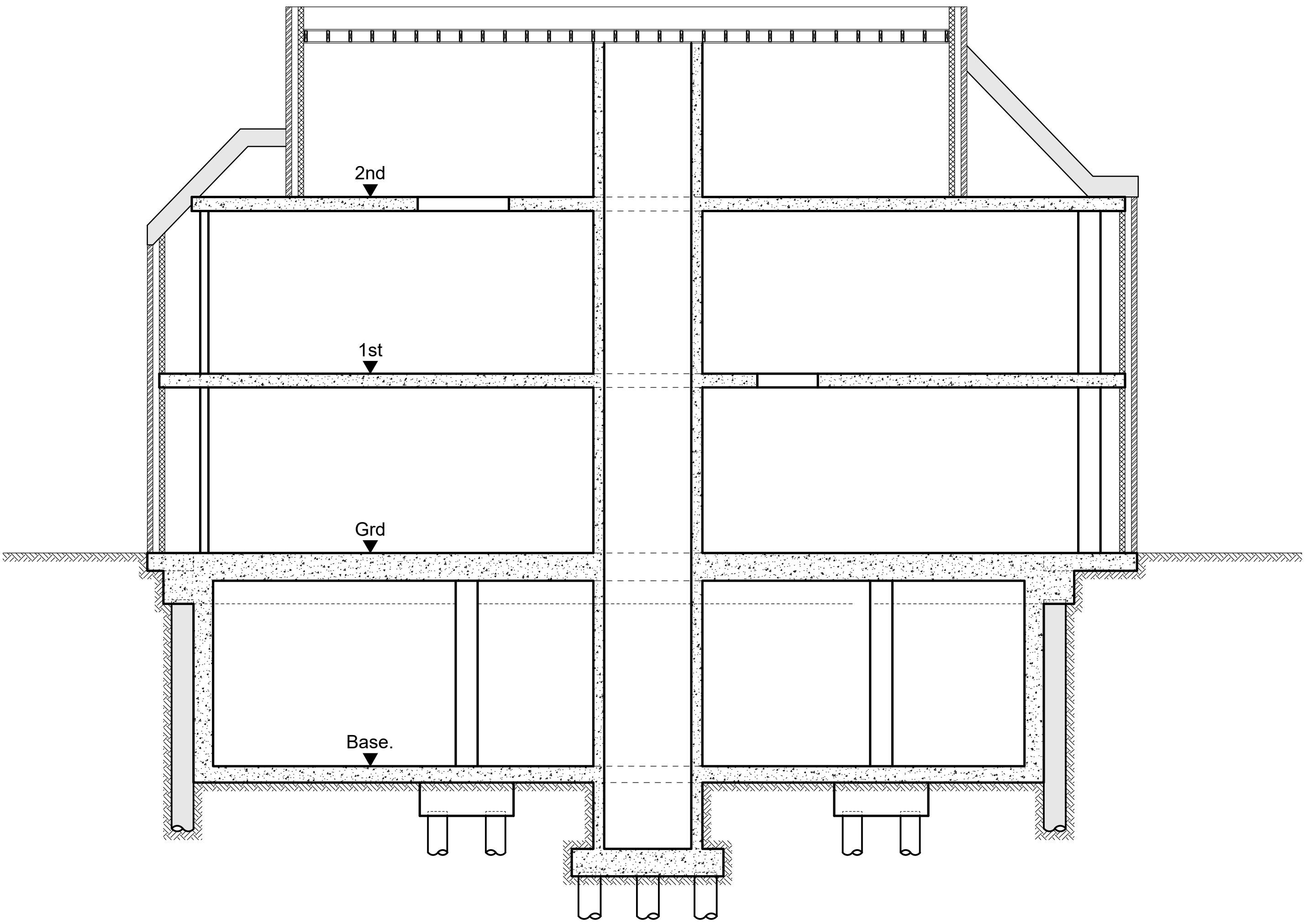
GROUND FLOOR PLAN

(NOT TO SCALE)

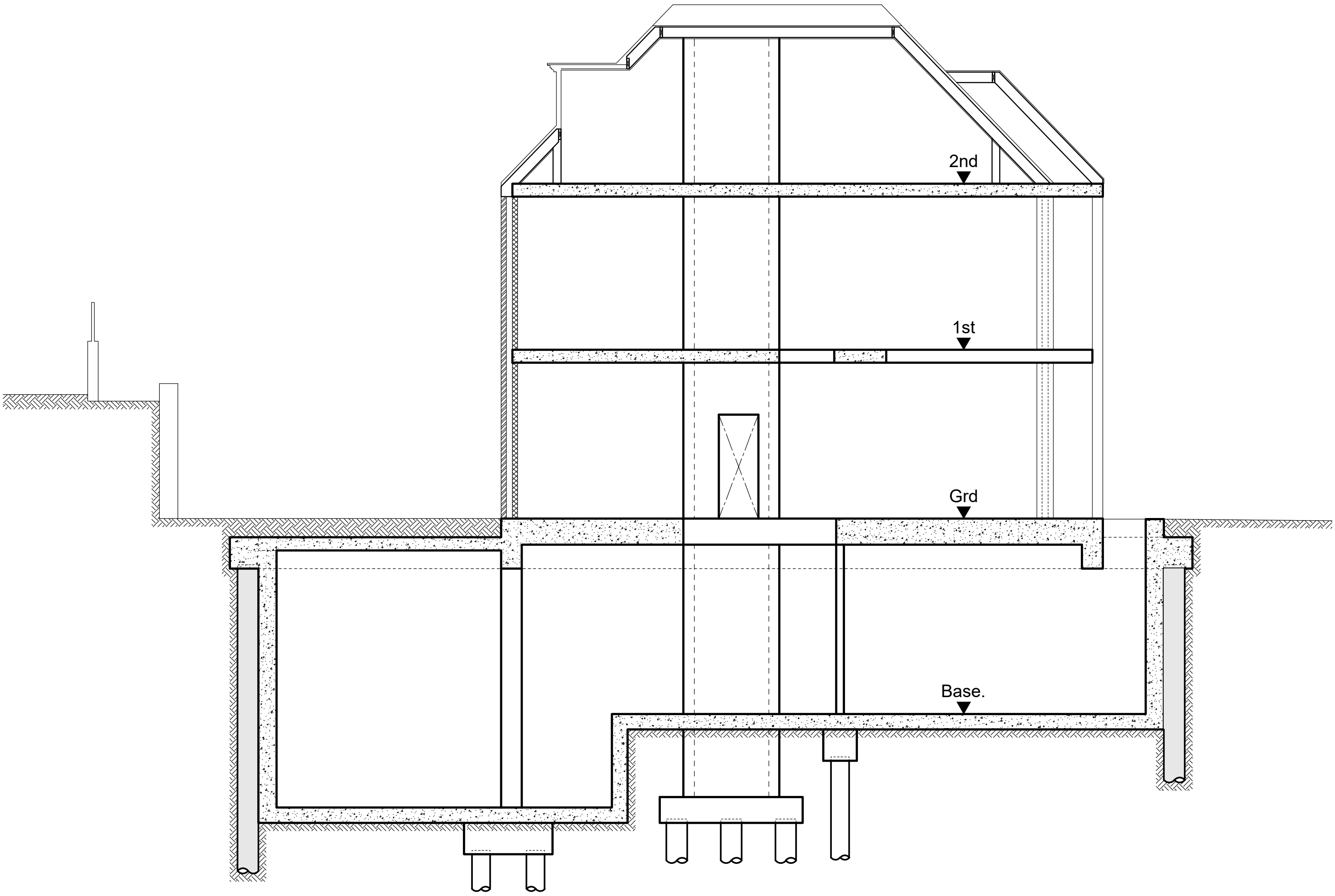


BASEMENT PLAN

(NOT TO SCALE)



SECTION (A/-)
(SCALE 1:50)



SECTION B
(SCALE 1:50)
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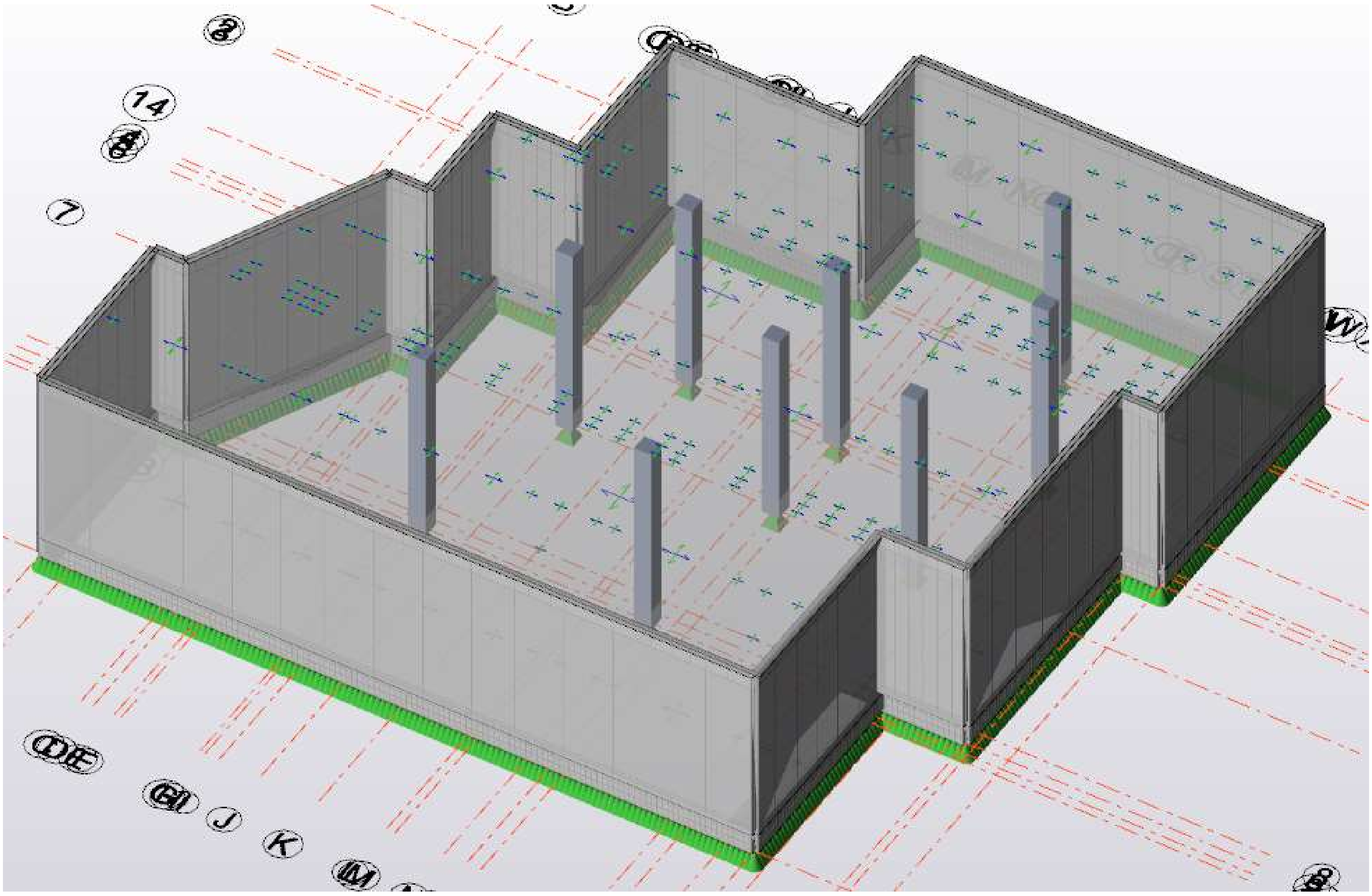
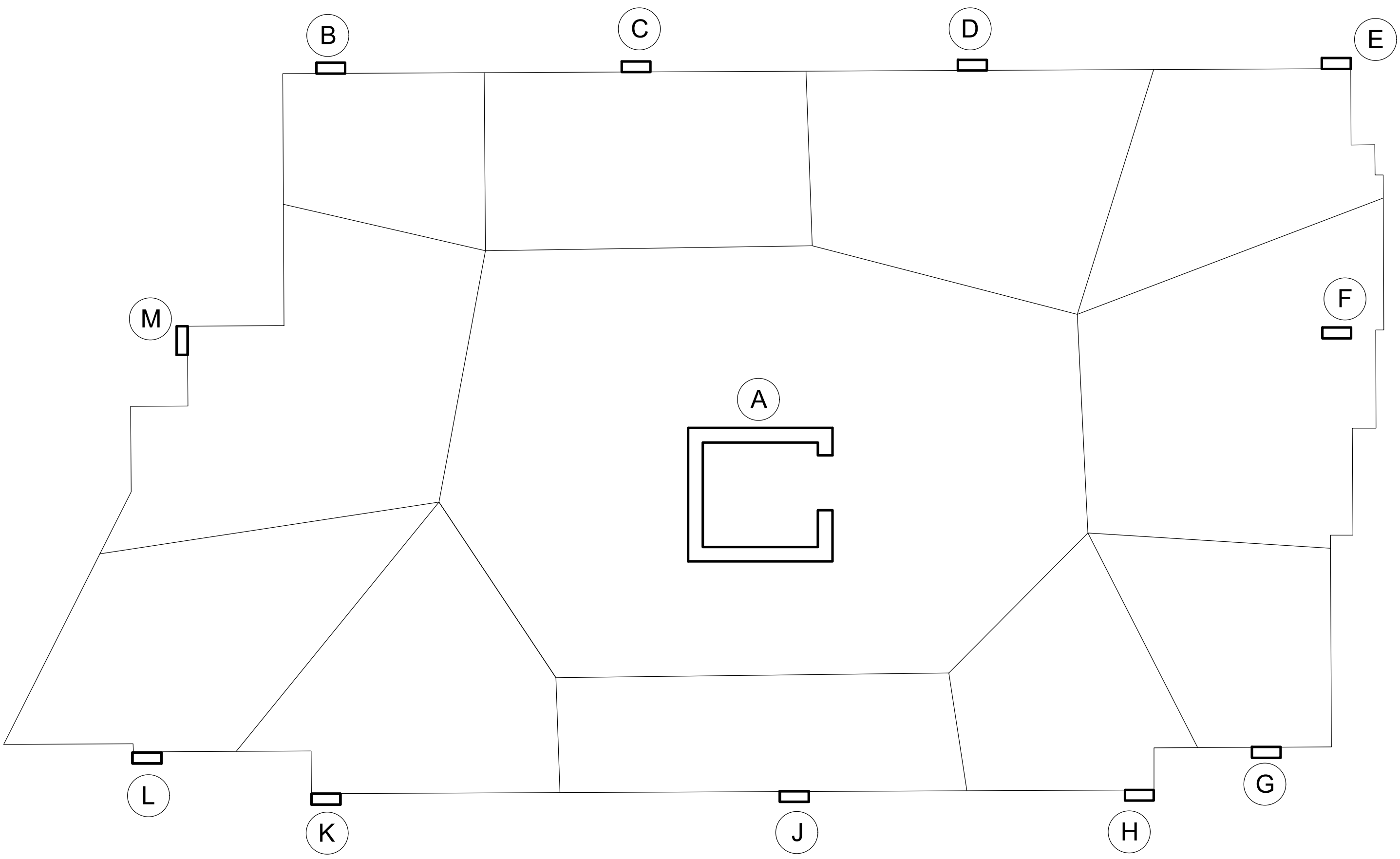
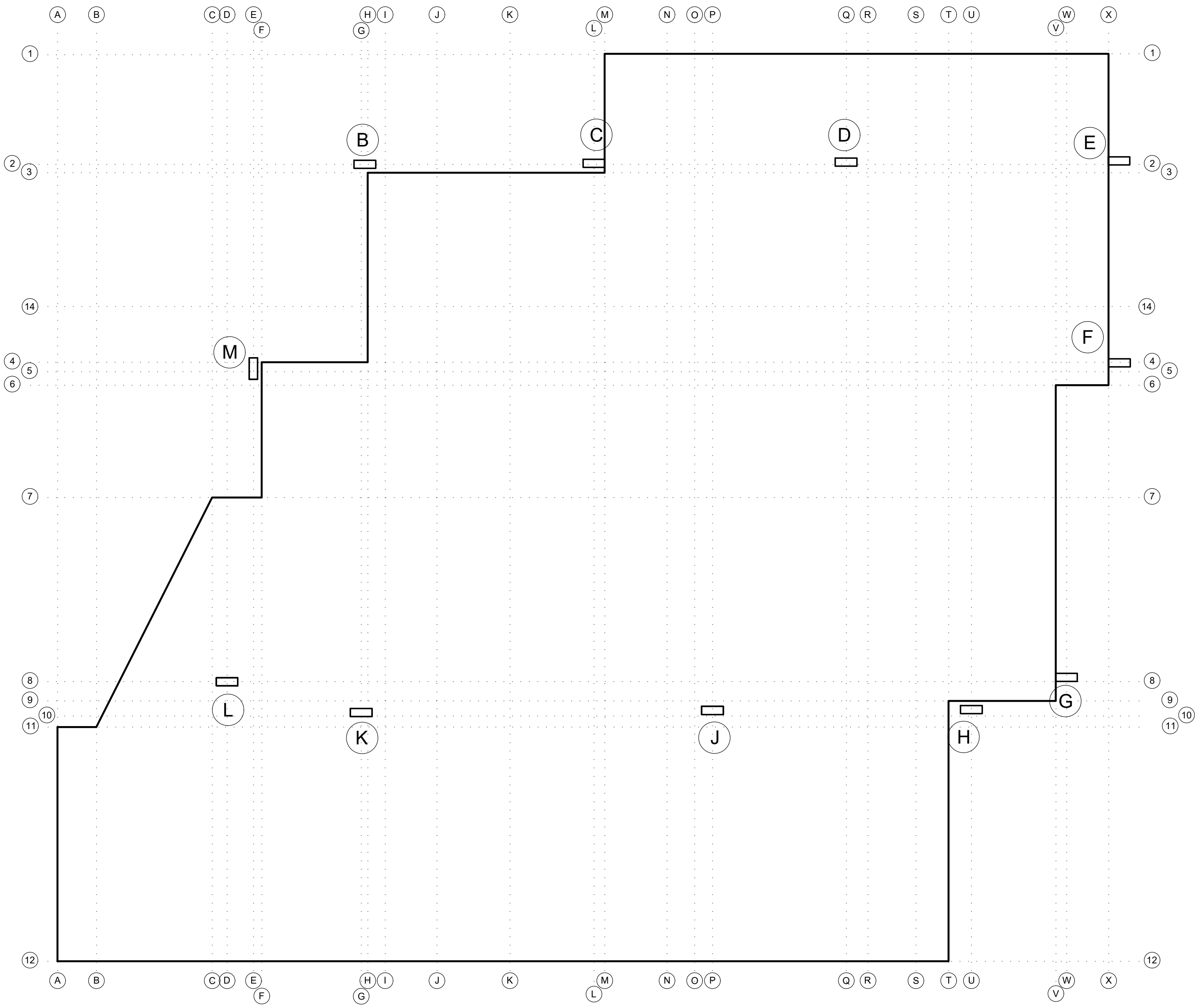


TEKLA MODEL



AREA LOADS UPON SUPPORTS



LOAD INPUTS INTO TEKLA

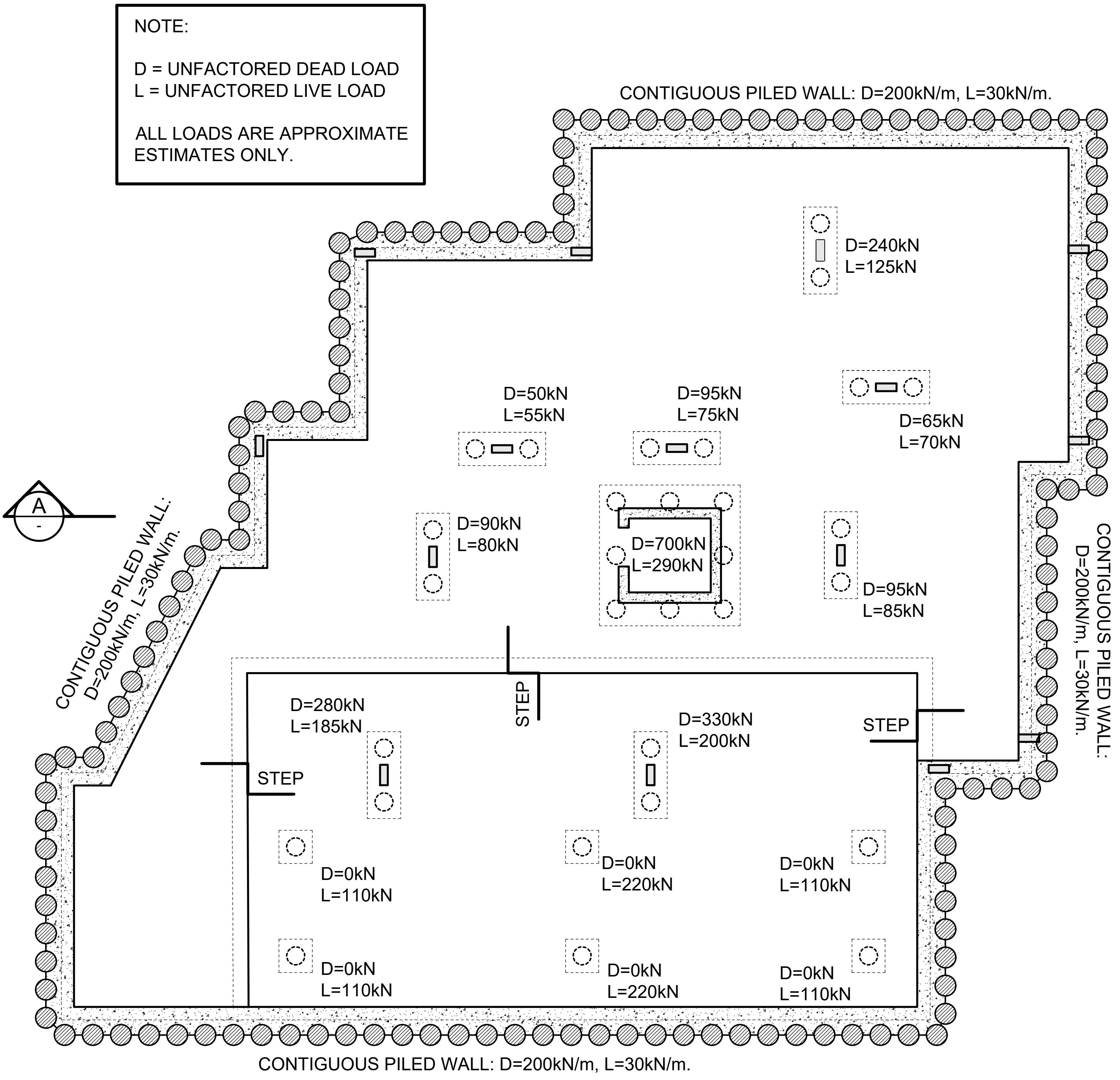
	Area	Perimeter Wall Length (m)	Perimeter Wall Load (kN)	Dead Load	Live Load	Total (kN)
Roof	183.5	0.0	0.0	330.3	137.6	467.9
2nd	183.5	41.0	328.9	1330.4	458.8	2118.0
1st	183.5	61.9	736.9	1330.4	458.8	2526.0
Grd	247.1	61.9	863.5	3027.0	617.8	4508.2
Base	247.1	70.9	2084.5	1791.5	617.8	4493.7
			4013.7	7809.5	2290.6	14113.8

	Column Loading		
	Wall Load (kN/m)	Dead (kN/m²)	Live (kN/m²)
Roof		1.8	0.8
2nd	0.0	7.3	2.5
1st	6.4	7.3	2.5
Grd		12.3	2.5
Base.	29.4	7.3	2.5

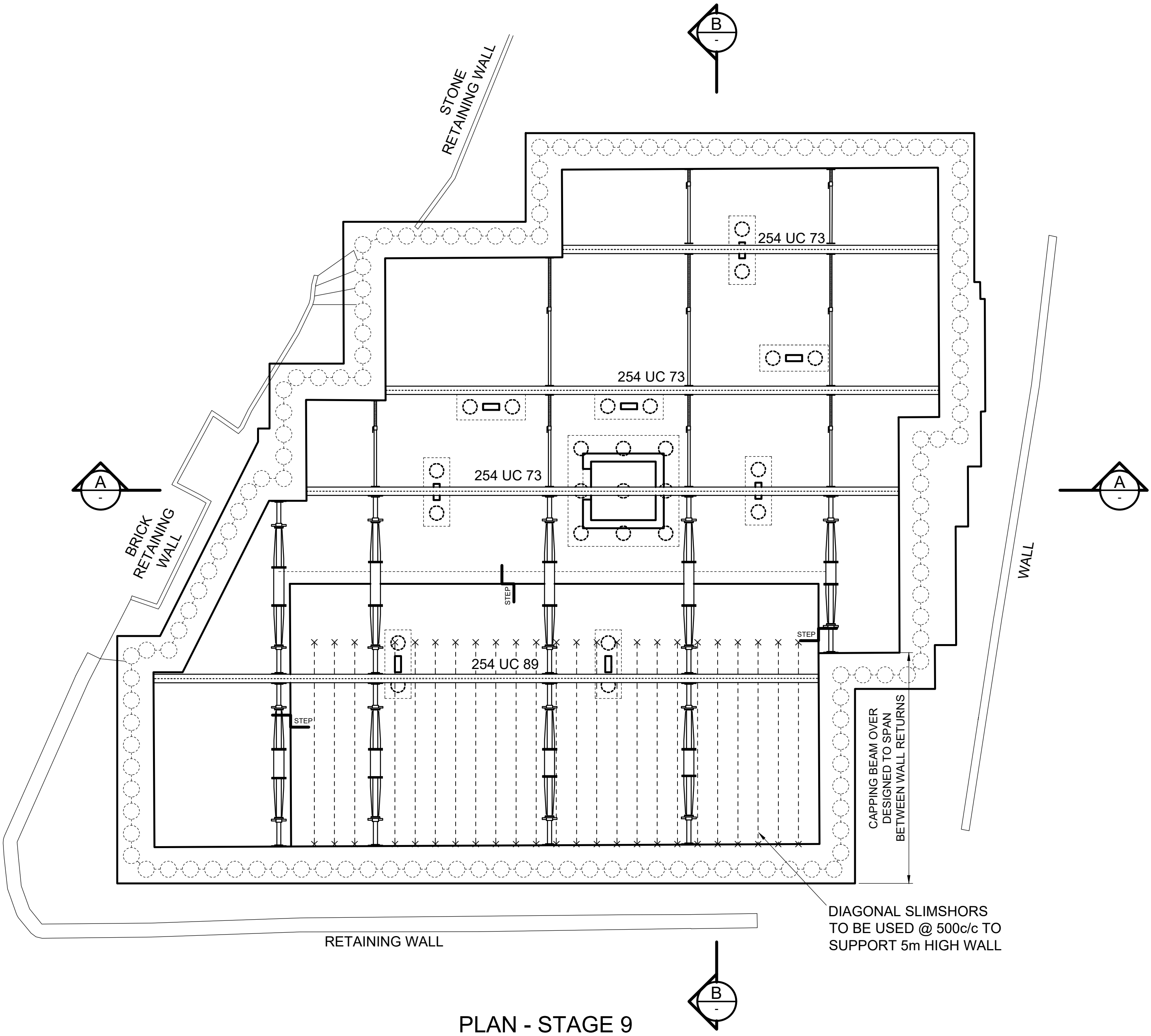
Zone	Area (m²)	Perimeter Wall Length (m)	Perimeter Wall Load (kN)	Support Load, Dead (kN)	Support Load, Live (kN)	Misc. (kN)	Total (kN)
A	42.7	0.0	0.0	696.0	245.5		941.5
B	6.0	4.6	29.4	97.8	34.5	33.3	195.0
C	11.0	4.5	28.5	179.3	63.3		271.1
D	12.6	4.8	30.9	205.4	72.5		308.7
E	8.7	5.0	31.9	141.8	50.0	33.3	257.0
F	15.7	5.6	35.9	255.9	90.3	33.3	415.4
G	7.4	4.6	29.5	120.6	42.6	33.3	226.0
H	7.7	3.8	24.3	125.5	44.3	33.3	227.3
J	9.0	5.7	36.2	146.7	51.8		234.6
K	10.5	5.1	32.6	171.2	60.4	33.3	297.4
L	11.5	6.3	40.3	187.5	66.1	33.3	327.2
M	15.5	7.1	45.3	252.7	89.1	33.3	420.4

2nd floor wall
33.3

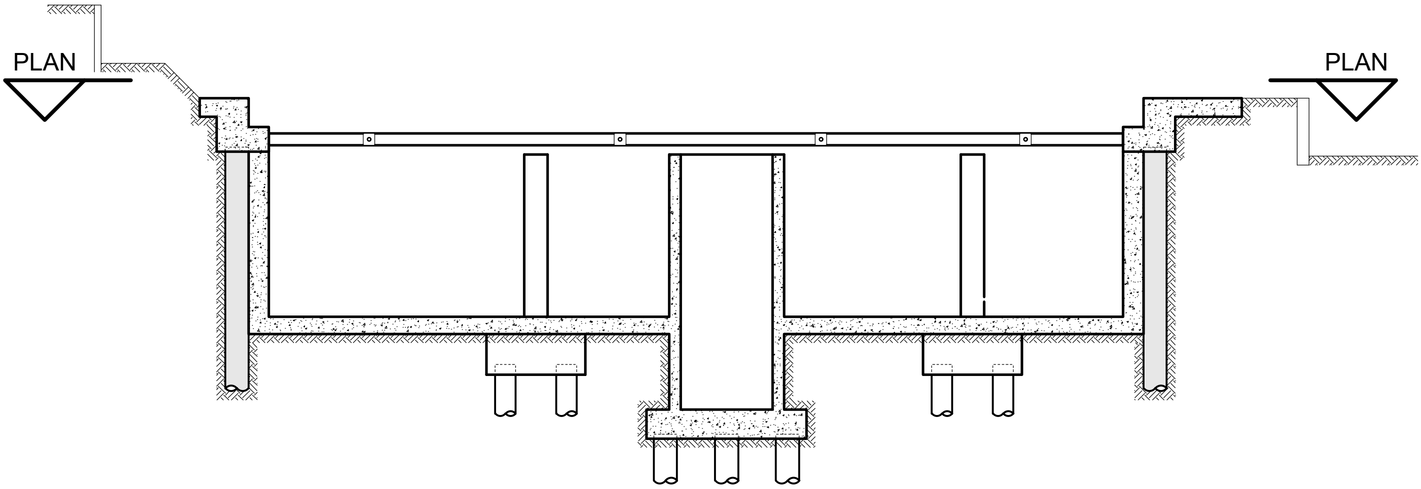
Water	10.0	kN/m³
Pool Volume	86.7	m³
Pool Load	866.6	kN
4No. Outer Piles	108.3	kN
2No. Inner Piles	216.7	kN



PILE LOADS
(NOT TO SCALE)



PLAN - STAGE 9
(SCALE 1:100)



SECTION A
(SCALE 1:100)
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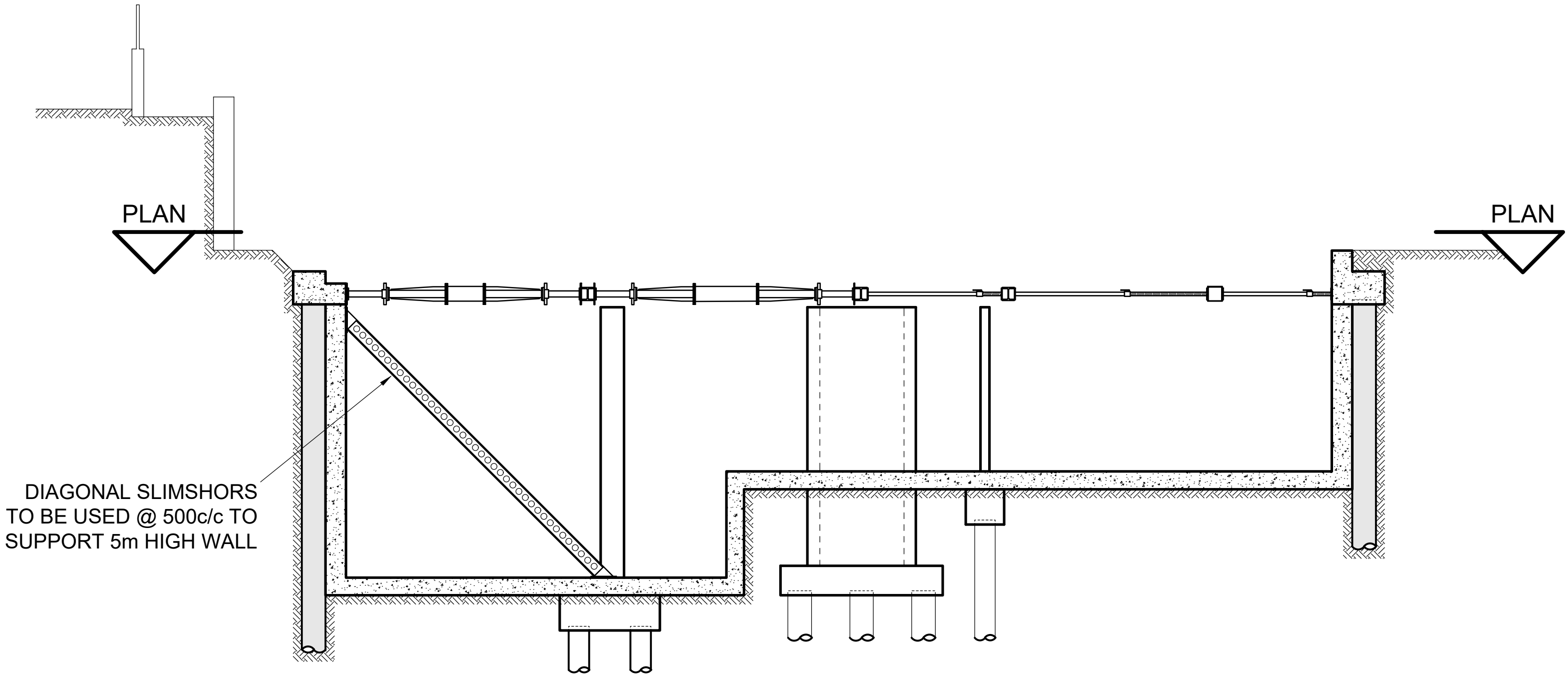

SECTION B
(SCALE 1:100)
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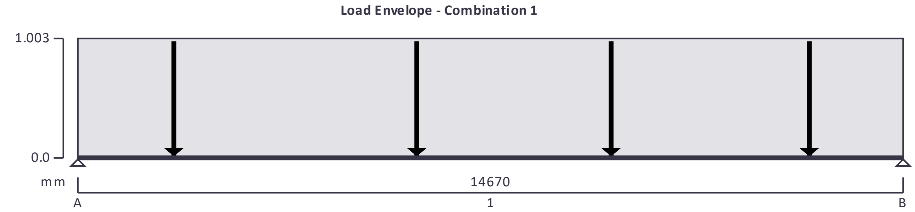
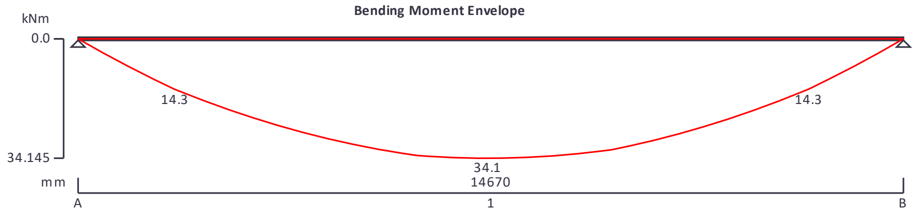
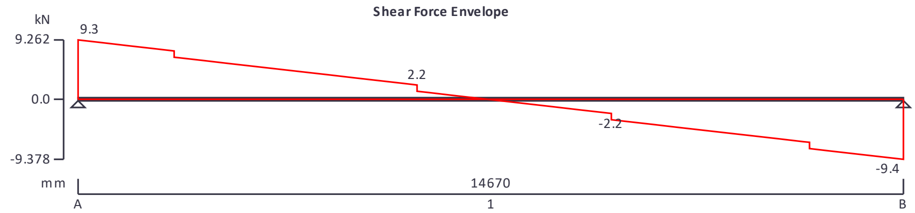
STEEL BEAM ANALYSIS & DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.07







Support conditions

Support A	Vertically restrained
	Rotationally free
Support B	Vertically restrained
	Rotationally free

Applied loading

Beam loads	Dead self weight of beam × 1
	Dead point load 0.7 kN at 1706 mm
	Dead point load 0.7 kN at 6025 mm
	Dead point load 0.7 kN at 9478 mm
	Dead point load 0.7 kN at 13000 mm

Load combinations

Load combination 1	Support A	Dead × 1.40
		Imposed × 1.60
		Dead × 1.40
		Imposed × 1.60
	Support B	Dead × 1.40

Imposed × 1.60

Analysis results

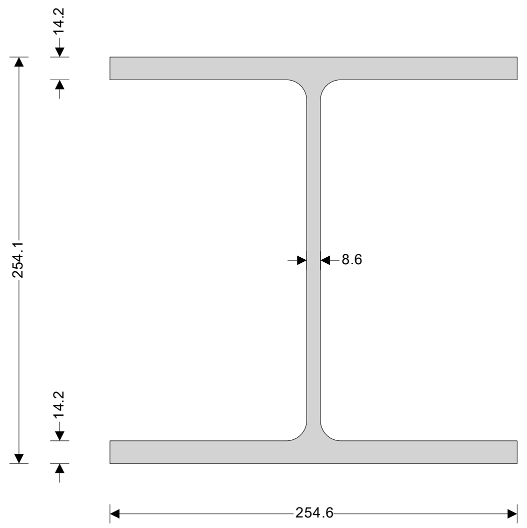
Maximum moment	M_{max} = **34.1** kNm	M_{min} = **0** kNm
Maximum shear	V_{max} = **9.3** kN	V_{min} = **-9.4** kN
Deflection	δ_{max} = **23.4** mm	δ_{min} = **0** mm
Maximum reaction at support A	R_{A_max} = **9.3** kN	R_{A_min} = **9.3** kN
Unfactored dead load reaction at support A	R_{A_Dead} = **6.6** kN	
Maximum reaction at support B	R_{B_max} = **9.4** kN	R_{B_min} = **9.4** kN
Unfactored dead load reaction at support B	R_{B_Dead} = **6.7** kN	

Section details

Section type	**UC 254x254x73 (BS4-1)**
Steel grade	**S275**

From table 9: Design strength p_y

Thickness of element	max(T, t) = **14.2** mm
Design strength	p_y = **275** N/mm^2
Modulus of elasticity	E = **205000** N/mm^2



Lateral restraint

Span 1 has lateral restraint at supports only

Effective length factors

Effective length factor in major axis	K_x = **1.00**
Effective length factor in minor axis	K_y = **1.00**
Effective length factor for lateral-torsional buckling	$K_{LT.A}$ = **1.00**
	$K_{LT.B}$ = **1.00**

Classification of cross sections - Section 3.5

$\varepsilon = \sqrt{[275 \text{ N/mm}^2 / p_y]}$ = **1.00**

Internal compression parts - Table 11

Depth of section	d = **200.3** mm	
	d / t = 23.3 × ε <= 80 × ε	Class 1 plastic

Outstand flanges - Table 11

Width of section	b = B / 2 = **127.3** mm

$b / T = 9.0 \times \varepsilon <= 9 \times \varepsilon$ Class 1 plastic

Section is class 1 plastic

Shear capacity - Section 4.2.3

Design shear force $F_v = max(abs(V_{max}), abs(V_{min})) = \mathbf{9.4}$ kN

$d / t < 70 \times \varepsilon$

Web does not need to be checked for shear buckling

Shear area $A_v = t \times D = \mathbf{2185}$ mm^2

Design shear resistance $P_v = 0.6 \times p_y \times A_v = \mathbf{360.6}$ kN

PASS - Design shear resistance exceeds design shear force

Moment capacity - Section 4.2.5

Design bending moment $M = max(abs(M_{s1\_max}), abs(M_{s1\_min})) = \mathbf{34.1}$ kNm

Moment capacity low shear - cl.4.2.5.2 $M_c = min(p_y \times S_{xx}, 1.2 \times p_y \times Z_{xx}) = \mathbf{272.8}$ kNm

Effective length for lateral-torsional buckling - Section 4.3.5

Effective length for lateral torsional buckling $L_E = 1.0 \times L_{s1} = \mathbf{14670}$ mm

Slenderness ratio $\lambda = L_E / r_{yy} = \mathbf{226.434}$

Equivalent slenderness - Section 4.3.6.7

Buckling parameter $u = \mathbf{0.849}$

Torsional index $x = \mathbf{17.259}$

Slenderness factor $v = 1 / [1 + 0.05 \times (\lambda / x)^2]^{0.25} = \mathbf{0.568}$

Ratio - cl.4.3.6.9 $\beta_W = \mathbf{1.000}$

Equivalent slenderness - cl.4.3.6.7 $\lambda_{LT} = u \times v \times \lambda \times \sqrt{[\beta_W]} = \mathbf{109.159}$

Limiting slenderness - Annex B.2.2 $\lambda_{L0} = 0.4 \times (\pi^2 \times E / p_y)^{0.5} = \mathbf{34.310}$

λ_{LT} > λ_{L0} - Allowance should be made for lateral-torsional buckling

Bending strength - Section 4.3.6.5

Robertson constant $\alpha_{LT} = \mathbf{7.0}$

Perry factor $\eta_{LT} = max(\alpha_{LT} \times (\lambda_{LT} - \lambda_{L0}) / 1000, 0) = \mathbf{0.524}$

Euler stress $p_E = \pi^2 \times E / \lambda_{LT}^2 = \mathbf{169.8}$ N/mm^2

$\phi_{LT} = (p_y + (\eta_{LT} + 1) \times p_E) / 2 = \mathbf{266.9}$ N/mm^2

Bending strength - Annex B.2.1 $p_b = p_E \times p_y / (\phi_{LT} + (\phi_{LT}^2 - p_E \times p_y)^{0.5}) = \mathbf{110.3}$ N/mm^2

Equivalent uniform moment factor - Section 4.3.6.6

Moment at quarter point of segment $M_2 = \mathbf{25.3}$ kNm

Moment at centre-line of segment $M_3 = \mathbf{34.1}$ kNm

Moment at three quarter point of segment $M_4 = \mathbf{25.7}$ kNm

Maximum moment in segment $M_{abs} = \mathbf{34.1}$ kNm

Maximum moment governing buckling resistance $M_{LT} = M_{abs} = \mathbf{34.1}$ kNm

Equivalent uniform moment factor for lateral-torsional buckling

$m_{LT} = max(0.2 + (0.15 \times M_2 + 0.5 \times M_3 + 0.15 \times M_4) / M_{abs}, 0.44) = \mathbf{0.924}$

Buckling resistance moment - Section 4.3.6.4

Buckling resistance moment $M_b = p_b \times S_{xx} = \mathbf{109.4}$ kNm

$M_b / m_{LT} = \mathbf{118.4}$ kNm

PASS - Buckling resistance moment exceeds design bending moment

Check vertical deflection - Section 2.5.2

Consider deflection due to dead and imposed loads

Limiting deflection $\delta_{lim} = L_{s1} / 360 = \mathbf{40.75}$ mm

Maximum deflection span 1 $\delta = max(abs(\delta_{max}), abs(\delta_{min}))$ = **23.44** mm

PASS - Maximum deflection does not exceed deflection limit

STEEL MEMBER DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.07

Section details

Section type **UC 254x254x73 (BS4-1)**

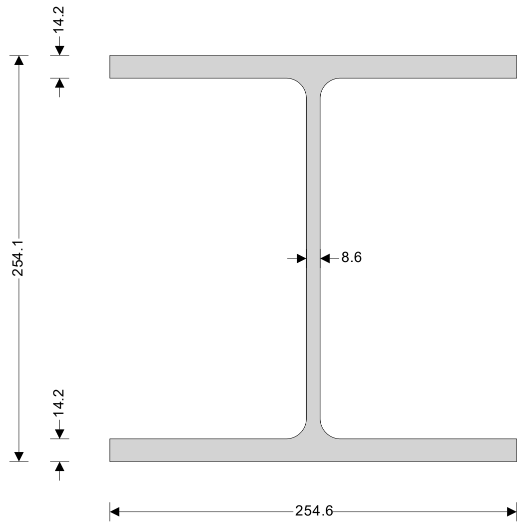
Steel grade **S355**

From table 9: Design strength p_y

Thickness of element max(T, t) = **14.2** mm

Design strength p_y = **355** N/mm^2

Modulus of elasticity E = **205000** N/mm^2



Lateral restraint

Distance between major axis restraints L_x = **16500** mm

Distance between minor axis restraints L_y = **16500** mm

Effective length factors

Effective length factor in major axis K_x = **1.00**

Effective length factor in minor axis K_y = **1.00**

Effective length factor for lateral-torsional buckling K_{LT} = **1.00**

Classification of cross sections - Section 3.5

$\varepsilon = \sqrt{[275 \text{ N/mm}^2 / p_y]}$ = **0.88**

Internal compression parts - Table 11

Depth of section d = **200.3** mm

Stress ratios $r1 = \min(F_c / (d \times t \times p_{yw}), 1)$ = **0.2**

$r2 = F_c / (A \times p_{yw})$ = **0.037**

$d / t = 26.5 \times \varepsilon <= \max(80 \times \varepsilon / (1 + r1), 40 \times \varepsilon)$ Class 1 plastic

Outstand flanges - Table 11

Width of section b = B / 2 = **127.3** mm

$b / T = 10.2 \times \varepsilon <= 15 \times \varepsilon$ Class 3 semi-compact

Section is class 3 semi-compact

Shear capacity - Section 4.2.3

Design shear force $F_{y,v}$ = **9.4** kN

$d / t < 70 \times \varepsilon$

Web does not need to be checked for shear buckling

Shear area $A_v = t \times D$ = **2185** mm^2

Design shear resistance $P_{y,v} = 0.6 \times p_y \times A_v$ = **465.5** kN

PASS - Design shear resistance exceeds design shear force

Shear capacity - Section 4.2.3

Design shear force $F_{x,v}$ = **0** kN

Moment capacity - Section 4.2.5

Design bending moment M = **34.1** kNm

Effective plastic modulus - Section 3.5.6

Limiting value for class 2 compact flange $\beta_{2f} = 10 \times \varepsilon$ = **8.801**

Limiting value for class 3 semi-compact flange $\beta_{3f} = 15 \times \varepsilon$ = **13.202**

Limiting value for class 2 compact web $\beta_{2w} = \max(100 \times \varepsilon / (1 + 1.5 \times r1), 40 \times \varepsilon)$ = **67.716**

Limiting value for class 3 semi-compact web $\beta_{3w} = \max(120 \times \varepsilon / (1 + 2 \times r2), 40 \times \varepsilon)$ = **98.345**

Effective plastic modulus - cl.3.5.6.2

$S_{eff} = \min(Z_{xx} + (S_{xx} - Z_{xx}) \times \min([((\beta_{3w} / (d / t))^2 - 1) / ((\beta_{3w} / \beta_{2w})^2 - 1)], [(\beta_{3f} / (b / T) - 1) / (\beta_{3f} / \beta_{2f} - 1)]), S_{xx})$ = **986918** mm^3

Moment capacity low shear - cl.4.2.5.2 $M_c = \min(p_y \times S_{eff}, 1.2 \times p_y \times Z_{xx})$ = **350.4** kNm

Effective length for lateral-torsional buckling - Section 4.3.5

Effective length for lateral torsional buckling $L_E = 1.0 \times L_y$ = **16500** mm

Slenderness ratio $\lambda = L_E / r_{yy}$ = **254.680**

Equivalent slenderness - Section 4.3.6.7

Buckling parameter u = **0.849**

Torsional index x = **17.259**

Slenderness factor $v = 1 / [1 + 0.05 \times (\lambda / x)^2]^{0.25}$ = **0.539**

Ratio - cl.4.3.6.9 $\beta_W = S_{eff} / S_{xx}$ = **0.995**

Equivalent slenderness - cl.4.3.6.7 $\lambda_{LT} = u \times v \times \lambda \times \sqrt{[\beta_W]}$ = **116.105**

Limiting slenderness - Annex B.2.2 $\lambda_{L0} = 0.4 \times (\pi^2 \times E / p_y)^{0.5}$ = **30.198**

$\lambda_{LT} > \lambda_{L0}$ - Allowance should be made for lateral-torsional buckling

Bending strength - Section 4.3.6.5

Robertson constant α_{LT} = **7.0**

Perry factor $\eta_{LT} = \max(\alpha_{LT} \times (\lambda_{LT} - \lambda_{L0}) / 1000, 0)$ = **0.601**

Euler stress $p_E = \pi^2 \times E / \lambda_{LT}^2$ = **150.1** N/mm^2

$\phi_{LT} = (p_y + (\eta_{LT} + 1) \times p_E) / 2$ = **297.7** N/mm^2

Bending strength - Annex B.2.1 $p_b = p_E \times p_y / (\phi_{LT} + (\phi_{LT}^2 - p_E \times p_y)^{0.5})$ = **109.7** N/mm^2

Equivalent uniform moment factor - Section 4.3.6.6

Equivalent uniform moment factor for LTB m_{LT} = **1.000**

Buckling resistance moment - Section 4.3.6.4

Buckling resistance moment $M_b = p_b \times S_{eff}$ = **108.3** kNm

M_b / m_{LT} = **108.3** kNm

PASS - Buckling resistance moment exceeds design bending moment

Compression members - Section 4.7

Design compression force F_c = **122.2** kN

Effective length for major (x-x) axis buckling - Section 4.7.3

Effective length for buckling $L_{Ex} = L_x \times K_x$ = **16500** mm

Slenderness ratio - cl.4.7.2 $\lambda_x = L_{Ex} / r_{xx}$ = **149.064**

Compressive strength - Section 4.7.5

Limiting slenderness $\lambda_0 = 0.2 \times (\pi^2 \times E / p_y)^{0.5}$ = **15.099**

Strut curve - Table 23 b

Robertson constant α_x = **3.5**

Perry factor $\eta_x = \alpha_x \times (\lambda_x - \lambda_0) / 1000$ = **0.469**

Euler stress $p_{Ex} = \pi^2 \times E / \lambda_x^2$ = **91.1** N/mm²

$\phi_x = (p_y + (\eta_x + 1) \times p_{Ex}) / 2$ = **244.4** N/mm²

Compressive strength - Annex C.1 $p_{cx} = p_{Ex} \times p_y / (\phi_x + (\phi_x^2 - p_{Ex} \times p_y)^{0.5})$ = **78.9** N/mm²

Compression resistance - Section 4.7.4

Compression resistance - cl.4.7.4 $P_{cx} = A \times p_{cx}$ = **734.2** kN

PASS - Compression resistance exceeds design compression force

Effective length for minor (y-y) axis buckling - Section 4.7.3

Effective length for buckling $L_{Ey} = L_y \times K_y$ = **16500** mm

Slenderness ratio - cl.4.7.2 $\lambda_y = L_{Ey} / r_{yy}$ = **254.680**

Compressive strength - Section 4.7.5

Limiting slenderness $\lambda_0 = 0.2 \times (\pi^2 \times E / p_y)^{0.5}$ = **15.099**

Strut curve - Table 23 c

Robertson constant α_y = **5.5**

Perry factor $\eta_y = \alpha_y \times (\lambda_y - \lambda_0) / 1000$ = **1.318**

Euler stress $p_{Ey} = \pi^2 \times E / \lambda_y^2$ = **31.2** N/mm²

$\phi_y = (p_y + (\eta_y + 1) \times p_{Ey}) / 2$ = **213.6** N/mm²

Compressive strength - Annex C.1 $p_{cy} = p_{Ey} \times p_y / (\phi_y + (\phi_y^2 - p_{Ey} \times p_y)^{0.5})$ = **27.7** N/mm²

Compression resistance - Section 4.7.4

Compression resistance - cl.4.7.4 $P_{cy} = A \times p_{cy}$ = **258** kN

PASS - Compression resistance exceeds design compression force

Compression members with moments - Section 4.8.3

Comb.compression & bending check - cl.4.8.3.2 $F_c / (A \times p_y) + M / M_c$ = **0.134**

PASS - Combined bending and compression check is satisfied

Member buckling resistance - Section 4.8.3.3

Max major axis moment governing M_b $M_{LT} = M_x$ = **34.10** kNm

Equivalent uniform moment factor for major axis flexural buckling

m_x = **1.000**

m_y = **1.000**

Buckling resistance checks - cl.4.8.3.3.2 $F_c / P_{cx} + m_x \times M / M_c \times (1 + 0.5 \times F_c / P_{cx})$ = **0.272**

$F_c / P_{cy} + m_{LT} \times M_{LT} / M_b$ = **0.789**

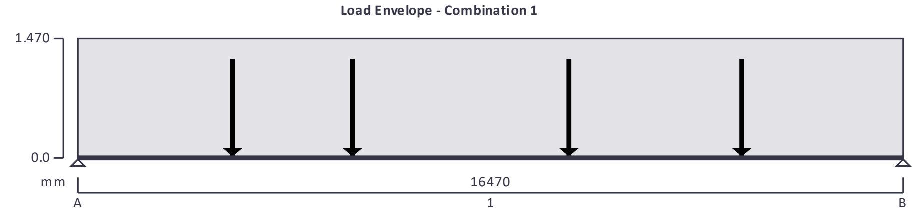
PASS - Member buckling resistance checks are satisfied

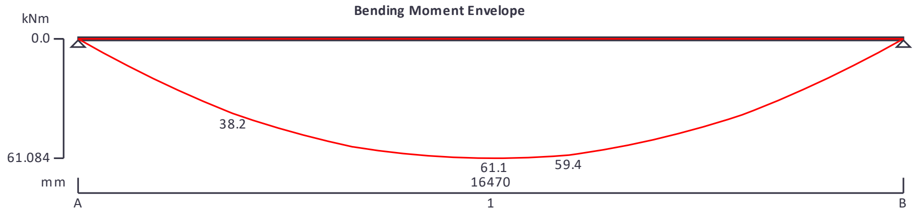
Tekla Tedds Train & Kemp 10 Kennington Park Place London SE11 4AS	Project 38 Frognal Lane				Job no. 20080	
	Calcs for 16.47m Prop				Start page no./Revision 1	
	Calcs by RH	Calcs date 13/05/2021	Checked by	Checked date	Approved by	Approved date

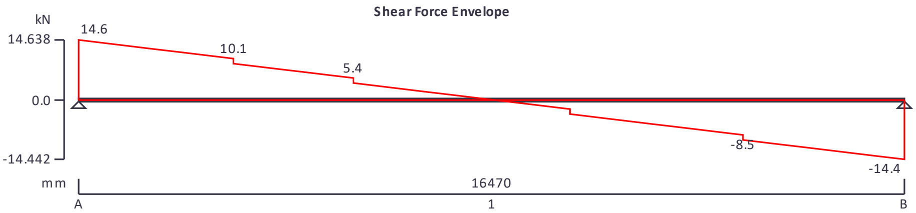
STEEL BEAM ANALYSIS & DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.07







Support conditions

Support A	Vertically restrained
	Rotationally free
Support B	Vertically restrained
	Rotationally free

Applied loading

Beam loads	Dead self weight of beam × 1
	Dead point load 0.87 kN at 3086 mm
	Dead point load 0.87 kN at 5480 mm
	Dead point load 0.87 kN at 9798 mm
	Dead point load 0.87 kN at 13250 mm

Load combinations

Load combination 1	Support A	Dead × 1.40
		Imposed × 1.60
		Dead × 1.40
		Imposed × 1.60
	Support B	Dead × 1.40

Imposed × 1.60

Analysis results

Maximum moment	M_{max} = **61.1** kNm	M_{min} = **0** kNm
Maximum shear	V_{max} = **14.6** kN	V_{min} = **-14.4** kN
Deflection	δ_{max} = **34.5** mm	δ_{min} = **0** mm
Maximum reaction at support A	R_{A_max} = **14.6** kN	R_{A_min} = **14.6** kN
Unfactored dead load reaction at support A	R_{A_Dead} = **10.5** kN	
Maximum reaction at support B	R_{B_max} = **14.4** kN	R_{B_min} = **14.4** kN
Unfactored dead load reaction at support B	R_{B_Dead} = **10.3** kN	

Section details

Section type — **UC 254x254x107 (BS4-1)**

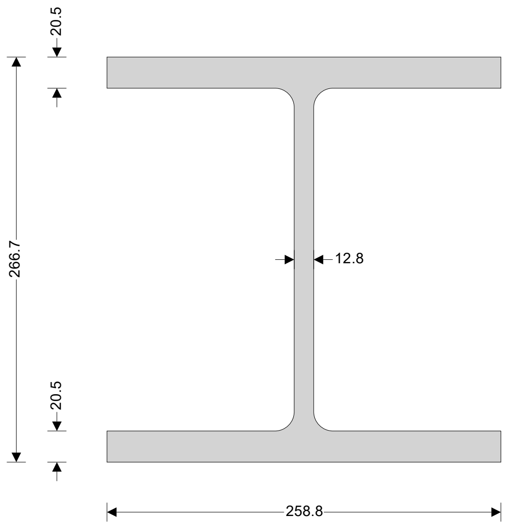
Steel grade — **S275**

From table 9: Design strength p_y

Thickness of element — max(T, t) = **20.5** mm

Design strength — p_y = **265** N/mm^2

Modulus of elasticity — E = **205000** N/mm^2



Lateral restraint

Span 1 has lateral restraint at supports only

Effective length factors

Effective length factor in major axis — K_x = **1.00**

Effective length factor in minor axis — K_y = **1.00**

Effective length factor for lateral-torsional buckling — $K_{LT.A}$ = **1.00**

$K_{LT.B}$ = **1.00**

Classification of cross sections - Section 3.5

$\varepsilon = \sqrt{[275 \text{ N/mm}^2 / p_y]}$ = **1.02**

Internal compression parts - Table 11

Depth of section — d = **200.3** mm

d / t = 15.4 × ε <= 80 × ε — Class 1 plastic

Outstand flanges - Table 11

Width of section — b = B / 2 = **129.4** mm

$b / T = 6.2 \times \varepsilon <= 9 \times \varepsilon$ Class 1 plastic

Section is class 1 plastic

Shear capacity - Section 4.2.3

Design shear force $F_v = \max(\text{abs}(V_{max}), \text{abs}(V_{min})) = \mathbf{14.6}$ kN

$d / t < 70 \times \varepsilon$

Web does not need to be checked for shear buckling

Shear area $A_v = t \times D = \mathbf{3414}$ mm^2

Design shear resistance $P_v = 0.6 \times p_y \times A_v = \mathbf{542.8}$ kN

PASS - Design shear resistance exceeds design shear force

Moment capacity - Section 4.2.5

Design bending moment $M = \max(\text{abs}(M_{s1\_max}), \text{abs}(M_{s1\_min})) = \mathbf{61.1}$ kNm

Moment capacity low shear - cl.4.2.5.2 $M_c = \min(p_y \times S_{xx}, 1.2 \times p_y \times Z_{xx}) = \mathbf{393.4}$ kNm

Effective length for lateral-torsional buckling - Section 4.3.5

Effective length for lateral torsional buckling $L_E = 1.0 \times L_{s1} = \mathbf{16470}$ mm

Slenderness ratio $\lambda = L_E / r_{yy} = \mathbf{249.824}$

Equivalent slenderness - Section 4.3.6.7

Buckling parameter $u = \mathbf{0.848}$

Torsional index $x = \mathbf{12.393}$

Slenderness factor $v = 1 / [1 + 0.05 \times (\lambda / x)^2]^{0.25} = \mathbf{0.465}$

Ratio - cl.4.3.6.9 $\beta_W = \mathbf{1.000}$

Equivalent slenderness - cl.4.3.6.7 $\lambda_{LT} = u \times v \times \lambda \times \sqrt{[\beta_W]} = \mathbf{98.593}$

Limiting slenderness - Annex B.2.2 $\lambda_{L0} = 0.4 \times (\pi^2 \times E / p_y)^{0.5} = \mathbf{34.951}$

λ_{LT} > λ_{L0} - Allowance should be made for lateral-torsional buckling

Bending strength - Section 4.3.6.5

Robertson constant $\alpha_{LT} = \mathbf{7.0}$

Perry factor $\eta_{LT} = \max(\alpha_{LT} \times (\lambda_{LT} - \lambda_{L0}) / 1000, 0) = \mathbf{0.445}$

Euler stress $p_E = \pi^2 \times E / \lambda_{LT}^2 = \mathbf{208.1}$ N/mm^2

$\phi_{LT} = (p_y + (\eta_{LT} + 1) \times p_E) / 2 = \mathbf{282.9}$ N/mm^2

Bending strength - Annex B.2.1 $p_b = p_E \times p_y / (\phi_{LT} + (\phi_{LT}^2 - p_E \times p_y)^{0.5}) = \mathbf{125.2}$ N/mm^2

Equivalent uniform moment factor - Section 4.3.6.6

Moment at quarter point of segment $M_2 = \mathbf{46.6}$ kNm

Moment at centre-line of segment $M_3 = \mathbf{61.1}$ kNm

Moment at three quarter point of segment $M_4 = \mathbf{45.9}$ kNm

Maximum moment in segment $M_{abs} = \mathbf{61.1}$ kNm

Maximum moment governing buckling resistance $M_{LT} = M_{abs} = \mathbf{61.1}$ kNm

Equivalent uniform moment factor for lateral-torsional buckling

$m_{LT} = \max(0.2 + (0.15 \times M_2 + 0.5 \times M_3 + 0.15 \times M_4) / M_{abs}, 0.44) = \mathbf{0.927}$

Buckling resistance moment - Section 4.3.6.4

Buckling resistance moment $M_b = p_b \times S_{xx} = \mathbf{185.8}$ kNm

$M_b / m_{LT} = \mathbf{200.4}$ kNm

PASS - Buckling resistance moment exceeds design bending moment

Check vertical deflection - Section 2.5.2

Consider deflection due to dead and imposed loads

Limiting deflection $\delta_{lim} = L_{s1} / 360 = \mathbf{45.75}$ mm

Maximum deflection span 1 $\delta = max(abs(\delta_{max}), abs(\delta_{min}))$ = **34.548** mm

PASS - Maximum deflection does not exceed deflection limit

STEEL MEMBER DESIGN (BS5950)

In accordance with BS5950-1:2000 incorporating Corrigendum No.1

TEDDS calculation version 3.0.07

Section details

Section type — **UC 254x254x107 (BS4-1)**

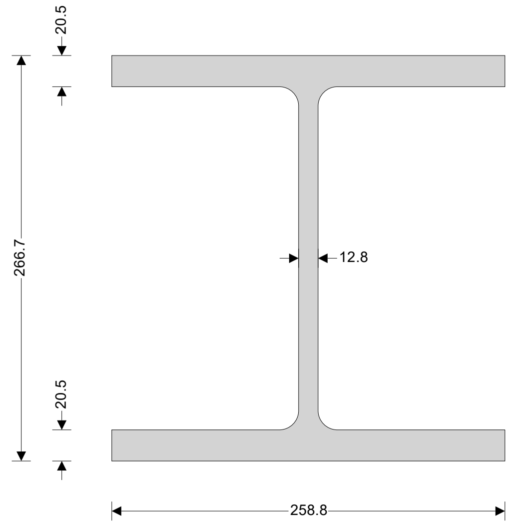
Steel grade — **S355**

From table 9: Design strength p_y

Thickness of element — max(T, t) = **20.5** mm

Design strength — p_y = **345** N/mm²

Modulus of elasticity — E = **205000** N/mm²



Lateral restraint

Distance between major axis restraints — L_x = **16500** mm

Distance between minor axis restraints — L_y = **16500** mm

Effective length factors

Effective length factor in major axis — K_x = **1.00**

Effective length factor in minor axis — K_y = **1.00**

Effective length factor for lateral-torsional buckling — K_{LT} = **1.00**

Classification of cross sections - Section 3.5

$\varepsilon = \sqrt{[275 \text{ N/mm}^2 / p_y]}$ = **0.89**

Internal compression parts - Table 11

Depth of section — d = **200.3** mm

Stress ratios — $r1 = \min(F_c / (d \times t \times p_{yw}), 1)$ = **0.245**

$r2 = F_c / (A \times p_{yw})$ = **0.046**

$d / t = 17.5 \times \varepsilon <= \max(80 \times \varepsilon / (1 + r1), 40 \times \varepsilon)$ — Class 1 plastic

Outstand flanges - Table 11

Width of section — b = B / 2 = **129.4** mm

$b / T = 7.1 \times \varepsilon <= 9 \times \varepsilon$ — Class 1 plastic

Section is class 1 plastic

Shear capacity - Section 4.2.3

Design shear force $F_{y,v}$ = **12.4** kN

$d / t < 70 \times \varepsilon$

Web does not need to be checked for shear buckling

Shear area $A_v = t \times D$ = **3414** mm^2

Design shear resistance $P_{y,v} = 0.6 \times p_y \times A_v$ = **706.6** kN

PASS - Design shear resistance exceeds design shear force

Shear capacity - Section 4.2.3

Design shear force $F_{x,v}$ = **0** kN

Moment capacity - Section 4.2.5

Design bending moment M = **61.1** kNm

Moment capacity low shear - cl.4.2.5.2 $M_c = \min(p_y \times S_{xx}, 1.2 \times p_y \times Z_{xx})$ = **512.1** kNm

Effective length for lateral-torsional buckling - Section 4.3.5

Effective length for lateral torsional buckling $L_E = 1.0 \times L_y$ = **16500** mm

Slenderness ratio $\lambda = L_E / r_{yy}$ = **250.279**

Equivalent slenderness - Section 4.3.6.7

Buckling parameter u = **0.848**

Torsional index x = **12.393**

Slenderness factor $v = 1 / [1 + 0.05 \times (\lambda / x)^2]^{0.25}$ = **0.465**

Ratio - cl.4.3.6.9 β_W = **1.000**

Equivalent slenderness - cl.4.3.6.7 $\lambda_{LT} = u \times v \times \lambda \times \sqrt{[\beta_W]}$ = **98.687**

Limiting slenderness - Annex B.2.2 $\lambda_{L0} = 0.4 \times (\pi^2 \times E / p_y)^{0.5}$ = **30.632**

$\lambda_{LT} > \lambda_{L0}$ - Allowance should be made for lateral-torsional buckling

Bending strength - Section 4.3.6.5

Robertson constant α_{LT} = **7.0**

Perry factor $\eta_{LT} = \max(\alpha_{LT} \times (\lambda_{LT} - \lambda_{L0}) / 1000, 0)$ = **0.476**

Euler stress $p_E = \pi^2 \times E / \lambda_{LT}^2$ = **207.7** N/mm^2

$\phi_{LT} = (p_y + (\eta_{LT} + 1) \times p_E) / 2$ = **325.9** N/mm^2

Bending strength - Annex B.2.1 $p_b = p_E \times p_y / (\phi_{LT} + (\phi_{LT}^2 - p_E \times p_y)^{0.5})$ = **140.1** N/mm^2

Equivalent uniform moment factor - Section 4.3.6.6

Equivalent uniform moment factor for LTB m_{LT} = **1.000**

Buckling resistance moment - Section 4.3.6.4

Buckling resistance moment $M_b = p_b \times S_{xx}$ = **208** kNm

M_b / m_{LT} = **208** kNm

PASS - Buckling resistance moment exceeds design bending moment

Compression members - Section 4.7

Design compression force F_c = **222.8** kN

Effective length for major (x-x) axis buckling - Section 4.7.3

Effective length for buckling $L_{Ex} = L_x \times K_x$ = **16500** mm

Slenderness ratio - cl.4.7.2 $\lambda_x = L_{Ex} / r_{xx}$ = **145.618**

Compressive strength - Section 4.7.5

Limiting slenderness $\lambda_0 = 0.2 \times (\pi^2 \times E / p_y)^{0.5}$ = **15.316**

Strut curve - Table 23 b

Robertson constant α_x = **3.5**

Perry factor $\eta_x = \alpha_x \times (\lambda_x - \lambda_0) / 1000$ = **0.456**

Euler stress $p_{Ex} = \pi^2 \times E / \lambda_x^2$ = **95.4** N/mm^2

$\phi_x = (p_y + (\eta_x + 1) \times p_{Ex}) / 2$ = **242** N/mm^2

Compressive strength - Annex C.1 $p_{cx} = p_{Ex} \times p_y / (\phi_x + (\phi_x^2 - p_{Ex} \times p_y)^{0.5})$ = **81.9** N/mm^2

Compression resistance - Section 4.7.4

Compression resistance - cl.4.7.4 $P_{cx} = A \times p_{cx}$ = **1116.6** kN

PASS - Compression resistance exceeds design compression force

Effective length for minor (y-y) axis buckling - Section 4.7.3

Effective length for buckling $L_{Ey} = L_y \times K_y$ = **16500** mm

Slenderness ratio - cl.4.7.2 $\lambda_y = L_{Ey} / r_{yy}$ = **250.279**

Compressive strength - Section 4.7.5

Limiting slenderness $\lambda_0 = 0.2 \times (\pi^2 \times E / p_y)^{0.5}$ = **15.316**

Strut curve - Table 23 c

Robertson constant α_y = **5.5**

Perry factor $\eta_y = \alpha_y \times (\lambda_y - \lambda_0) / 1000$ = **1.292**

Euler stress $p_{Ey} = \pi^2 \times E / \lambda_y^2$ = **32.3** N/mm^2

$\phi_y = (p_y + (\eta_y + 1) \times p_{Ey}) / 2$ = **209.5** N/mm^2

Compressive strength - Annex C.1 $p_{cy} = p_{Ey} \times p_y / (\phi_y + (\phi_y^2 - p_{Ey} \times p_y)^{0.5})$ = **28.5** N/mm^2

Compression resistance - Section 4.7.4

Compression resistance - cl.4.7.4 $P_{cy} = A \times p_{cy}$ = **389.2** kN

PASS - Compression resistance exceeds design compression force

Compression members with moments - Section 4.8.3

Comb.compression & bending check - cl.4.8.3.2 $F_c / (A \times p_y) + M / M_c$ = **0.167**

PASS - Combined bending and compression check is satisfied

Member buckling resistance - Section 4.8.3.3

Max major axis moment governing M_b $M_{LT} = M_x$ = **61.10** kNm

Equivalent uniform moment factor for major axis flexural buckling

m_x = **1.000**

m_y = **1.000**

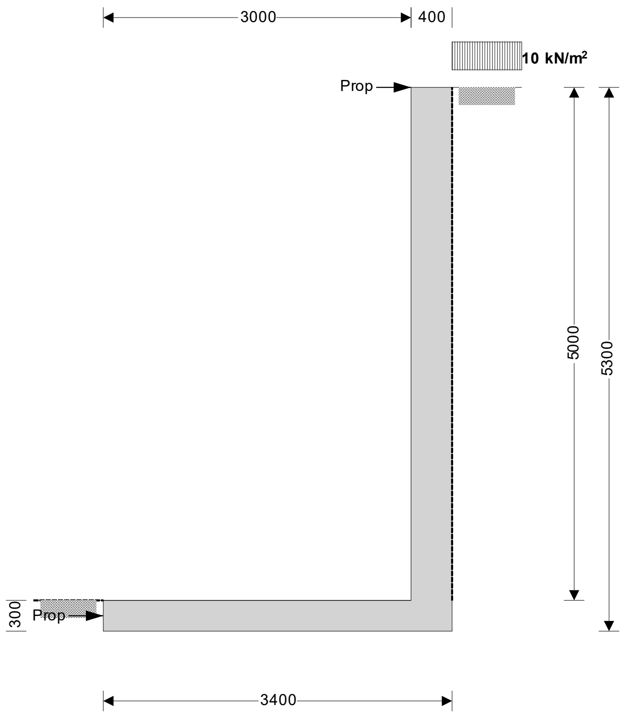
Buckling resistance checks - cl.4.8.3.3.2 $F_c / P_{cx} + m_x \times M / M_c \times (1 + 0.5 \times F_c / P_{cx})$ = **0.331**

$F_c / P_{cy} + m_{LT} \times M_{LT} / M_b$ = **0.866**

PASS - Member buckling resistance checks are satisfied

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **5000** mm
Thickness of wall stem	t_{wall} = **400** mm
Length of toe	l_{toe} = **3000** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **3400** mm
Thickness of base	t_{base} = **300** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **900** mm
Thickness of downstand	t_{ds} = **300** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **5300** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **5300** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **21.0** kN/m^3

Saturated density of retained material γ_s = **23.0** kN/m^3

Design shear strength ϕ' = **24.2** deg

Angle of wall friction δ = **18.6** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3

Design shear strength ϕ'_b = **24.2** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

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

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi') = \mathbf{0.590}$

Loading details

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

Applied vertical dead load on wall W_{dead} = **0.0** kN/m

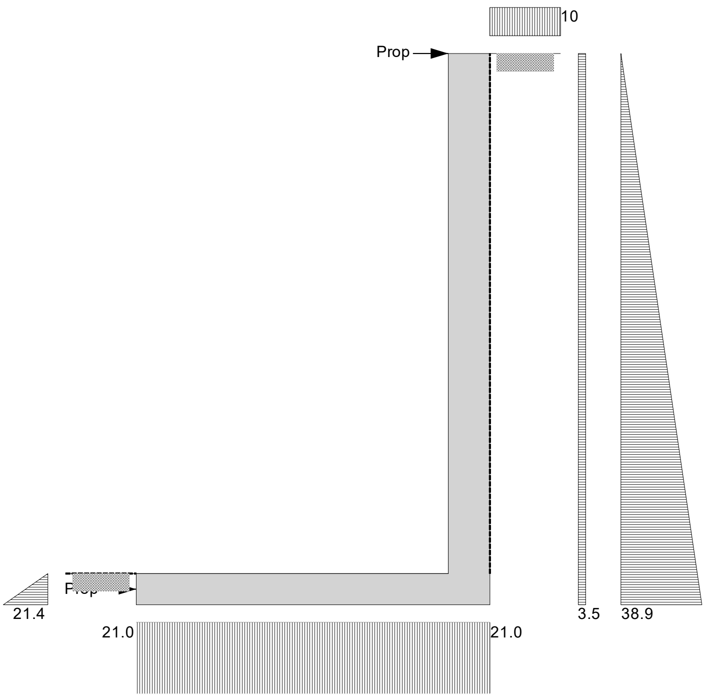
Applied vertical live load on wall W_{live} = **0.0** kN/m

Position of applied vertical load on wall l_{load} = **0** mm

Applied horizontal dead load on wall F_{dead} = **0.0** kN/m

Applied horizontal live load on wall F_{live} = **0.0** kN/m

Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **47.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **24.1** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base}$ = **71.3** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff}$ = **18.5** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **103.2** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a}$ = **121.7** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.2** kN/m

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

F_{prop} = **94.5** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **49.1** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **182.3** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a}$ = **231.4** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **151** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **40.9** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base}$ = **192** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **71.3** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **1700** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **21** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **21** kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **28.437** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **66.091** kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.08

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **66.1** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **33.7** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f}$ = **99.8** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **50** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **243.7** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **293.7** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.5** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **255.6** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **132.6** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **430.5** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f}$ = **563.1** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **211.5** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **57.3** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f}$ = **268.7** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **99.8** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **1700** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **29.3** kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **29.3** kN/m²

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0 \text{ kN/m}^2)$ = **29.3** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **29.3** kN/m²

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **29.3** kN/m²

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **82.641** kN/m

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f}$ = **172.975** kN/m

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

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

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

Base details

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

Cover to reinforcement in toe c_{toe} = **50** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **88** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **29.7** kN/m

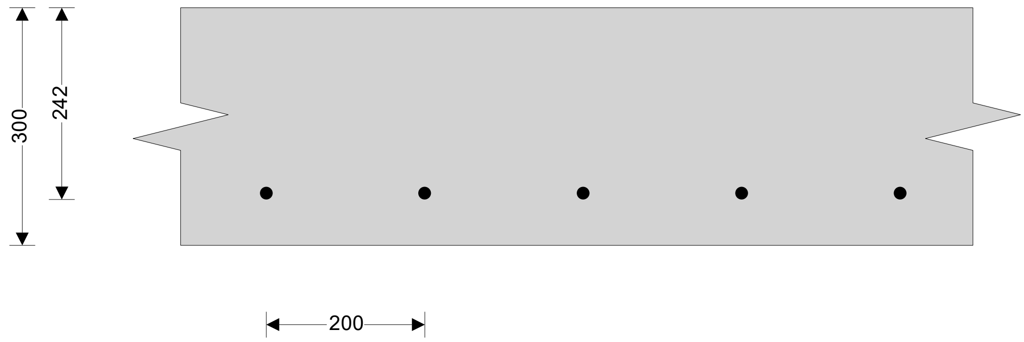
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **58.3** kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **150.3** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **50.7** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **99.5** kNm/m



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **242.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.042**

Compression reinforcement is not required

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

z_{toe} = **230** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **995** mm^2/m

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

Area of tension reinforcement required $A_{s\_toe\_req} = \mathrm{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **995** mm^2/m

Reinforcement provided **16 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **1005** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.241** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.625** N/mm^2

v_{toe} < v_{c_toe} - No shear reinforcement required

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

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

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

Wall details

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

Cover to reinforcement in stem c_{stem} = **50** mm

Cover to reinforcement in wall c_{wall} = **50** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **47.2** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **216.9** kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **29.5** kN/m

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **170.8** kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f}$ = **200.4** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **30.4** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **157** kNm/m

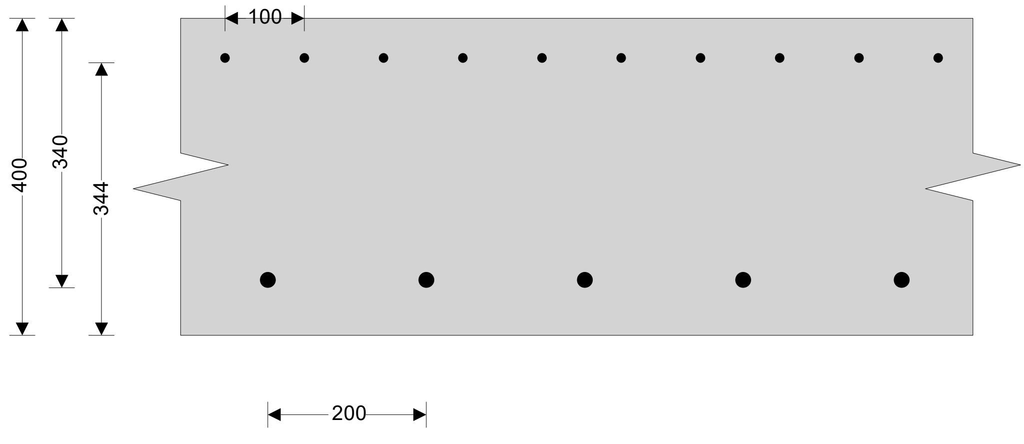
Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **187.4** kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **17.1** kNm/m

Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2)/(5 \times L^3) - 0.577^2/3]$ = **63.3**
kNm/m

Total moment for wall design $M_{wall} = M_{w\_sur} + M_{w\_m\_a}$ = **80.4** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **340.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.041**

Compression reinforcement is not required

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

z_{stem} = **323** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **1334** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **520** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **1334** mm²/m

Reinforcement provided **20 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **1571** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.589** N/mm²

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2$ = **5.000** N/mm²

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.595** N/mm²

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

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **344.0** mm

Constant $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu})$ = **0.017**

Compression reinforcement is not required

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

z_{wall} = **327** mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall})$ = **566** mm²/m

Minimum area of tension reinforcement $A_{s\_wall\_min} = k \times b \times t_{wall}$ = **520** mm²/m

Area of tension reinforcement required $A_{s\_wall\_req} = Max(A_{s\_wall\_des}, A_{s\_wall\_min})$ = **566** mm²/m

Reinforcement provided **12 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov}$ = **1131** mm²/m

PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas}$ = **20**

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **283.0** N/mm²

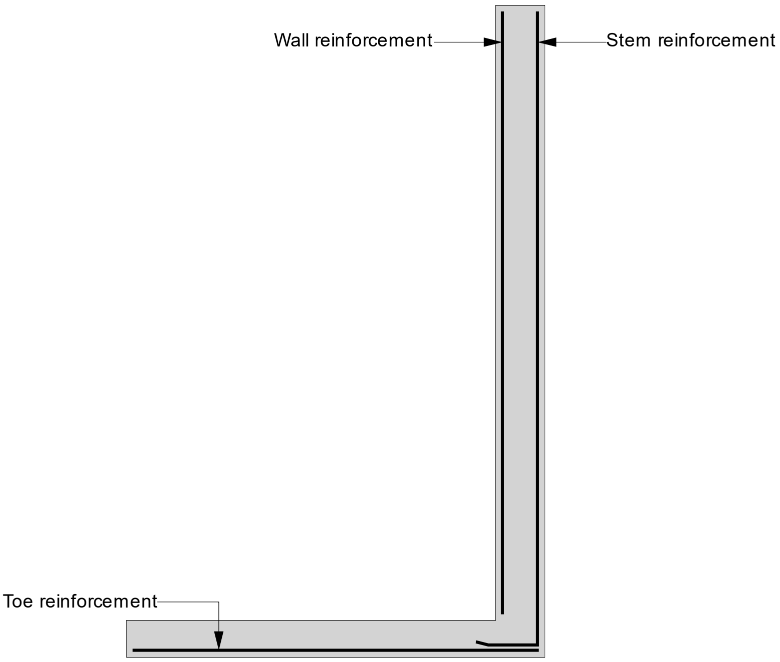
Modification factor $factor_{tens} = min(0.55 + (477 N/mm^2 - f_s)/(120 \times (0.9 N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.19**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **23.82**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **14.71**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 200 mm centres - (1005 mm^2/m)
Wall bars - 12 mm dia.@ 100 mm centres - (1131 mm^2/m)
Stem bars - 20 mm dia.@ 200 mm centres - (1571 mm^2/m)

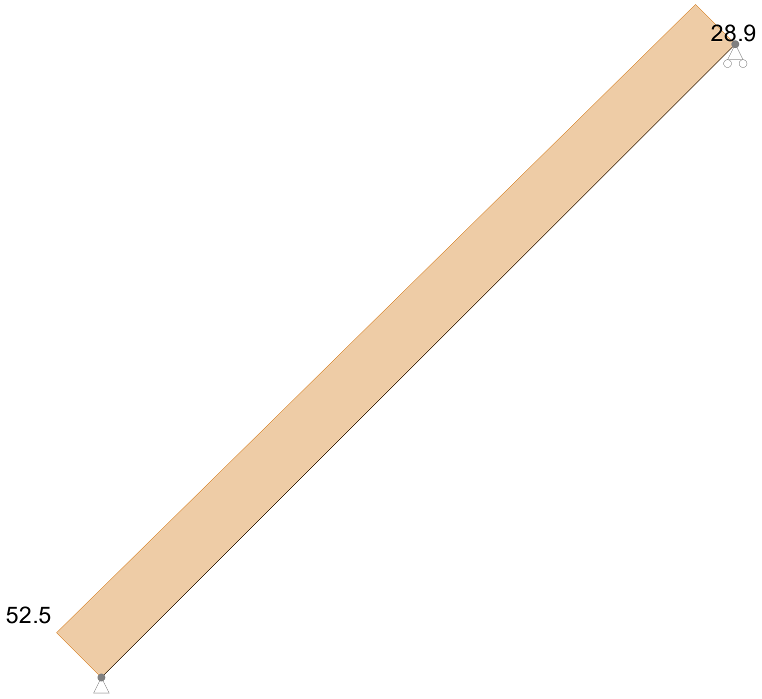
ANALYSIS

Tedds calculation version 1.0.36

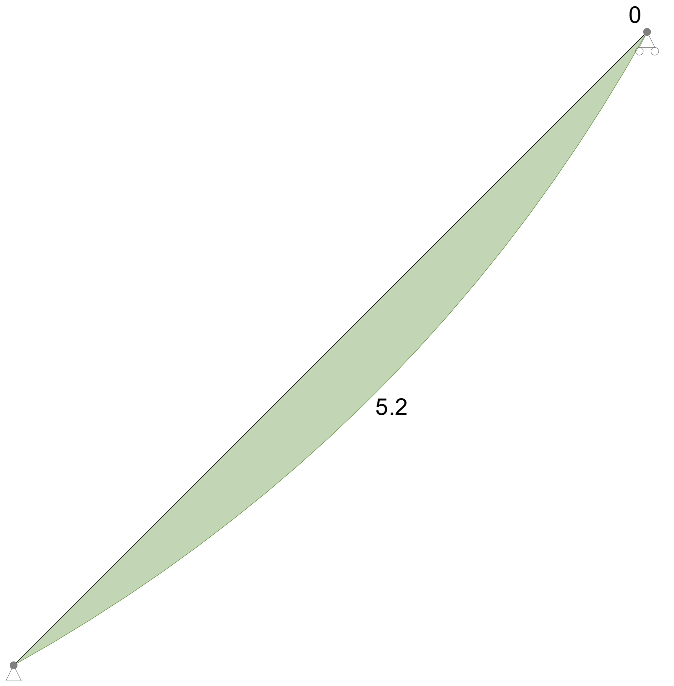
Results

Forces

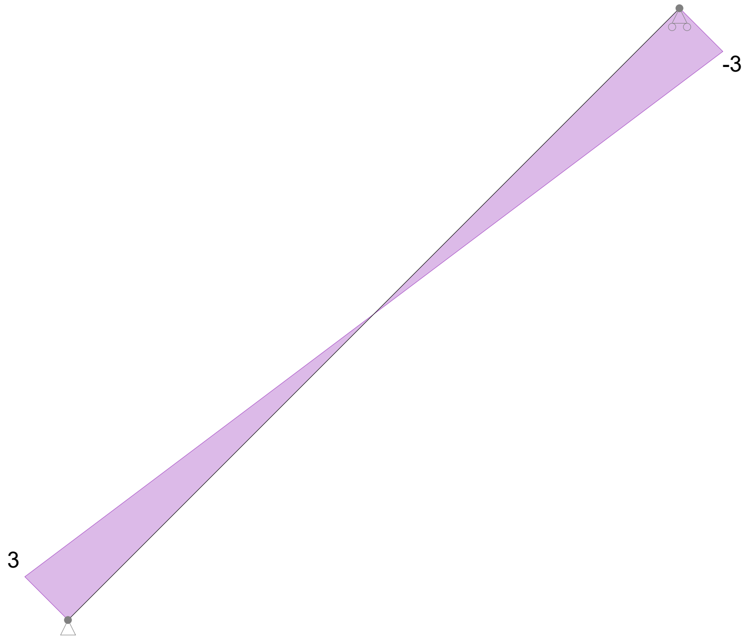
All combinations - Axial force envelope (kN)



1.4D + 1.6I + 1.6RI (Strength) - Moment (kNm)

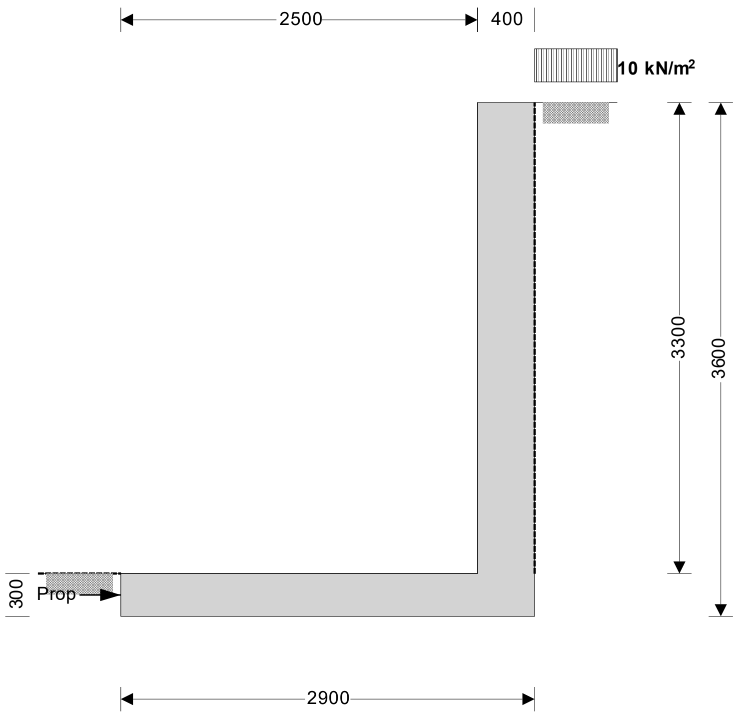


1.4D + 1.6I + 1.6RI (Strength) - Shear (kN)



RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.08



Wall details

Retaining wall type	**Cantilever propped at base**
Height of retaining wall stem	h_{stem} = **3300** mm
Thickness of wall stem	t_{wall} = **400** mm
Length of toe	l_{toe} = **2500** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2900** mm
Thickness of base	t_{base} = **300** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **900** mm
Thickness of downstand	t_{ds} = **300** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3600** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3600** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **21.0** kN/m^3

Saturated density of retained material γ_s = **23.0** kN/m^3

Design shear strength ϕ' = **24.2** deg

Angle of wall friction δ = **18.6** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3

Design shear strength ϕ'_b = **24.2** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

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

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

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

Applied vertical dead load on wall W_{dead} = **0.0** kN/m

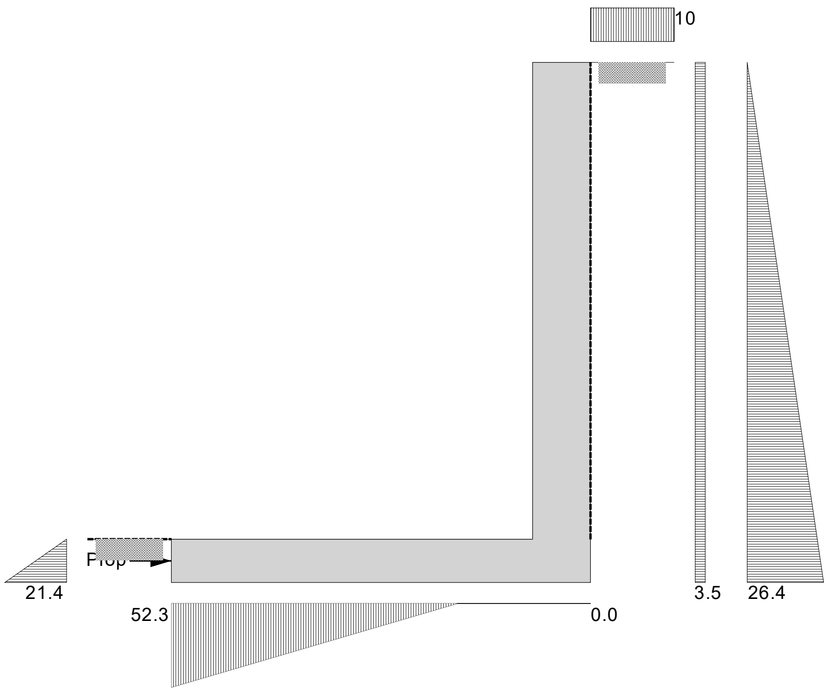
Applied vertical live load on wall W_{live} = **0.0** kN/m

Position of applied vertical load on wall l_{load} = **0** mm

Applied horizontal dead load on wall F_{dead} = **0.0** kN/m

Applied horizontal live load on wall F_{live} = **0.0** kN/m

Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **31.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **20.5** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base}$ = **51.7** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \cos(90 - \alpha + \delta) \times \text{Surcharge} \times h_{eff}$ = **12.6** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **47.6** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a}$ = **60.2** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.2** kN/m

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

F_{prop} = **39.6** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **22.7** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **57.1** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a}$ = **79.8** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **84.1** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **29.8** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base}$ = **113.9** kNm/m

Check bearing pressure

Total moment for bearing $M_{total} = M_{rest} - M_{ot}$ = **34.1** kNm/m

Total vertical reaction $R = W_{total}$ = **51.7** kN/m

Distance to reaction $x_{bar} = M_{total} / R$ = **659** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **791** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe} = R / (1.5 \times x_{bar})$ = **52.3** kN/m²

Bearing pressure at heel $p_{heel} = 0 \text{ kN/m}^2$ = **0** kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.08

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **43.6** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **28.7** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f}$ = **72.4** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times h_{eff}$ = **34** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **112.4** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **146.4** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.5** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f}) \times \tan(\delta_b), 0\ \text{kN/m})$

F_{prop_f} = **117.6** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **61.2** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **134.9** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f}$ = **196.1** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **117.8** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **41.7** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f}$ = **159.4** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **-36.6** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **72.4** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **-506** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **1956** mm

WARNING - Beyond scope of calculation

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **-95.3** kN/m^2

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

Rate of change of base reaction $\text{rate} = p_{toe\_f} / (3 \times x_{bar\_f})$ = **62.69** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0\ \text{kN/m}^2)$ = **0** kN/m^2

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

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0\ \text{kN/m}^2)$ = **0** kN/m^2

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

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

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

Base details

Minimum area of reinforcement $k = \mathbf{0.13}$ %

Cover to reinforcement in toe $c_{toe} = \mathbf{50}$ mm

Calculate shear for toe design

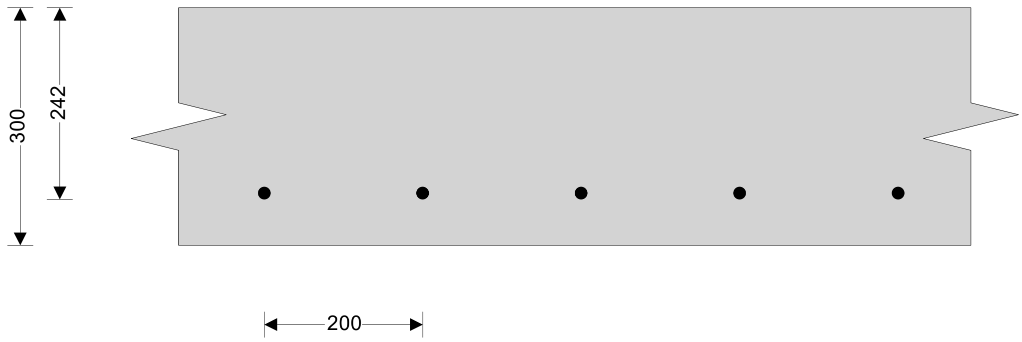
Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{24.8}$ kN/m

Total shear for toe design $V_{toe} = V_{toe\_wt\_base} = \mathbf{24.8}$ kN/m

Calculate moment for toe design

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{36.1}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_wt\_base} = \mathbf{36.1}$ kNm/m



Check toe in bending

Width of toe $b = \mathbf{1000}$ mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{242.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.015}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{230}$ mm

Area of tension reinforcement required $As_{toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{361}$ mm²/m

Minimum area of tension reinforcement $As_{toe\_min} = k \times b \times t_{base} = \mathbf{390}$ mm²/m

Area of tension reinforcement required $As_{toe\_req} = \mathrm{Max}(As_{toe\_des}, As_{toe\_min}) = \mathbf{390}$ mm²/m

Reinforcement provided **16 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $As_{toe\_prov} = \mathbf{1005}$ mm²/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.102}$ N/mm²

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \mathrm{N/mm^2})}, 5) \times 1\ \mathrm{N/mm^2} = \mathbf{5.000}$ N/mm²

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_toe} = \mathbf{0.625}$ N/mm²

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

<u>Design of reinforced concrete retaining wall stem (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}$ N/mm²

Characteristic strength of reinforcement $f_y = \mathbf{500}$ N/mm²

Wall details

Minimum area of reinforcement $k = \mathbf{0.13}$ %

Cover to reinforcement in stem c_{stem} = **50** mm

Cover to reinforcement in wall c_{wall} = **50** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **31.2** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **94.5** kN/m

Calculate shear for stem design

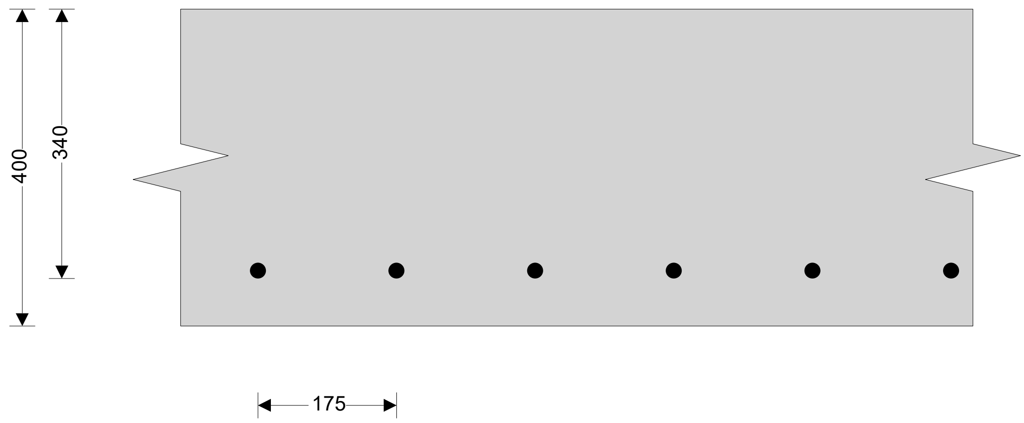
Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} - F_{prop\_f}$ = **8.1** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **56.1** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **118.1** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **174.2** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **340.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.038**

Compression reinforcement is not required

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

z_{stem} = **323** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **1240** mm²/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **520** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **1240** mm²/m

Reinforcement provided **20 mm dia.bars @ 175 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **1795** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.024** N/mm²

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\text{ N/mm}^2)}, 5) \times 1\text{ N/mm}^2$ = **5.000** N/mm²

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.622** N/mm²

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

Check retaining wall deflection

Basic span/effective depth ratio ratio_{bas} = **7**

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **230.2** N/mm^2

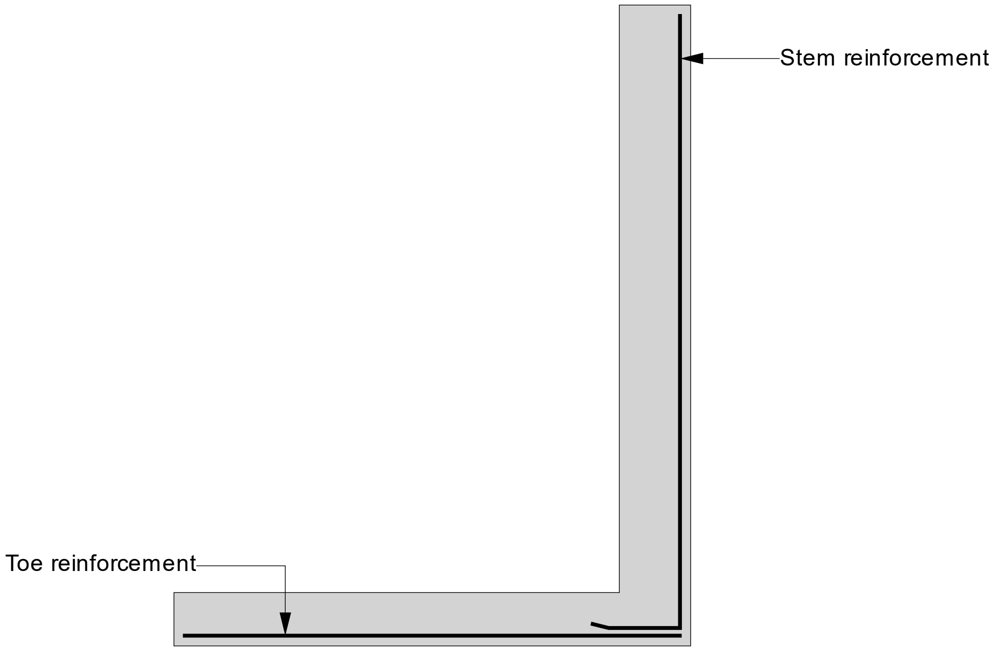
Modification factor $factor_{tens} = \min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.40**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **9.83**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **9.71**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 200 mm centres - (1005 mm^2/m)
Stem bars - 20 mm dia.@ 175 mm centres - (1795 mm^2/m)