Structural Calculations

for a proposed new basement at

10, Downside Crescent

Belsize Park, London

NW3

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Structural Calculations

for

10, Downside Crescent
Belsize Park, London NW3
for

Asif Noor and Sabina Khan
10 Downside Crescent, London
NW3 2AP

Job No 1411

Rev	Date	Notes
-	01.05.18	First issue

CONTENTS

1. CALCULATION PLAN

This report contains the structural engineering initial calculations for a proposed new basement at No.10 Downside Crescent.

The development consists of a new basement built mostly under an existing semi-detached house and partially under a new rear extension. The extension over the basement will be single storey with flat roof. The access to the new basement and rear extension will be provided creating a new opening in the existing building back wall and a new flight under the main stair at ground floor. At the ground floor of the main building are also proposed internal alteration and demolition of existing partitions.

1.1. SUMMARY OF STRUCTURE

Proposed plan area – extension

Maximum plan dimensions	14.7m by 8.9m, say
Footprint area	114m^2
Storeys	Basement, Ground, First & Second floor
Rear extension maximum height	3.6m over ground level
Basement maximum depth	3.5m below ground level

1.2. IMPOSED LOADS

The following imposed loads have been used

Typical imposed loads on pitched roofs	0.75 kN/m^2
Typical imposed loads on floors	1.50 kN/m^2
Partitions loads on floors (as imposed loads)	1.00 kN/m^2
Typical imposed loads on flat roofs allowing for maintenance	1.50 kN/m^2

1.3. REAR EXTENSION AND BASEMENT

The basement box will be realized with reinforced concrete walls and slabs. Rear extension walls at ground floor walls will be constructed as cavity block wall and the roof will be mainly built in timber elements and steel beams.

2. RESOURCES

2.1 CODES & REFERENCES

BS6399 Pt1	Loadings for buildings. Code of practice for dead and imposed loads.
BS6399 Pt2	Loadings for buildings. Code of practice for wind loads.
BS6399 Pt3	Loadings for buildings. Code of practice for imposed roof loads.
BS5269 Pt2	Structural use of Timber. Code of practice for permissible stress design, materials and workmanship.
BS5628 Pt1	Use of masonry. Structural use of unreinforced masonry.
BS5950 Pt1	Structural use of steelwork in building. Code of practice for design in simple and continuous construction hot rolled sections.
BS8110 Pt1	Structural use of concrete

Manual for the design of plain masonry in building structures – The Institution of Structural Engineers. July 1997.

2.2 SOFTWARE

Tekla Structural Designer suite of design and analysis tools.

Existing pitched roof

Dead	Tiles		0.77 kN/m^2
	Battens and felt		0.05 kN/m^2
	Rafters		0.15 kN/m^2
	Insulation		0.01 kN/m^2
	Services		0.05 kN/m^2
	Plasterboard and skim coat		0.15 kN/m^2
			1.18 kN/m^2
	Roof Angle	51 °	1.88 kN/m^2
Imposed			0.75 kN/m^2

Existing typical floor

Dead	Finishes	0.15 kN/m^2
	Boarding	0.14 kN/m^2
	Joists	0.15 kN/m^2
	Insulation	0.05 kN/m^2
	Services	0.05 kN/m^2
	Lath and plaster	0.25 kN/m^2
		0.79 kN/m^2
Dead with tiles as finishes		0.96 kN/m^2
Imposed		1.50 kN/m^2
	Partitions	1.00 kN/m^2
		2.50 kN/m^2

External brick wall

Dead	External render	0.60 kN/m^2
	215mm brickwork	4.73 kN/m^2
	Plaster	0.25 kN/m^2
		5.58 kN/m^2

Internal loadbearing stud walls

Dead	Lath and plaster (both sides)	0.50 kN/m^2
	Studs and blocking	0.15 kN/m^2
		0.65 kN/m^2

Internal brick walls

Dead	Lath and plaster (both sides)	0.50 kN/m^2
	102.5mm brickwork	2.24 kN/m^2
		2.74 kN/m^2

Proposed ground floor slab

Dead	Finishes	0.30 kN/m^2
	Screed 50mm	1.00 kN/m^2
	Insulation	0.05 kN/m^2
	200mm slab	4.80 kN/m^2
	Services	0.15 kN/m^2
	Allowance for possible down-stand beams	0.50 kN/m^2
		6.80 kN/m^2
Patio	Stone slab as finishes	7.25 kN/m^2
Imposed		1.50 kN/m^2
	Partitions	1.00 kN/m^2
		2.50 kN/m^2

Proposed basement floor slab

Dead	Finishes	0.15 kN/m^2
	Screed	1.80 kN/m^2
	Insulation	0.05 kN/m^2
	400mm slab	9.60 kN/m^2
	Services	0.15 kN/m^2
		11.75 kN/m^2
Imposed		1.50 kN/m^2
	Partitions	1.00 kN/m^2
		2.50 kN/m^2

Proposed flat roof

Dead	Asphalt	0.40 kN/m^2
	Boarding	0.14 kN/m^2
	Insulation	0.05 kN/m^2
	Joists	0.15 kN/m^2
	Services	0.05 kN/m^2
	Plasterboard and skim coat	0.15 kN/m^2
		0.94 kN/m^2
Imposed (allowing for maintenance of structure above)		1.50 kN/m^2

Glazing

Dead	Glazing (Double)	0.65 kN/m^2
	Framing	0.20 kN/m^2
		0.85 kN/m^2
Imposed (for horizontal glazing accounting for snow)		0.75 kN/m^2

Proposed external wall

Dead	External render	0.60 kN/m^2
	100mm blockwork	1.50 kN/m^2
	Insulation	0.05 kN/m^2
	100mm block work	1.50 kN/m^2
	Plasterboard and skim coat	0.15 kN/m^2
		3.80 kN/m^2

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
Retaining wall in rear extension toward No.12										
Assumed load at foundation level of rear extension wall at No.12										
Flat roof/terrace @ N.12		0.94	1.50	2000			1.88	3.00		
External wall SW		5.58		3200			17.86			
TOT							19.74	3.00		

Assuming a distribution of the load at 45degree and a distance between this wall and the new retaining wall of 2m we can consider the following surcharge at 2.2m depth (refer to image below)

(DL + LL) / (2m * 2) = 5.68 kN/m2

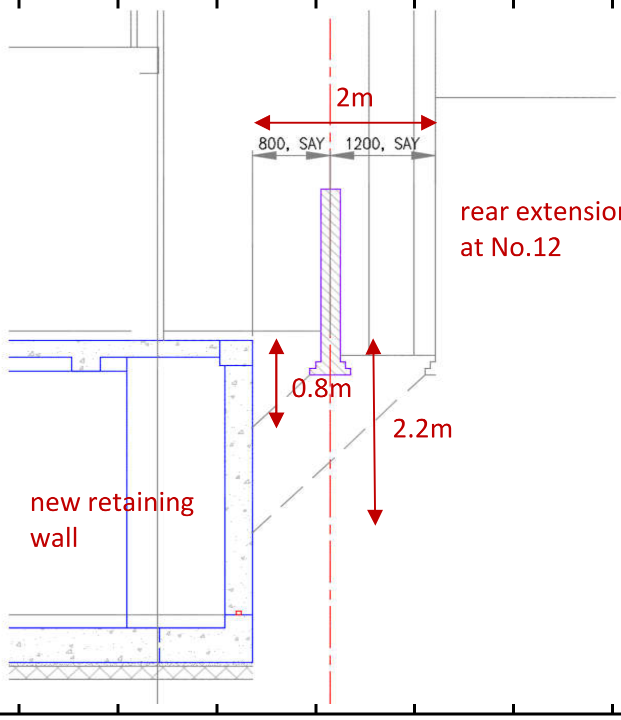
<u>Assumed load at foundation level of party wall with No.12</u>

External wall SW		4.73		2100			9.93			

Assuming a distribution of the load at 45degree and a distance between this wall and the new retaining wall of 0.8m we can consider the following surcharge at 1m depth(refer to image below)

(DL + LL) / (0.8m * 2) = 6.21 kN/m2

For the retaining wall design will be considered a surcharge of 12 kN/m2.



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Calculations: Loads on elements	Designed: ab	Date: 05/04/2018	Ckd: -

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN

Retaining wall under main building toward No.12

Assumed load at foundation level of external wall at No.12

Beam & Load description	Span mm	Area loads DL kN/m²	Area loads LL kN/m²	Width mm	Location from mm	Location to mm	UDL DL kN/m	UDL LL kN/m	Point loads DL kN	Point loads LL kN
roof		1.18	0.75	2000			2.36	1.50		
attic		0.79	2.50	2000			1.58	5.00		
wall SW at "f		4.98		3000			14.94	0.00		
2F		0.79	2.50	2000			1.58	5.00		
wall SW at 1F		4.98		3000			14.94	0.00		
1F		0.79	2.50	2000			1.58	5.00		
wall SW at GF		7.51		3000			22.53	0.00		
TOT							59.51	16.50		

Assuming a distribution of the load at 45degree and a distance between this wall and the new retaining wall of 2.4m we can consider the following surcharge at 2.7m depth (refer to image below)

(DL + LL) / (2m * 2) = 19.00 kN/m2

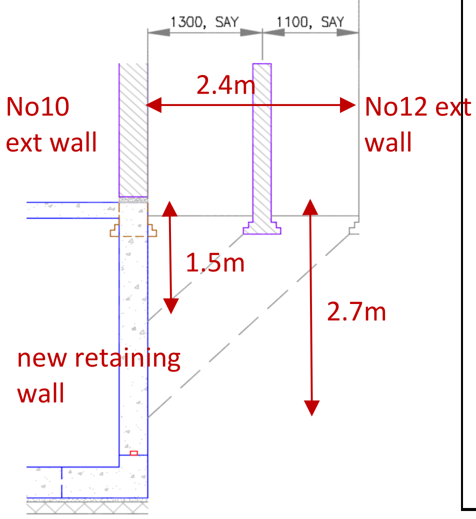
Assumed load at foundation level of party wall with No.12

Beam & Load description	Span mm	Area loads DL kN/m²	Area loads LL kN/m²	Width mm	Location from mm	Location to mm	UDL DL kN/m	UDL LL kN/m	Point loads DL kN	Point loads LL kN
External wall SW		4.73		2100			9.93			

Assuming a distribution of the load at 45degree and a distance between this wall and the new retaining wall of 1.3m we can consider the following surcharge at 1.5m depth (refer to image below)

(DL + LL) / (1.3m * 2) = 3.82 kN/m2

For the retaining wall design will be considered a conservative surcharge of 25 kN/m2 at the top.



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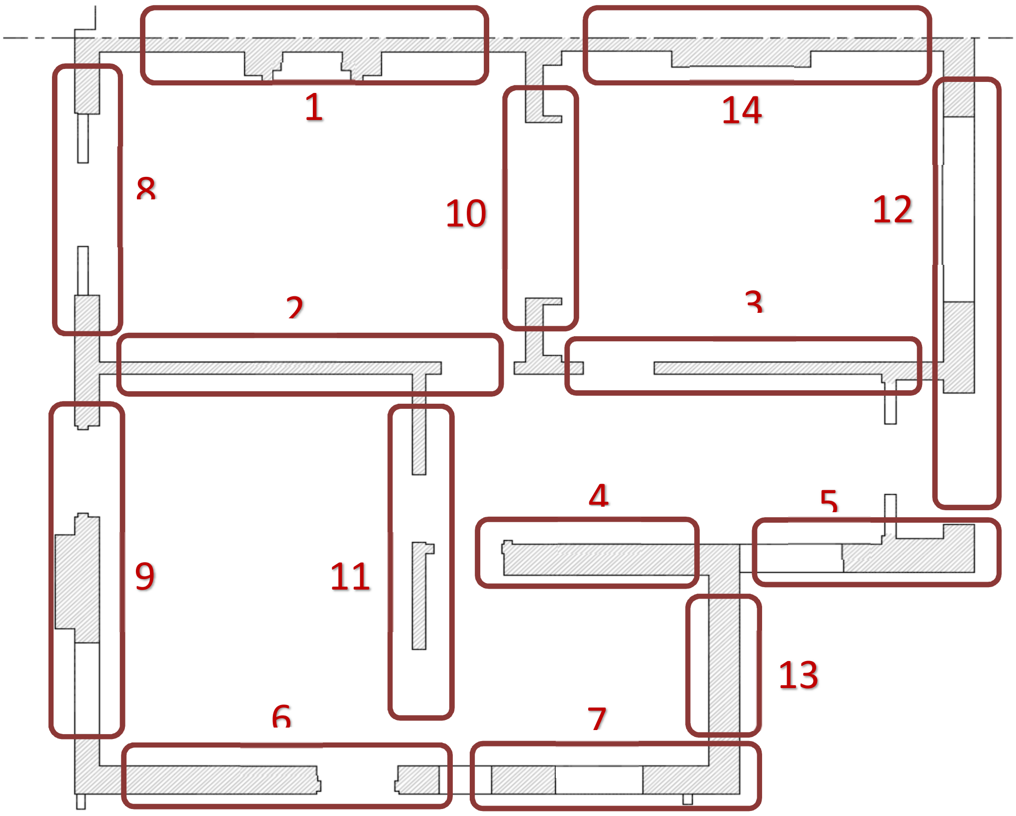
Calculations: Existing loads take down	Designed: ab	Date: 05/04/2018	Ckd: -

Picture below shows existing loaded walls at ground floor



WALL / PIER	DEAD LOAD kN/m	IMPOSED LOAD kN/m
1	73.00	4.00
2	17.00	4.00
3	11.00	2.00
4	50.00	4.00
5	50.00	6.00
6	46.00	2.00
7	36.00	4.00
8	41.00	14.00
9	40.00	10.00
10	20.00	24.00
11	24.00	20.00
12	66.00	13.00
13	38.00	5.00
14	59.00	4.00

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Calculations: Existing loads take down	Designed: ab	Date: 05/04/2018	Ckd: -

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
WALL 1										
(assumed 330 thk party wall)										
roof (both side)		1.88	0.75	2000			3.75	1.50		
2F (both side)		0.79	2.50	350			0.28	0.88		
1F (both side)		0.79	2.50	350			0.28	0.88		
party wall SW		7.76		8800			68.29	0.00		
							72.59	3.25		
WALL 2										
(assumed 103 thk brick wall)										
roof		1.88	0.75	2250			4.22	1.69		
2F		0.79	2.50	350			0.28	0.88		
1F		0.79	2.50	350			0.28	0.88		
stud wall at 2F		0.65		2700			1.76	0.00		
stud wall at 1F		0.65		2900			1.89	0.00		
wall SW at GF		2.74		3000			8.23	0.00		
							16.64	3.44		
WALL 3										
(assumed 103 thk brick wall)										
roof		1.88	0.75	0			0.00	0.00		
2F		0.79	2.50	350			0.28	0.88		
1F		0.79	2.50	350			0.28	0.88		
stud wall at 2F		0.65		0			0.00	0.00		
stud wall at 1F		0.65		2900			1.89	0.00		
wall SW at GF		2.74		3000			8.23	0.00		
							10.67	1.75		
WALL 4										
(assumed 330 thk brick wall)										
roof		1.88	0.75	1000			1.88	0.75		
2F		0.79	2.50	0			0.00	0.00		
1F		0.79	2.50	1200			0.95	3.00		
wall SW		7.76		6000			46.56	0.00		
							49.38	3.75		
WALL 5										
(assumed 330 thk brick wall)										
roof		1.88	0.75	1000			1.88	0.75		
2F		0.79	2.50	350			0.28	0.88		
1F		0.79	2.50	1550			1.22	3.88		
wall SW		7.76		6000			46.56	0.00		
							49.94	5.50		

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
WALL 6										
(assumed 215 thk brick wall)										
roof		1.88	0.75	1125			2.11	0.84		
2F		0.79	2.50	175			0.14	0.44		
1F		0.79	2.50	175			0.14	0.44		
wall SW		5.58		7800			43.52	0.00		
							45.91	1.72		
WALL 7										
(assumed 215 thk brick wall)										
roof		1.88	0.75	350			0.66	0.26		
2F		0.79	2.50	0			0.00	0.00		
1F		0.79	2.50	1200			0.95	3.00		
wall SW		5.58		6000			33.48	0.00		
							35.08	3.26		
WALL 8										
(assumed 215 thk brick wall)										
roof		1.88	0.75	1500			2.81	1.13		
2F		0.79	2.50	2450			1.94	6.13		
1F		0.79	2.50	2450			1.94	6.13		
wall SW		5.58		6000			33.48	0.00		
							40.16	13.38		
WALL 9										
(assumed 215 thk brick wall)										
roof		1.88	0.75	1500			2.81	1.13		
2F		0.79	2.50	1750			1.38	4.38		
1F		0.79	2.50	1750			1.38	4.38		
wall SW		5.58		6000			33.48	0.00		
							39.06	9.88		
WALL 10										
(assumed 103 thk brick wall)										
roof		1.88	0.75	200			0.38	0.15		
2F		0.79	2.50	4700			3.71	11.75		
1F		0.79	2.50	4700			3.71	11.75		
stud wall at 2F		0.65		2700			1.76	0.00		
stud wall at 1F		0.65		2900			1.89	0.00		
wall SW at GF		2.74		3000			8.23	0.00		
							19.67	23.65		

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Calculations: Existing loads take down	Designed: ab	Date: 05/04/2018	Ckd: -

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
WALL 11										
(assumed 103 thk brick wall)										
roof		1.88	0.75	3500			6.56	2.63		
2F		0.79	2.50	3400			2.69	8.50		
1F		0.79	2.50	3400			2.69	8.50		
stud wall at 2F		0.65		2700			1.76	0.00		
stud wall at 1F		0.65		2900			1.89	0.00		
wall SW at GF		2.74		3000			8.23	0.00		
							23.81	19.63		
WALL 12										
(assumed 330 thk brick wall)										
roof		1.88	0.75	1000			1.88	0.75		
2F		0.79	2.50	2300			1.82	5.75		
1F		0.79	2.50	2300			1.82	5.75		
wall SW		7.51		8000			60.08	0.00		
							65.59	12.25		
WALL 13										
(assumed 330 thk brick wall)										
roof		1.88	0.75	1500			2.81	1.13		
2F		0.79	2.50	1000			0.79	2.50		
1F		0.79	2.50	350			0.28	0.88		
wall SW		7.51		4500			33.80	0.00		
							37.67	4.50		
WALL 14										
(assumed 330 thk party wall)										
roof (both side)		1.88	0.75	2000			3.75	1.50		
2F (both side)		0.79	2.50	350			0.28	0.88		
1F (both side)		0.79	2.50	350			0.28	0.88		
party wall SW		7.76		7000			54.32	0.00		
							58.62	3.25		

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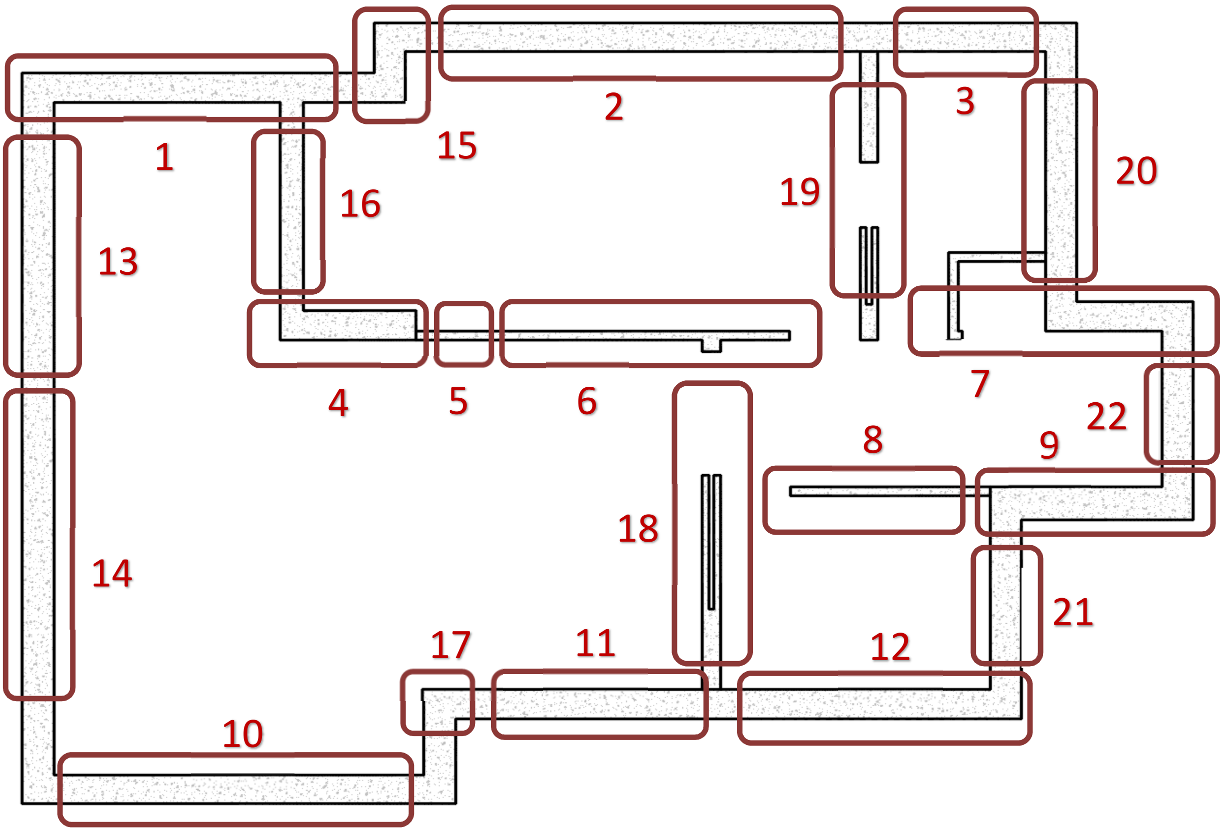
Calculations: Proposed loads take down	Designed: ab	Date: 05/04/2018	Ckd: -

Picture below shows proposed loaded walls at basement floor



WALL / PIER	DEAD LOAD kN/m - kN	IMPOSED LOAD kN/m - kN
1	32.00	3.00
2	108.00	6.00
3	94.00	6.00
4	52.00	12.00
5	119.00 kN	46.00 kN
6	45.00	9.00
7	60.00	10.00
8	78.00	10.00
9	86.00	8.00
10	27.00	0.00
11	84.00	5.00
12	73.00	7.00
13	37.00	4.00
14	43.00	6.00
15	89.00 kN	21.00 kN
16	28.00	4.00
17	114.00 kN	33.00 kN
18	54.00	24.00
19	54.00	30.00
20	103.00	16.00
21	72.00	7.00
22	99.00	14.00

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
WALL 1										
(assumed 300 thk rc wall)										
GF		6.80	2.50	825			5.61	2.06		
wall SW		7.50		3500			26.25			
							31.86	2.06		
WALL 2										
(assumed 330 thk rc wall)										
from existing wall 1 (see sheet 5.1)							72.59	3.25		
GF		6.80	2.50	950			6.46	2.38		
wall SW		8.25		3500			28.88			
							107.93	5.63		
WALL 3										
(assumed 330 thk rc wall)										
from existing wall 14 (see sheet 5.1)							58.62	3.25		
GF		6.80	2.50	950			6.46	2.38		
wall SW		8.25		3500			28.88			
							93.96	5.63		
WALL 4										
(assumed 300 thk rc wall)										
new flat roof		0.94	1.50	2250			5.50	8.78		
GF		6.80	2.50	1175			7.99	2.94		
cavity wall at GF		3.80		3000			11.40			
wall SW		7.50		3500			26.25			
							51.14	11.71		

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
PIER 5										
from existing wall 8 (see sheet 5.1)									58.24	19.39
from existing wall 9 @1F (see sheet 5.1)									49.10	21.73
GF		6.80	2.50						10.88	4.00
									118.22	45.12
WALL 6										
(assumed 150 thk rc wall)										
from existing wall 2 (see sheet 5.1)							16.64	3.44		
GF		6.80	2.50	2200			14.96	5.50		
wall SW		3.75		3500			13.13			
							44.73	8.94		
WALL 7										
(assumed 330 thk rc wall)										
from existing wall 3 (see sheet 5.1)							10.67	1.75		
GF		6.80	2.50	2950			20.06	7.38		
wall SW		8.25		3500			28.88			
							59.61	9.13		
WALL 8										
(assumed 150 thk rc wall)										
from existing wall 4 (see sheet 5.1)							49.38	3.75		
GF		6.80	2.50	2250			15.30	5.63		
wall SW		3.75		3500			13.13			
							77.81	9.38		
WALL 9										
(assumed 330 thk rc wall)										
from existing wall 5 (see sheet 5.1)							49.94	5.50		
GF		6.80	2.50	1000			6.80	2.50		
wall SW		8.25		3500			28.88			
							85.61	8.00		
WALL 10										
(assumed 300 thk rc wall)										
wall SW		7.50		3500			26.25			

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Job title:	10 Downside Crescent
Calculations:	Proposed loads take down
Designed:	ab
Date:	05/04/2018
Ckd:	-

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
WALL 11										
(assumed 330 thk rc wall)										
from existing wall 6 (see sheet 5.1)							45.91	1.72		
GF		6.80	2.50	1250			8.50	3.13		
wall SW		8.25		3500			28.88			
							83.28	4.84		
WALL 12										
(assumed 330 thk rc wall)										
from existing wall 7 (see sheet 5.1)							35.08	3.26		
GF		6.80	2.50	1250			8.50	3.13		
wall SW		8.25		3500			28.88			
							72.46	6.39		
WALL 13										
(assumed 300 thk rc wall)										
GF		6.80	2.50	1450			9.86	3.63		
wall SW		7.50		3500			26.25			
							36.11	3.63		
WALL 14										
(assumed 300 thk rc wall)										
GF		6.80	2.50	2350			15.98	5.88		
wall SW		7.50		3500			26.25			
							42.23	5.88		
PIER 15										
from existing wall 8 (see sheet 5.1)									58.24	19.39
pier SW		7.50		3500					26.25	
GF		6.80	2.50						4.08	1.50
									88.57	20.89
WALL 16										
(assumed 200 thk rc wall)										
GF		6.80	2.50	1450			9.86	3.63		
wall SW		5.00		3500			17.50			
							27.36	3.63		

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
PIER 17										
from existing wall 9 @1F (see sheet 5.1)									49.10	21.73
GF		6.80	2.50						6.80	2.50
new flat roof	2350	0.94	1.50	2250					4.97	7.93
cavity wall at GF	2350	3.80		3000					26.79	
pier SW		7.50		3500					26.25	
									113.91	32.16
WALL 18										
(assumed 200 thk rc wall)										
from existing wall 11 @ GF (see sheet 5.1)							23.81	19.63		
GF		6.80	2.50	1725			11.73	4.31		
wall SW		5.00		3500			17.50			
							53.04	23.94		
WALL 19										
(assumed 200 thk rc wall)										
from existing wall 10 @ GF (see sheet 5.1)							19.67	23.65		
GF		6.80	2.50	2400			16.32	6.00		
wall SW		5.00		3500			17.50			
							53.49	29.65		
WALL 20										
(assumed 330 thk rc wall)										
from existing wall 12 @ GF (see sheet 5.1)							65.59	12.25		
GF		6.80	2.50	1150			7.82	2.88		
wall SW		8.25		3500			28.88			
							102.28	15.13		
WALL 21										
(assumed 330 thk rc wall)										
from existing wall 13 @ GF (see sheet 5.1)							37.67	4.50		
GF		6.80	2.50	800			5.44	2.00		
wall SW		8.25		3500			28.88			
							71.99	6.50		
WALL 22										
(assumed 330 thk rc wall)										
from existing wall 12 @ GF (see sheet 5.1)							65.59	12.25		
GF		6.80	2.50	550			3.74	1.38		
wall SW		8.25		3500			28.88			
							98.20	13.63		

Beam & Load description	Span	Area loads		Width	Location		UDL		Point loads	
		DL	LL		from	to	DL	LL	DL	LL
	mm	kN/m²	kN/m²	mm	mm	mm	kN/m	kN/m	kN	kN
Check under main building										
Water uplift force										
3m high water table	7600	30.00		9500					**2166.0**	
Gravitational load										
roof DL	7600	1.88		9500					135.4	
2F DL	7600	0.79		9500					57.0	
1F ext walls SW		22.00	kN/m3	22.06	m3				485.3	
1F DL	7600	0.79		9500					57.0	
GF side&spine wall SW		22.00	kN/m3	12.65	m3				278.4	
GF DL	7600	6.80		9500					491.0	
BF walls SW		24.00	kN/m3	26.79	m3				643.0	
BF DL	7600	11.75		9500					848.4	
TOT									**2995.4**	**PASS**
Check under rear extension										
Water uplift force										
3m high water table	5100	30.00		6500					**994.5**	
Gravitational load										
roof DL	5100	0.94		5300					25.4	
GF walls SW	2800	3.80		6900					73.4	
GF DL	5300	6.80		6200					223.4	
BF walls SW		24.00	kN/m3	11.934	m3				286.4	
BF DL	5100	11.75		6500					389.5	
TOT									**998.2**	**PASS**
Check under rear courtyard										
Water uplift force										
3m high water table	5000	30.00		3100					**465.0**	
Gravitational load										
GF DL	3800	6.80		3100					80.1	
BF walls SW		24.00	kN/m3	10.38	m3				249.1	
BF DL	5000	11.75		3100					182.1	
TOT									**511.3**	**PASS**

RC SLAB DESIGN (BS8110:PART1:1997)

TEDDS calculation version 1.0.04

TWO WAY SPANNING SLAB DEFINITION – SIMPLY SUPPORTED

Overall depth of slab h = **200** mm

Outer sagging steel

Cover to outer tension reinforcement resisting sagging c_{sag} = **25** mm

Trial bar diameter D_{tryx} = **10** mm

Depth to outer tension steel (resisting sagging)

$d_x = h - c_{sag} - D_{tryx}/2$ = **170** mm

Inner sagging steel

Trial bar diameter D_{tryy} = **10** mm

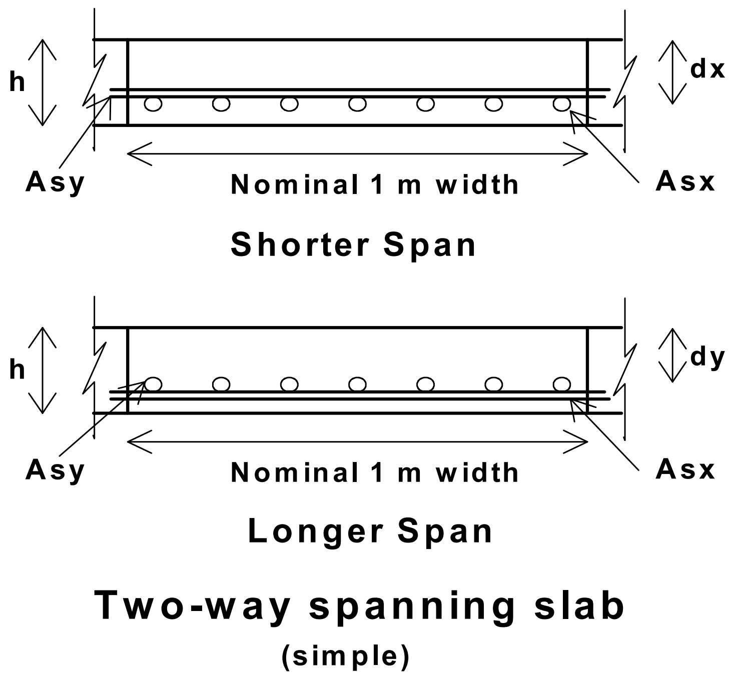
Depth to inner tension steel (resisting sagging)

$d_y = h - c_{sag} - D_{tryx} - D_{tryy}/2$ = **160** mm

Materials

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

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



MAXIMUM DESIGN MOMENTS

Length of shorter side of slab l_x = **4.300** m

Length of longer side of slab l_y = **4.800** m

Design ultimate load per unit area n_s = **13.5** kN/m^2

Moment coefficients

$\alpha_{sx} = (l_y / l_x)^4 / (8 \times (1+(l_y / l_x)^4))$ = **0.076**

$\alpha_{sy} = (l_y / l_x)^2 / (8 \times (1+(l_y / l_x)^4))$ = **0.061**

Maximum moments per unit width - simply supported slabs

$m_{sx} = \alpha_{sx} \times n_s \times l_x^2$ = **19.0** kNm/m

$m_{sy} = \alpha_{sy} \times n_s \times l_x^2$ = **15.2** kNm/m

CONCRETE SLAB DESIGN – SAGGING – OUTER LAYER OF STEEL (CL 3.5.4)

Design sagging moment (per m width of slab) m_{sx} = **19.0** kNm/m

Moment Redistribution Factor β_{bx} = **1.0**

Area of reinforcement required

$K_x = abs(m_{sx}) / (d_x^2 \times f_{cu})$ = **0.016**

$K'_x = \min (0.156 , (0.402 \times (\beta_{bx} - 0.4)) - (0.18 \times (\beta_{bx} - 0.4)^2))$ = **0.156**

Outer compression steel not required to resist sagging

Slab requiring outer tension steel only - bars (sagging)

$z_x = \min ((0.95 \times d_x),(d_x \times (0.5+\sqrt{(0.25-K_x/0.9)})))$ = **162** mm

Neutral axis depth $x_x = (d_x - z_x) / 0.45$ = **19** mm

Area of tension steel required

$A_{sx\_req} = abs(m_{sx}) / (1/\gamma_{ms} \times f_y \times z_x)$ = **270** mm²/m

Tension steel

Provide 10 dia bars @ 200 centres outer tension steel resisting sagging

$A_{sx\_prov} = A_{sx}$ = **393** mm²/m

Area of outer tension steel provided sufficient to resist sagging

Concrete Slab Design - Sagging - Inner layer of steel (cl. 3.5.4)

Design sagging moment (per m width of slab) m_{sy} = **15.2** kNm/m

Moment Redistribution Factor β_{by} = **1.0**

Area of reinforcement required

$K_y = abs(m_{sy}) / (d_y^2 \times f_{cu})$ = **0.015**

$K'_y = \min (0.156 , (0.402 \times (\beta_{by} - 0.4)) - (0.18 \times (\beta_{by} - 0.4)^2))$ = **0.156**

Inner compression steel not required to resist sagging

Slab requiring inner tension steel only - bars (sagging)

$z_y = \min ((0.95 \times d_y),(d_y \times (0.5+\sqrt{(0.25-K_y/0.9)})))$ = **152** mm

Neutral axis depth $x_y = (d_y - z_y) / 0.45$ = **18** mm

Area of tension steel required

A_{sy_req} = abs(m_{sy}) / (1/γ_{ms} × f_y × z_y) = **230** mm²/m

Tension steel

Provide 10 dia bars @ 200 centres inner tension steel resisting sagging

A_{sy_prov} = A_{sy} = **393** mm²/m

Area of inner tension steel provided sufficient to resist sagging

Check min and max areas of steel resisting sagging

Total area of concrete A_c = h = **200000** mm²/m

Minimum % reinforcement k = **0.13** %

A_{st_min} = k × A_c = **260** mm²/m

A_{st_max} = 4 % × A_c = **8000** mm²/m

Steel defined:

Outer steel resisting sagging A_{sx_prov} = **393** mm²/m

Area of outer steel provided (sagging) OK

Inner steel resisting sagging A_{sy_prov} = **393** mm²/m

Area of inner steel provided (sagging) OK

SHEAR RESISTANCE OF CONCRETE SLABS (CL 3.5.5)

Outer tension steel resisting sagging moments

Depth to tension steel from compression face d_x = **170** mm

Area of tension reinforcement provided (per m width of slab) A_{sx_prov} = **393** mm²/m

Design ultimate shear force (per m width of slab) V_x = **29** kN/m

Characteristic strength of concrete f_{cu} = **40** N/mm²

Applied shear stress

v_x = V_x / d_x = **0.17** N/mm²

Check shear stress to clause 3.5.5.2

$v_{allowable}$ = min ((0.8 $N^{1/2}$/mm) × $\sqrt{f_{cu}}$), 5 N/mm²) = **5.00** N/mm²

Shear stress - OK

Shear stresses to clause 3.5.5.3

Design shear stress

f_{cu_ratio} = if (f_{cu} > 40 N/mm², 40/25, f_{cu}/(25 N/mm²)) = **1.600**

v_{cx} = 0.79 N/mm² × min(3,100 × A_{sx_prov} / d_x)$^{1/3}$ × max(0.67,(400 mm / d_x)$^{1/4}$) / 1.25 × $f_{cu\_ratio}^{1/3}$

v_{cx} = **0.56** N/mm²

Applied shear stress

v_x = **0.17** N/mm²

No shear reinforcement required

SHEAR RESISTANCE OF CONCRETE SLABS (CL 3.5.5)

Inner tension steel resisting sagging moments

Depth to tension steel from compression face d_y = **160** mm

Area of tension reinforcement provided (per m width of slab) A_{sy_prov} = **393** mm^2/m

Design ultimate shear force (per m width of slab) V_y = **32** kN/m

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

Applied shear stress

$v_y = V_y / d_y$ = **0.20** N/mm^2

Check shear stress to clause 3.5.5.2

$v_{allowable} = \min((0.8\ N^{1/2}/mm) \times \sqrt{(f_{cu})}, 5\ N/mm^2)$ = **5.00** N/mm^2

Shear stress - OK

Shear stresses to clause 3.5.5.3

Design shear stress

f_{cu_ratio} = if (f_{cu} > 40 N/mm^2 , 40/25 , f_{cu}/(25 N/mm^2)) = **1.600**

$v_{cy} = 0.79\ N/mm^2 \times \min(3,100 \times A_{sy\_prov} / d_y)^{1/3} \times \max(0.67,(400\ mm) / d_y)^{1/4} / 1.25 \times f_{cu\_ratio}^{1/3}$

v_{cy} = **0.58** N/mm^2

Applied shear stress

v_y = **0.20** N/mm^2

No shear reinforcement required

CONCRETE SLAB DEFLECTION CHECK (CL 3.5.7)

Slab span length l_x = **4.300** m

Design ultimate moment in shorter span per m width m_{sx} = **19** kNm/m

Depth to outer tension steel d_x = **170** mm

Tension steel

Area of outer tension reinforcement provided A_{sx_prov} = **393** mm^2/m

Area of tension reinforcement required A_{sx_req} = **270** mm^2/m

Moment Redistribution Factor β_{bx} = **1.00**

Modification Factors

Basic span / effective depth ratio (Table 3.9) $ratio_{span\_depth}$ = **20**

The modification factor for spans in excess of 10m (ref. cl 3.4.6.4) has not been included.

$f_s = 2 \times f_y \times A_{sx\_req} / (3 \times A_{sx\_prov} \times \beta_{bx})$ = **229.3** N/mm^2

$factor_{tens} = \min(2, 0.55 + (477\ N/mm^2 - f_s) / (120 \times (0.9\ N/mm^2 + m_{sx} / d_x^2)))$ = **1.876**

Calculate Maximum Span

This is a simplified approach and further attention should be given where special circumstances exist. Refer to clauses 3.4.6.4 and 3.4.6.7.

Maximum span l_{max} = $ratio_{span\_depth} \times factor_{tens} \times d_x$ = **6.38** m

Check the actual beam span

Actual span/depth ratio l_x / d_x = **25.29**

Span depth limit $ratio_{span\_depth} \times factor_{tens}$ = **37.52**

Span/Depth ratio check satisfied

CHECK OF NOMINAL COVER (SAGGING) – (BS8110:PT 1, TABLE 3.4)

Slab thickness h = **200** mm

Effective depth to bottom outer tension reinforcement d_x = **170.0** mm

Diameter of tension reinforcement D_x = **10** mm

Diameter of links L_{diax} = **0** mm

Cover to outer tension reinforcement

$c_{tenx} = h - d_x - D_x / 2$ = **25.0** mm

Nominal cover to links steel

$c_{nomx} = c_{tenx} - L_{diax}$ = **25.0** mm

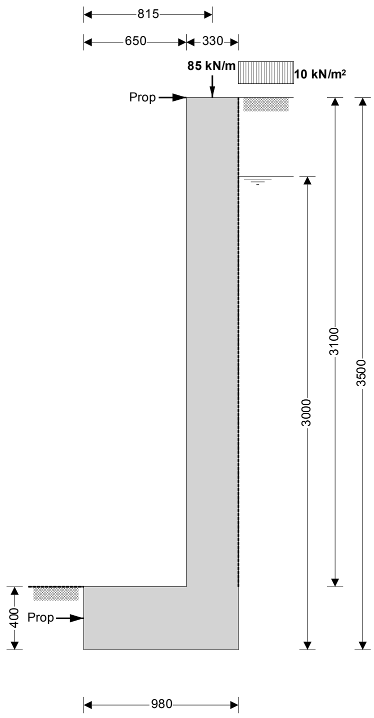
Permissable minimum nominal cover to all reinforcement (Table 3.4)

c_{min} = **25** mm

Cover over steel resisting sagging OK

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **3100** mm
Thickness of wall stem	t_{wall} = **330** mm
Length of toe	l_{toe} = **650** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **980** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **15** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3500** 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} = **3000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **2600** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3500** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3

Saturated density of retained material γ_s = **21.0** kN/m³

Design shear strength ϕ' = **18.6** deg

Angle of wall friction δ = **0.0** deg

Base material details

Firm clay

Moist density γ_{mb} = **18.0** kN/m³

Design shear strength ϕ'_b = **16.5** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **150** kN/m²

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.516}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{2.835}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi') = \mathbf{0.681}$

Loading details

Surcharge load on plan Surcharge = **10.0** kN/m²

Applied vertical dead load on wall W_{dead} = **79.0** kN/m

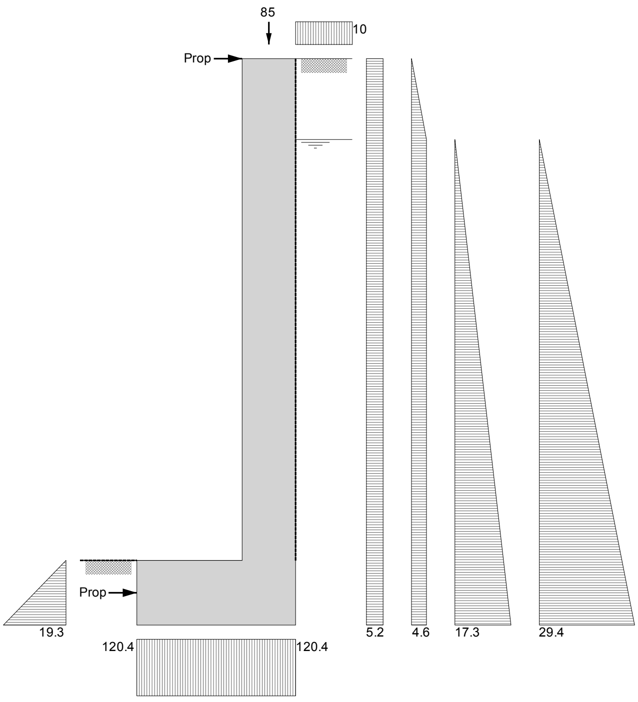
Applied vertical live load on wall W_{live} = **5.6** kN/m

Position of applied vertical load on wall l_{load} = **815** 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/m²

Vertical forces on wall

Wall stem — $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **24.1** kN/m

Wall base — $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **9.3** kN/m

Applied vertical load — $W_v = W_{dead} + W_{live}$ = **84.6** kN/m

Total vertical load — $W_{total} = w_{wall} + w_{base} + W_v$ = **118** kN/m

Horizontal forces on wall

Surcharge — $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **18.1** kN/m

Moist backfill above water table — $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **1.2** kN/m

Moist backfill below water table — $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **13.9** kN/m

Saturated backfill — $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **26** kN/m

Water — $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **44.1** kN/m

Total horizontal load — $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **103.3** kN/m

Calculate total propping force

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.9** kN/m

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

F_{prop} = **61.6** kN/m

Overturning moments

Surcharge — $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **31.6** kNm/m

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **3.7** kNm/m

Moist backfill below water table — $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **20.9** kNm/m

Saturated backfill — $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **26** kNm/m

Water — $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **44.1** kNm/m

Total overturning moment — $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **126.4** kNm/m

Restoring moments

Wall stem — $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **19.7** kNm/m

Wall base — $M_{base} = w_{base} \times l_{base} / 2$ = **4.5** kNm/m

Design vertical dead load — $M_{dead} = W_{dead} \times l_{load}$ = **64.4** kNm/m

Total restoring moment — $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **88.6** kNm/m

Check bearing pressure

Total vertical reaction — $R = W_{total}$ = **118.0** kN/m

Distance to reaction — $x_{bar} = l_{base} / 2$ = **490** 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 — $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **120.4** kN/m^2

Bearing pressure at heel — $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **120.4** kN/m^2

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

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **25.230** kN/m

Propping force to base of wall — $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **36.396** kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

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 $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **33.8** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **13** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **119.6** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **166.3** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times h_{eff}$ = **38.1** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **2.1** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **25.7** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **48** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **61.8** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **175.8** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.4** kN/m

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

F_{prop_f} = **117.5** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **66.7** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **6.8** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **38.6** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **48** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **61.8** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **222** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **27.5** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **6.3** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **97.4** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **131.3** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **166.3** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **490** mm

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

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **169.7** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **169.7** kN/m^2

Rate of change of base reaction $\text{rate} = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2)$ = **169.7** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{169.7}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{169.7}\ kN/m^2$

Calculate propping forces to top and base of wall

Propping force to top of wall

$$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{45.039}\ kN/m$$

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{72.430}\ kN/m$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}\ N/mm^2$

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

Base details

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

Cover to reinforcement in toe $c_{toe} = \mathbf{45}\ mm$

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{110.3}\ kN/m$

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{8.6}\ kN/m$

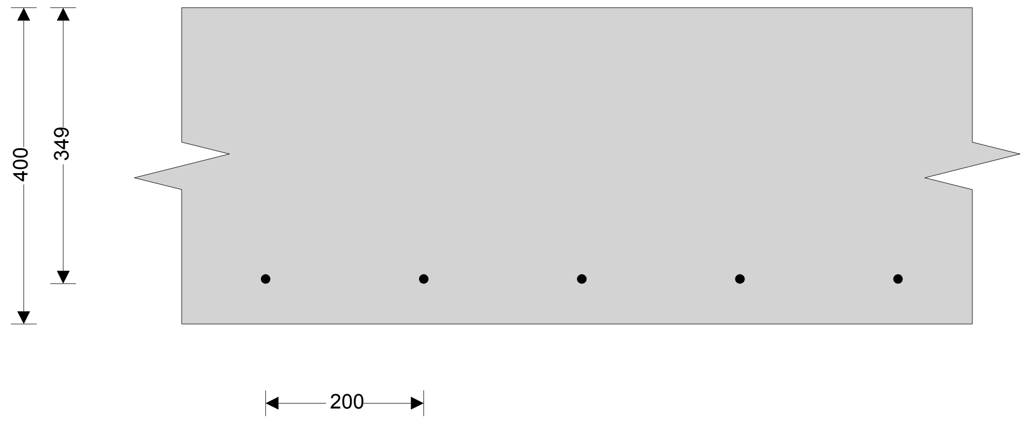
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{101.7}\ kN/m$

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{56.4}\ kNm/m$

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{4.4}\ kNm/m$

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{52}\ kNm/m$



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{349.0}\ mm$

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.011}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{332}\ mm$

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{360}\ mm^2/m$

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{520}\ mm^2/m$

Area of tension reinforcement required $A_{s\_toe\_req} = \max(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{520}\ mm^2/m$

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov} = \mathbf{565}\ mm^2/m$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.291}$ N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000}$ 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 $v_{c\_toe} = \mathbf{0.417}$ 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 $f_{cu} = \mathbf{40}$ N/mm^2

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

Wall details

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

Cover to reinforcement in stem $c_{stem} = \mathbf{45}$ mm

Cover to reinforcement in wall $c_{wall} = \mathbf{45}$ mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = \mathbf{33.8}$ kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = \mathbf{2.1}$ kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat} = \mathbf{22.3}$ kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2 = \mathbf{36.1}$ kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2 = \mathbf{46.4}$ kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8 = \mathbf{21.1}$ kN/m

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3) = \mathbf{0.3}$ kN/m

Moist backfill below water table $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8 = \mathbf{16}$ kN/m

Saturated backfill $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3))) = \mathbf{30.7}$ kN/m

Water $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3))) = \mathbf{39.5}$ kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f} = \mathbf{107.6}$ kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8 = \mathbf{13.9}$ kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2) = \mathbf{0.4}$ kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8 = \mathbf{10.4}$ kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2) = \mathbf{15.9}$ kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2) = \mathbf{20.4}$
kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water} = \mathbf{60.9}$ kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128 = \mathbf{7.8}$ kNm/m

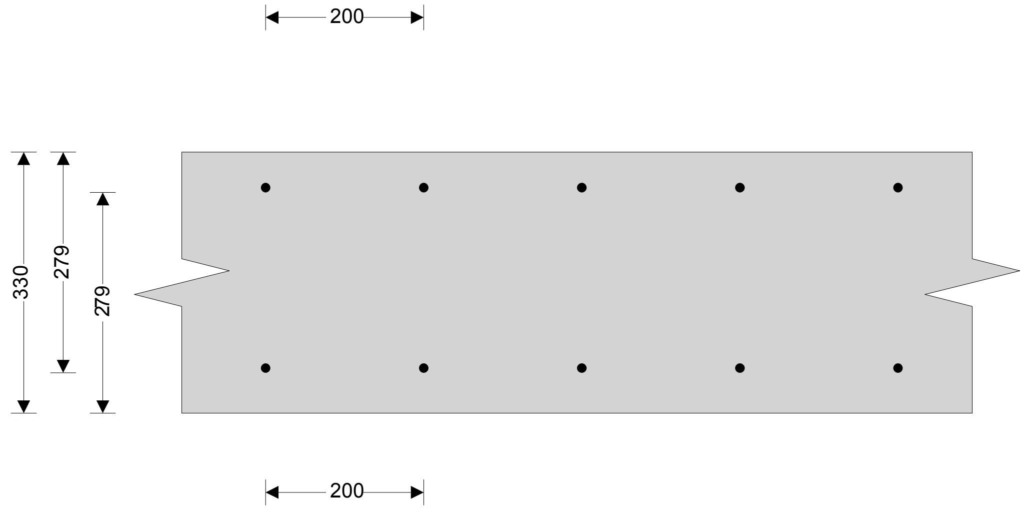
Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2)/(5 \times L^3) - 0.577^2/3] = \mathbf{0.5}$
kNm/m

Moist backfill below water table $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8 - n^2 \times (4 - n))^2 / 16) - 4 + n \times (4 - n)]/8 = \mathbf{5.7}$ kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l)/(20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)] = \mathbf{6.6}$ kNm/m

Water kNm/m — $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l)/(20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)] = \mathbf{8.5}$

Total moment for wall design — $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water} = \mathbf{29}$ kNm/m



Check wall stem in bending

Width of wall stem — $b = \mathbf{1000}$ mm/m

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2) = \mathbf{279.0}$ mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu}) = \mathbf{0.020}$

Compression reinforcement is not required

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

$z_{stem} = \mathbf{265}$ mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem}) = \mathbf{529}$ mm^2/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall} = \mathbf{429}$ mm^2/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \max(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{529}$ mm^2/m

Reinforcement provided — **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided — $A_{s\_stem\_prov} = \mathbf{565}$ mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.386}$ N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000}$ 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 — $v_{c\_stem} = \mathbf{0.475}$ N/mm^2

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

Check mid height of wall in bending

Depth of reinforcement — $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2) = \mathbf{279.0}$ mm

Constant — $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu}) = \mathbf{0.009}$

Compression reinforcement is not required

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

$z_{wall} = \mathbf{265}$ mm

Area of tension reinforcement required — $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall}) = \mathbf{252}$ mm^2/m

Minimum area of tension reinforcement — $A_{s\_wall\_min} = k \times b \times t_{wall} = \mathbf{429}$ mm^2/m

Area of tension reinforcement required $A_{s\_wall\_req}$ = Max($A_{s\_wall\_des}$, $A_{s\_wall\_min}$) = **429** mm²/m

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov}$ = **565** 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 $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **311.6** N/mm²

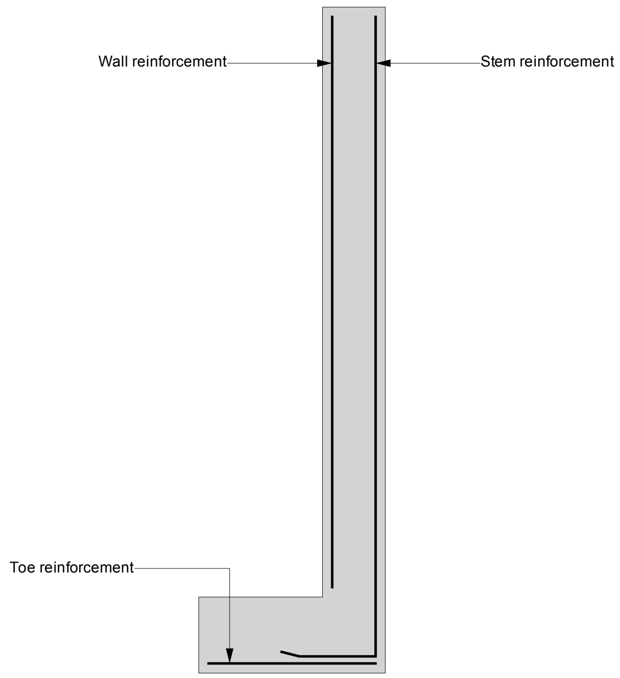
Modification factor $factor_{tens}$ = min(0.55 + (477 N/mm² - f_s)/(120 × (0.9 N/mm² + (M_{stem}/(b × d_{stem}^2)))),2) = **1.37**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **27.38**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **11.11**

PASS - Span to depth ratio is acceptable

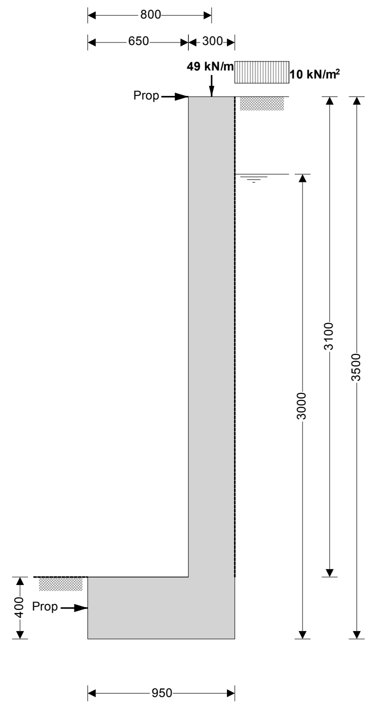
Indicative retaining wall reinforcement diagram



Toe bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Wall bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Stem bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **3100** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **650** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **950** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **15** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3500** 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} = **3000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **2600** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3500** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3

Saturated density of retained material — γ_s = **21.0** kN/m^3

Design shear strength — ϕ' = **18.6** deg

Angle of wall friction — δ = **0.0** deg

Base material details

Firm clay

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

Design shear strength — ϕ'_b = **16.5** deg

Design base friction — δ_b = **18.6** deg

Allowable bearing pressure — $P_{bearing}$ = **150** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.516}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{2.835}$$

At-rest pressure

At-rest pressure for retained material — $K_0 = 1 - \sin(\phi') = \mathbf{0.681}$

Loading details

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

Applied vertical dead load on wall — W_{dead} = **43.0** kN/m

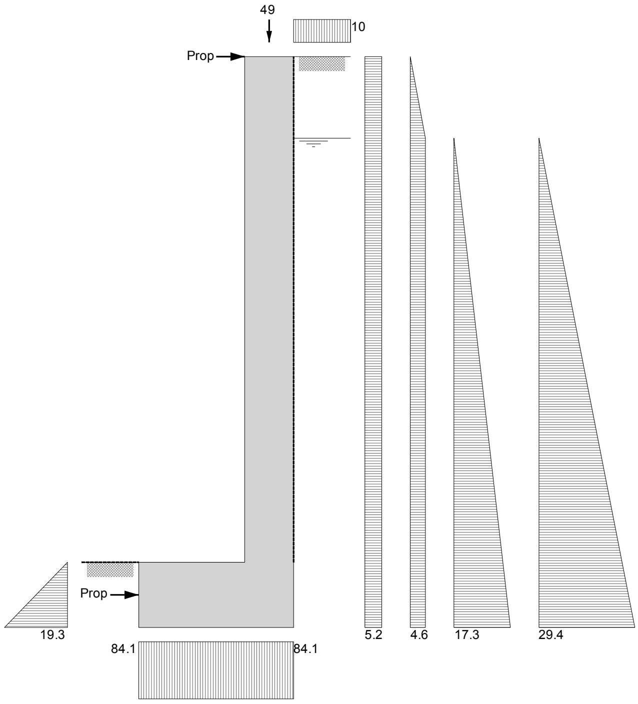
Applied vertical live load on wall — W_{live} = **6.0** kN/m

Position of applied vertical load on wall — l_{load} = **800** 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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **21.9** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **9** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **49** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **79.9** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times Surcharge \times h_{eff}$ = **18.1** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **1.2** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **13.9** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **26** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **44.1** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **103.3** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.9** kN/m

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

F_{prop} = **74.6** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **31.6** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **3.7** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **20.9** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **26** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **44.1** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **126.4** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **17.6** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **4.3** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load}$ = **34.4** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **56.2** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **79.9** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **475** mm

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

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **84.1** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **84.1** 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

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **28.239** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **46.336** kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

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 $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **30.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **12.6** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **69.8** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **113.1** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times h_{eff}$ = **38.1** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **2.1** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **25.7** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **48** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **61.8** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **175.8** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.4** kN/m

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

F_{prop_f} = **135.6** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **66.7** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **6.8** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **38.6** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **48** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **61.8** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **222** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **24.6** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **6** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **55.8** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **86.4** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **113.1** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **475** mm

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

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **119** kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **119** 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 $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2)$ = **119** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2) = \mathbf{119} \text{ kN/m}^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2) = \mathbf{119} \text{ kN/m}^2$

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{49.144} \text{ kN/m}$

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{86.454} \text{ kN/m}$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40} \text{ N/mm}^2$

Characteristic strength of reinforcement $f_y = \mathbf{500} \text{ N/mm}^2$

Base details

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

Cover to reinforcement in toe $c_{toe} = \mathbf{45}$ mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{77.4} \text{ kN/m}$

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{8.6} \text{ kN/m}$

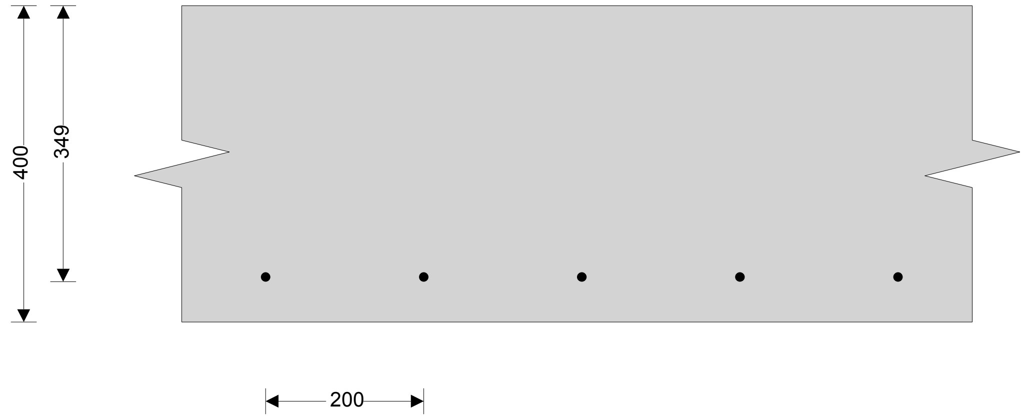
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{68.8} \text{ kN/m}$

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{38.1} \text{ kNm/m}$

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{4.2} \text{ kNm/m}$

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{33.9} \text{ kNm/m}$



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{349.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.007}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{332}$ mm

Area of tension reinforcement required $As_{toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{235} \text{ mm}^2\text{/m}$

Minimum area of tension reinforcement $As_{toe\_min} = k \times b \times t_{base} = \mathbf{520} \text{ mm}^2\text{/m}$

Area of tension reinforcement required $As_{toe\_req} = \text{Max}(As_{toe\_des}, As_{toe\_min}) = \mathbf{520} \text{ mm}^2\text{/m}$

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $As_{toe\_prov} = \mathbf{565} \text{ mm}^2\text{/m}$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.197}$ N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000}$ 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 $v_{c\_toe} = \mathbf{0.417}$ 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 $f_{cu} = \mathbf{40}$ N/mm^2

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

Wall details

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

Cover to reinforcement in stem $c_{stem} = \mathbf{45}$ mm

Cover to reinforcement in wall $c_{wall} = \mathbf{45}$ mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds}) = \mathbf{33.8}$ kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2 = \mathbf{2.1}$ kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat} = \mathbf{22.3}$ kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2 = \mathbf{36.1}$ kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2 = \mathbf{46.4}$ kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8 = \mathbf{21.1}$ kN/m

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3) = \mathbf{0.3}$ kN/m

Moist backfill below water table $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8 = \mathbf{16}$ kN/m

Saturated backfill $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3))) = \mathbf{30.7}$ kN/m

Water $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3))) = \mathbf{39.5}$ kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f} = \mathbf{107.6}$ kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8 = \mathbf{13.9}$ kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2) = \mathbf{0.4}$ kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8 = \mathbf{10.4}$ kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2) = \mathbf{15.9}$ kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2) = \mathbf{20.4}$
kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water} = \mathbf{60.9}$ kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128 = \mathbf{7.8}$ kNm/m

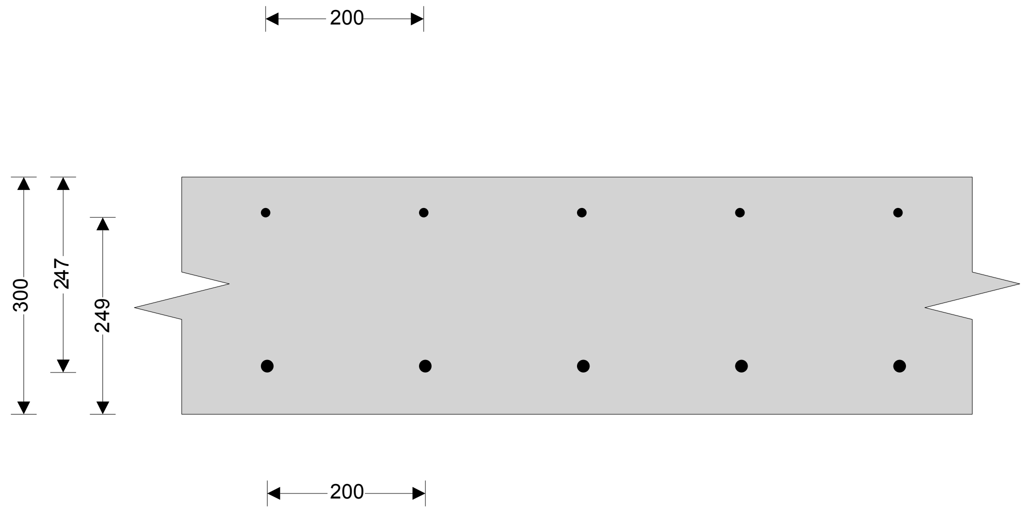
Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2) / (5 \times L^3) - 0.577^2/3] = \mathbf{0.5}$
kNm/m

Moist backfill below water table $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8 - n^2 \times (4-n))^2 / 16) - 4 + n \times (4-n)] / 8 = \mathbf{5.7}$ kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l) / (20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)] = \mathbf{6.6}$ kNm/m

Water $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **8.5**
kNm/m

Total moment for wall design $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water}$ = **29** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **247.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.025**

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} = **235** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **597** mm²/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **597** mm²/m

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

Area of reinforcement provided $A_{s\_stem\_prov}$ = **1005** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.436** 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} = **0.618** N/mm²

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

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **249.0** mm

Constant $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu})$ = **0.012**

Compression reinforcement is not required

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

z_{wall} = **237** mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall})$ = **282** mm²/m

Minimum area of tension reinforcement $A_{s\_wall\_min} = k \times b \times t_{wall}$ = **390** mm²/m

Area of tension reinforcement required $A_{s\_wall\_req} = Max(A_{s\_wall\_des}, A_{s\_wall\_min}) = \mathbf{390}\ mm^2/m$

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov} = \mathbf{565}\ mm^2/m$

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

Check retaining wall deflection

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

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) = \mathbf{198.0}\ N/mm^2$

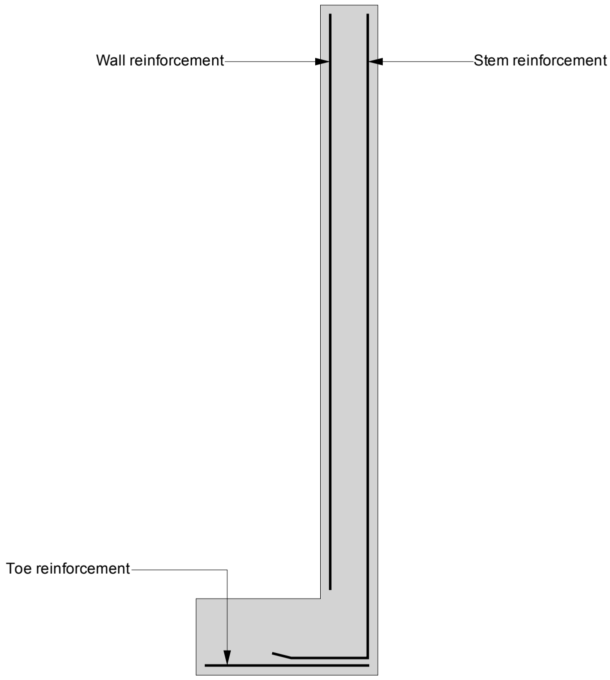
Modification factor $factor_{tens} = min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2) = \mathbf{1.77}$

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens} = \mathbf{35.49}$

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem} = \mathbf{12.55}$

PASS - Span to depth ratio is acceptable

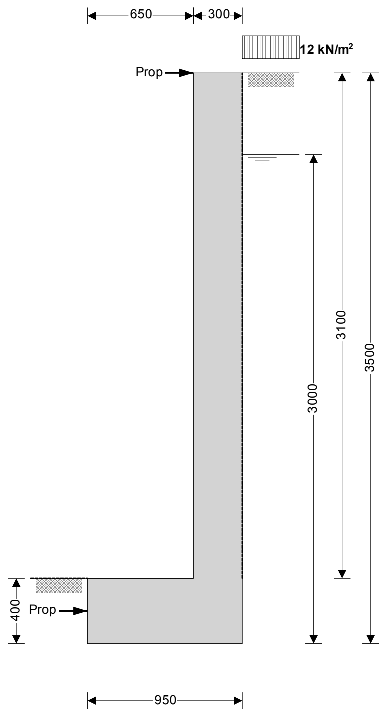
Indicative retaining wall reinforcement diagram



Toe bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Wall bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Stem bars - 16 mm dia.@ 200 mm centres - (1005 mm^2/m)

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **3100** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **650** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **950** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **15** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3500** 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} = **3000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **2600** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3500** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3

Saturated density of retained material γ_s = **21.0** kN/m^3

Design shear strength ϕ' = **18.6** deg

Angle of wall friction δ = **0.0** deg

Base material details

Firm clay

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

Design shear strength ϕ'_b = **16.5** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **150** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.516}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{2.835}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi') = \mathbf{0.681}$

Loading details

Surcharge load on plan Surcharge = **12.0** kN/m^2

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

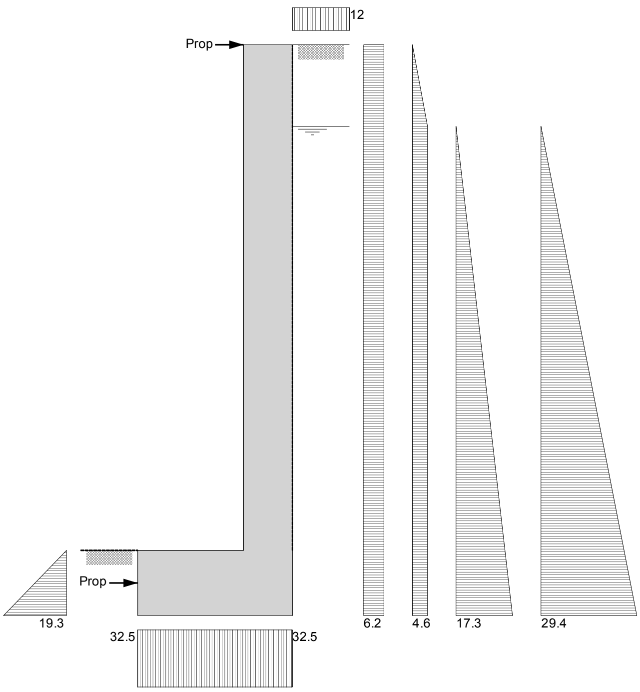
Applied vertical live load on wall W_{live} = **0.0** kN/m

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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **21.9** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **9** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base}$ = **30.9** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **21.7** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **1.2** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **13.9** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **26** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **44.1** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **106.9** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.9** kN/m

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

F_{prop} = **92.7** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **38** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **3.7** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **20.9** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **26** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **44.1** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **132.7** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **17.6** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **4.3** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base}$ = **21.8** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **30.9** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **475** 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 $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **32.5** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **32.5** 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

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **32.431** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **60.230** kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

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 $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **30.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **12.6** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f}$ = **43.3** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **45.8** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **2.1** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **25.7** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **48** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **61.8** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **183.5** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.4** 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} = **163.5** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **80.1** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **6.8** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **38.6** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **48** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **61.8** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **235.3** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **24.6** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **6** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f}$ = **30.5** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **43.3** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **475** 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 $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **45.6** kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **45.6** 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 $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0 \text{ kN/m}^2)$ = **45.6** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **45.6** kN/m²

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **45.6** kN/m²

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{58.373}$ kN/m

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{105.113}$ kN/m

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}$ N/mm^2

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

Base details

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

Cover to reinforcement in toe $c_{toe} = \mathbf{45}$ mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{29.6}$ kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{8.6}$ kN/m

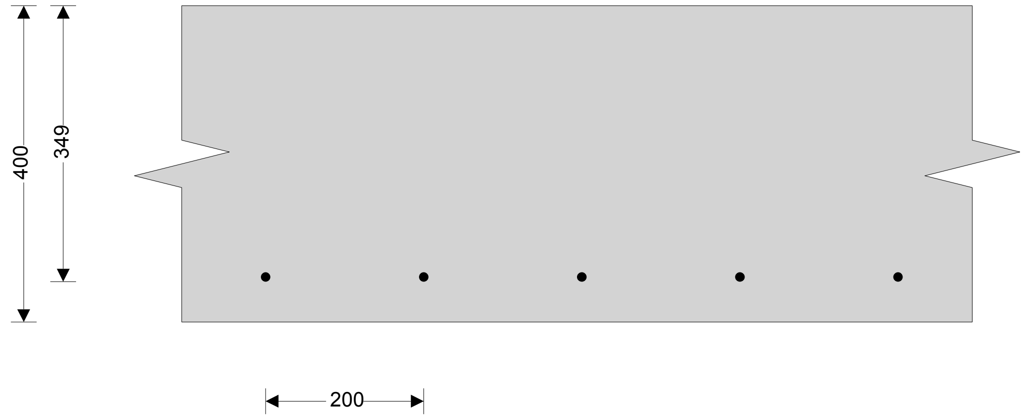
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{21}$ kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{14.6}$ kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{4.2}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{10.4}$ kNm/m



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{349.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.002}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{332}$ mm

Area of tension reinforcement required $As_{toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{72}$ mm^2/m

Minimum area of tension reinforcement $As_{toe\_min} = k \times b \times t_{base} = \mathbf{520}$ mm^2/m

Area of tension reinforcement required $As_{toe\_req} = \mathrm{Max}(As_{toe\_des}, As_{toe\_min}) = \mathbf{520}$ mm^2/m

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $As_{toe\_prov} = \mathbf{565}$ mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.060** 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_toe} = **0.417** N/mm²

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

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

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm²

Characteristic strength of reinforcement f_y = **500** N/mm²

Wall details

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

Cover to reinforcement in stem c_{stem} = **45** mm

Cover to reinforcement in wall c_{wall} = **45** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **40.5** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **2.1** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **22.3** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **36.1** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **46.4** kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **25.3** kN/m

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **0.3** kN/m

Moist backfill below water table $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8$ = **16** kN/m

Saturated backfill $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **30.7** kN/m

Water $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **39.5** kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **111.8** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **16.7** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **0.4** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8$ = **10.4** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **15.9** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **20.4**
kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **63.7** kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **9.4** kNm/m

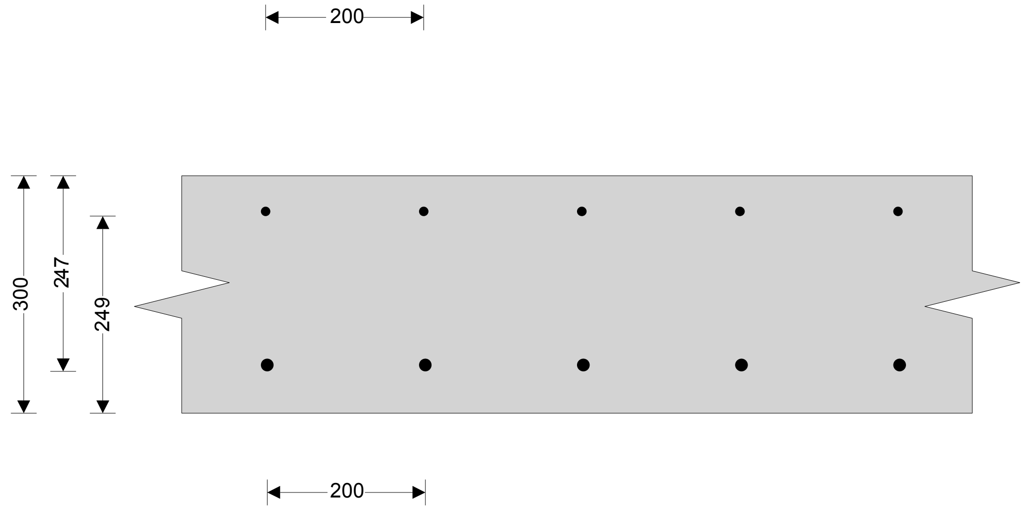
Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2)/(5 \times L^3) - 0.577^2/3]$ = **0.5**
kNm/m

Moist backfill below water table $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8 - n^2 \times (4 - n))^2 / 16) - 4 + n \times (4 - n)]/8$ = **5.7** kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l)/(20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)]$ = **6.6** kNm/m

Water $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l)/(20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)]$ = **8.5**
kNm/m

Total moment for wall design $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water}$ = **30.6** kNm/m



Check wall stem in bending

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

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **247.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.026**

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} = **235** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **624** mm²/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **624** mm²/m

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

Area of reinforcement provided $A_{s\_stem\_prov}$ = **1005** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.453** 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} = **0.618** N/mm²

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

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **249.0** mm

Constant $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu})$ = **0.012**

Compression reinforcement is not required

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

z_{wall} = **237** mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall})$ = **297** mm²/m

Minimum area of tension reinforcement $A_{s\_wall\_min} = k \times b \times t_{wall}$ = **390** mm²/m

Area of tension reinforcement required $A_{s\_wall\_req} = \mathrm{Max}(A_{s\_wall\_des}, A_{s\_wall\_min})$ = **390** mm²/m

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov}$ = **565** 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 $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **207.0** N/mm²

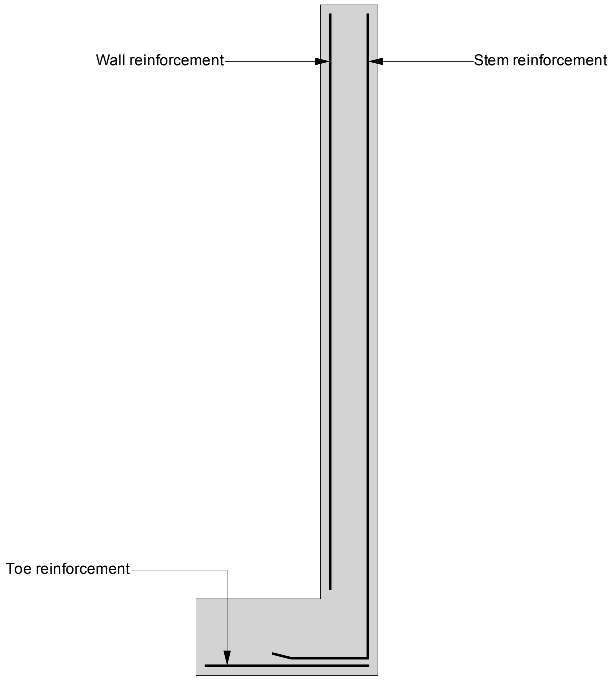
Modification factor $factor_{tens} = \min(0.55 + (477 N/mm^2 - f_s)/(120 \times (0.9 N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.71**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **34.14**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **12.55**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram

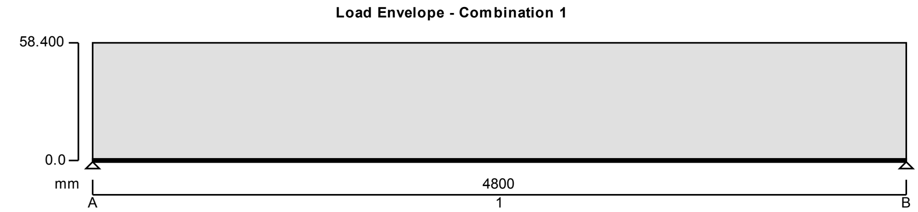


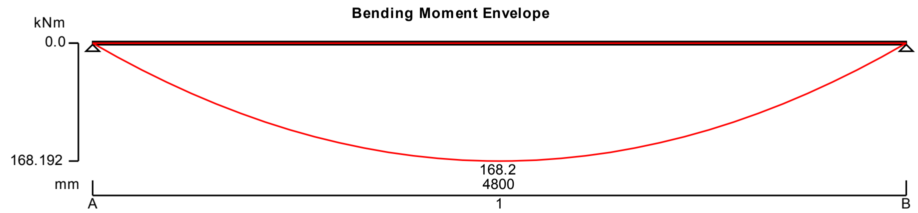
Toe bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Wall bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Stem bars - 16 mm dia.@ 200 mm centres - (1005 mm^2/m)

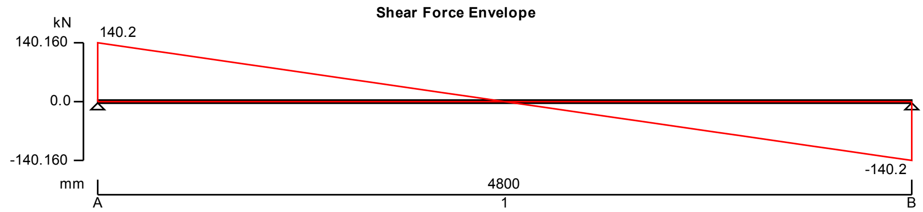
RODRIGUES ASSOCIATES 1 AMWELL STREET LONDON EC1R 1UL	Project 10 Downside Crescent				Job no. 1411	
	Calcs for side retaining wall under rear extension top beam				Start page no./Revision 6.5B. 1	
	Calcs by ab	Calcs date 01/05/2018	Checked by	Checked date	Approved by	Approved date

RC BEAM ANALYSIS & DESIGN BS8110

TEDDS calculation version 2.1.12







Support conditions

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

Applied loading

	Dead self weight of beam × 0	
	Dead full UDL 58.4 kN/m	

Load combinations

Load combination 1	Support A	Dead × 1.00
		Imposed × 1.00
	Span 1	Dead × 1.00
		Imposed × 1.00
	Support B	Dead × 1.00
		Imposed × 1.00

Analysis results

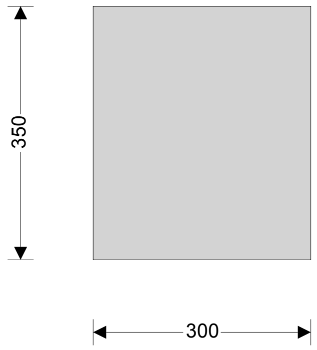
Maximum moment support A	M_{A_max} = **0** kNm	M_{A_red} = **0** kNm
Maximum moment span 1 at 2400 mm	M_{s1_max} = **168** kNm	M_{s1_red} = **168** kNm

Maximum moment support B	M_{B_max} = **0** kNm	M_{B_red} = **0** kNm
Maximum shear support A	V_{A_max} = **140** kN	V_{A_red} = **140** kN
Maximum shear support A span 1 at 293 mm	$V_{A\_s1\_max}$ = **124** kN	$V_{A\_s1\_red}$ = **124** kN
Maximum shear support B	V_{B_max} = **-140** kN	V_{B_red} = **-140** kN
Maximum shear support B span 1 at 4507 mm	$V_{B\_s1\_max}$ = **-124** kN	$V_{B\_s1\_red}$ = **-124** kN
Maximum reaction at support A	R_A = **140** kN	
Unfactored dead load reaction at support A	R_{A_Dead} = **140** kN	
Maximum reaction at support B	R_B = **140** kN	
Unfactored dead load reaction at support B	R_{B_Dead} = **140** kN	

Rectangular section details

Section width b = **300** mm

Section depth h = **350** mm



Concrete details

Concrete strength class **C32/40**

Characteristic compressive cube strength f_{cu} = **40** N/mm^2

Modulus of elasticity of concrete E_c = 20kN/mm^2 + 200 $\times$ f_{cu} = **28000** N/mm^2

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

Reinforcement details

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

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

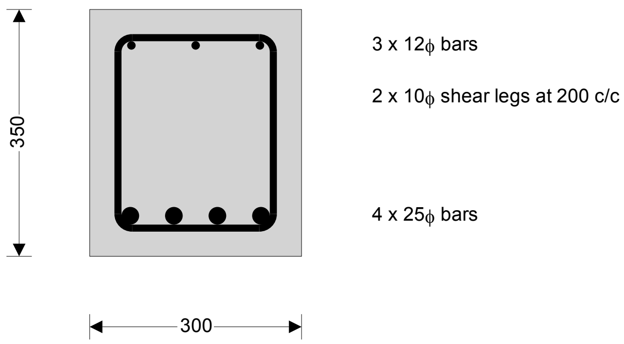
Nominal cover to reinforcement

Nominal cover to top reinforcement c_{nom_t} = **35** mm

Nominal cover to bottom reinforcement c_{nom_b} = **35** mm

Nominal cover to side reinforcement c_{nom_s} = **35** mm

Support A



Rectangular section in shear

Design shear force span 1 at 293 mm — $V = \max(V_{A\_s1\_max}, V_{A\_s1\_red})$ = **124** kN

Design shear stress — $v = V / (b \times d)$ = **1.409** N/mm^2

Design concrete shear stress — $v_c = 0.79 \times \min(3,[100 \times A_{s,prov} / (b \times d)]^{1/3}) \times \max(1, (400 /d)^{1/4}) \times (\min(f_{cu}, 40) / 25)^{1/3} / \gamma_m$

v_c = **1.046** N/mm^2

Allowable design shear stress — $v_{max} = \min(0.8\ N/mm^2 \times (f_{cu}/1\ N/mm^2)^{0.5}, 5\ N/mm^2)$ = **5.000** N/mm^2

PASS - Design shear stress is less than maximum allowable

Value of v from Table 3.7 — $0.5 \times v_c < v < (v_c + 0.4\ N/mm^2)$

Design shear resistance required — $v_s = \max(v - v_c, 0.4\ N/mm^2)$ = **0.400** N/mm^2

Area of shear reinforcement required — $A_{sv,req} = v_s \times b / (0.87 \times f_{yv})$ = **276** mm^2/m

Shear reinforcement provided — 2 × 10ϕ legs at 200 c/c

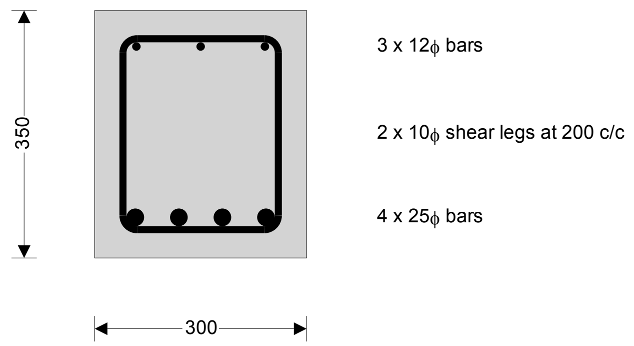
Area of shear reinforcement provided — $A_{sv,prov}$ = **785** mm^2/m

PASS - Area of shear reinforcement provided exceeds minimum required

Maximum longitudinal spacing — $s_{vl,max} = 0.75 \times d$ = **219** mm

PASS - Longitudinal spacing of shear reinforcement provided is less than maximum

<u>**Mid span 1**</u>



Design moment resistance of rectangular section (cl. 3.4.4) - Positive moment

Design bending moment — $M = abs(M_{s1\_red})$ = **168** kNm

Depth to tension reinforcement — $d = h - c_{nom\_b} - \phi_v - \phi_{bot} / 2$ = **293** mm

Redistribution ratio — $\beta_b = \min(1 - m_{rs1}, 1)$ = **1.000**

$K = M / (b \times d^2 \times f_{cu})$ = **0.164**

$K' = 0.156$

K > K' - Compression reinforcement is required

Lever arm — $z = d \times (0.5 + (0.25 - K' / 0.9)^{0.5})$ = **227** mm

Depth of neutral axis — $x = (d - z) / 0.45$ = **145** mm

Depth of compression reinforcement — $d_2 = c_{nom\_t} + \phi_v + \phi_{top} / 2$ = **51** mm

Area of compression reinforcement required — $A_{s2,req} = (K - K') \times f_{cu} \times b \times d^2 / (0.87 \times f_y \times (d - d_2))$ = **76** mm^2

Compression reinforcement provided — 3 × 12ϕ bars

Area of compression reinforcement provided — $A_{s2,prov}$ = **339** mm^2

Maximum area of reinforcement (cl.9.2.1.1(3)) — $A_{s,max} = 0.04 \times b \times h$ = **4200** mm^2

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

Area of tension reinforcement required — $A_{s,req} = K' \times f_{cu} \times b \times d^2 / (0.87 \times f_y \times z) + A_{s2,req}$ = **1697** mm^2

Tension reinforcement provided — 4 × 25ϕ bars

Area of tension reinforcement provided — $A_{s,prov}$ = **1963** mm^2

Minimum area of reinforcement (exp.9.1N) $A_{s,min} = 0.0013 \times b \times h =$ **137** mm²

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

Rectangular section in shear

Shear reinforcement provided 2 × 10ϕ legs at 200 c/c

Area of shear reinforcement provided $A_{sv,prov} =$ **785** mm²/m

Minimum area of shear reinforcement (Table 3.7) $A_{sv,min} = 0.4N/mm^2 \times b / (0.87 \times f_{yv}) =$ **276** mm²/m

PASS - Area of shear reinforcement provided exceeds minimum required

Maximum longitudinal spacing (cl. 3.4.5.5) $s_{vl,max} = 0.75 \times d =$ **219** mm

PASS - Longitudinal spacing of shear reinforcement provided is less than maximum

Design concrete shear stress $v_c = 0.79N/mm^2 \times \min(3,[100 \times A_{s,prov} / (b \times d)]^{1/3}) \times \max(1, (400mm /d)^{1/4}) \times (\min(f_{cu}, 40N/mm^2) / 25N/mm^2)^{1/3} / \gamma_m =$ **1.046** N/mm²

Design shear resistance provided $v_{s,prov} = A_{sv,prov} \times 0.87 \times f_{yv} / b =$ **1.139** N/mm²

Design shear stress provided $v_{prov} = v_{s,prov} + v_c =$ **2.184** N/mm²

Design shear resistance $V_{prov} = v_{prov} \times (b \times d) =$ **191.7** kN

Shear links provided valid between 0 mm and 4800 mm with tension reinforcement of 1963 mm²

Spacing of reinforcement (cl 3.12.11)

Actual distance between bars in tension $s = (b - 2 \times (c_{nom\_s} + \phi_v + \phi_{bot}/2)) /(N_{bot} - 1) - \phi_{bot} =$ **37** mm

Minimum distance between bars in tension (cl 3.12.11.1)

Minimum distance between bars in tension $s_{min} = h_{agg} + 5$ mm $=$ **25** mm

PASS - Satisfies the minimum spacing criteria

Maximum distance between bars in tension (cl 3.12.11.2)

Design service stress $f_s = (2 \times f_y \times A_{s,req}) / (3 \times A_{s,prov} \times \beta_b) =$ **288.0** N/mm²

Maximum distance between bars in tension $s_{max} = \min(47000 N/mm / f_s, 300 mm) =$ **163** mm

PASS - Satisfies the maximum spacing criteria

Span to depth ratio (cl. 3.4.6)

Basic span to depth ratio (Table 3.9) $span\_to\_depth_{basic} =$ **20.0**

Design service stress in tension reinforcement $f_s = (2 \times f_y \times A_{s,req})/ (3 \times A_{s,prov} \times \beta_b) =$ **288.0** N/mm²

Modification for tension reinforcement

$f_{tens} = \min(2.0, 0.55 + (477N/mm^2 - f_s) / (120 \times (0.9N/mm^2 + (M / (b \times d^2))))) =$ **0.761**

Modification for compression reinforcement

$f_{comp} = \min(1.5, 1 + (100 \times A_{s2,prov} / (b \times d)) / (3 + (100 \times A_{s2,prov} / (b \times d)))) =$ **1.114**

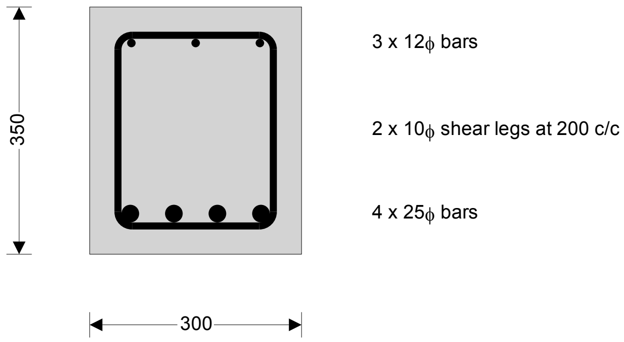
Modification for span length $f_{long} = 1.000$

Allowable span to depth ratio $span\_to\_depth_{allow} = span\_to\_depth_{basic} \times f_{tens} \times f_{comp} =$ **17.0**

Actual span to depth ratio $span\_to\_depth_{actual} = L_{s1} / d =$ **16.4**

PASS - Actual span to depth ratio is within the allowable limit

Support B



Rectangular section in shear

Design shear force span 1 at 4507 mm $V = abs(min(V_{B\_s1\_max}, V_{B\_s1\_red}))$ = **124** kN

Design shear stress $v = V / (b \times d)$ = **1.409** N/mm²

Design concrete shear stress $v_c = 0.79 \times min(3,[100 \times A_{s,prov} / (b \times d)]^{1/3}) \times max(1, (400 /d)^{1/4}) \times (min(f_{cu}, 40) / 25)^{1/3} / \gamma_m$

v_c = **1.046** N/mm²

Allowable design shear stress $v_{max} = min(0.8 N/mm^2 \times (f_{cu}/1 N/mm^2)^{0.5}, 5 N/mm^2)$ = **5.000** N/mm²

PASS - Design shear stress is less than maximum allowable

Value of v from Table 3.7 $0.5 \times v_c < v < (v_c + 0.4 N/mm^2)$

Design shear resistance required $v_s = max(v - v_c, 0.4 N/mm^2)$ = **0.400** N/mm²

Area of shear reinforcement required $A_{sv,req} = v_s \times b / (0.87 \times f_{yv})$ = **276** mm²/m

Shear reinforcement provided 2 × 10ϕ legs at 200 c/c

Area of shear reinforcement provided $A_{sv,prov}$ = **785** mm²/m

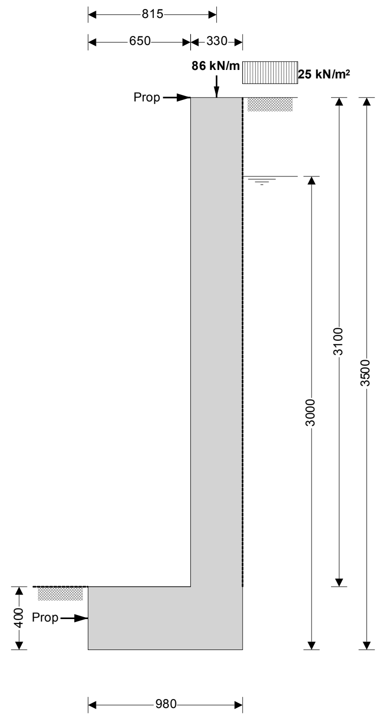
PASS - Area of shear reinforcement provided exceeds minimum required

Maximum longitudinal spacing $s_{vl,max} = 0.75 \times d$ = **219** mm

PASS - Longitudinal spacing of shear reinforcement provided is less than maximum

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at both**
Height of retaining wall stem	h_{stem} = **3100** mm
Thickness of wall stem	t_{wall} = **330** mm
Length of toe	l_{toe} = **650** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **980** mm
Thickness of base	t_{base} = **400** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **15** mm
Thickness of downstand	t_{ds} = **400** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **3500** 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} = **3000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **2600** 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	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **3500** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3

Saturated density of retained material γ_s = **21.0** kN/m^3

Design shear strength ϕ' = **18.6** deg

Angle of wall friction δ = **0.0** deg

Base material details

Firm clay

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

Design shear strength ϕ'_b = **16.5** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **150** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.516}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{2.835}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi') = \mathbf{0.681}$

Loading details

Surcharge load on plan Surcharge = **25.0** kN/m^2

Applied vertical dead load on wall W_{dead} = **80.7** kN/m

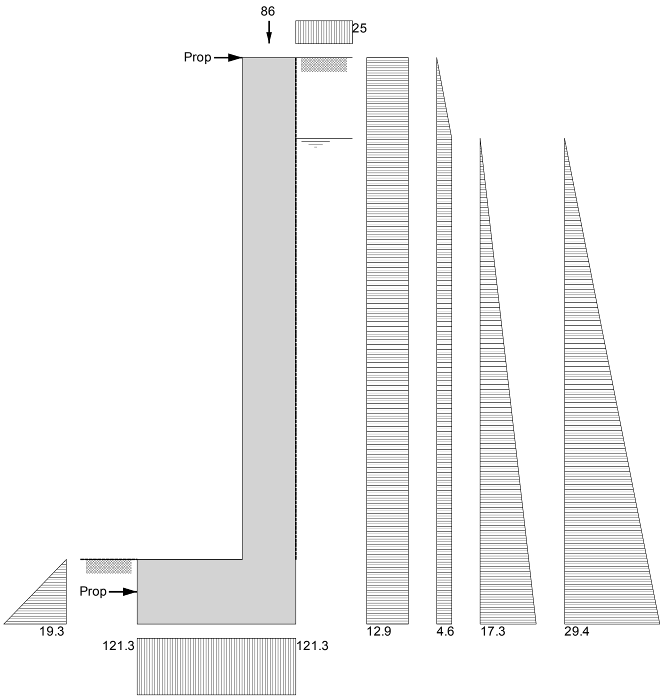
Applied vertical live load on wall W_{live} = **4.8** kN/m

Position of applied vertical load on wall l_{load} = **815** 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 $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **24.1** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **9.3** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **85.5** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **118.9** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **45.2** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **1.2** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **13.9** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **26** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **44.1** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **130.4** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **3.9** kN/m

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

F_{prop} = **88.2** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **79.1** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **3.7** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **20.9** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **26** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **44.1** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **173.8** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **19.7** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **4.5** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load}$ = **65.8** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **90** kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total}$ = **118.9** kN/m

Distance to reaction $x_{bar} = l_{base} / 2$ = **490** 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 $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **121.3** kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **121.3** 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

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **37.711** kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top}$ = **50.451** kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

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 $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **33.8** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **13** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **120.7** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **167.4** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times h_{eff}$ = **95.3** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **2.1** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **25.7** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **48** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **61.8** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **233** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **5.4** kN/m

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

F_{prop_f} = **173.9** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **166.9** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **6.8** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **38.6** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **48** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **61.8** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **322.1** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **27.5** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **6.3** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **98.3** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **132.2** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **167.4** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **490** mm

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

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **170.8** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **170.8** kN/m^2

Rate of change of base reaction $\text{rate} = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2)$ = **170.8** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{170.8}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{170.8}\ kN/m^2$

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{71.849}\ kN/m$

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f} = \mathbf{102.026}\ kN/m$

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

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}\ N/mm^2$

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

Base details

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

Cover to reinforcement in toe $c_{toe} = \mathbf{45}\ mm$

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{111}\ kN/m$

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{8.6}\ kN/m$

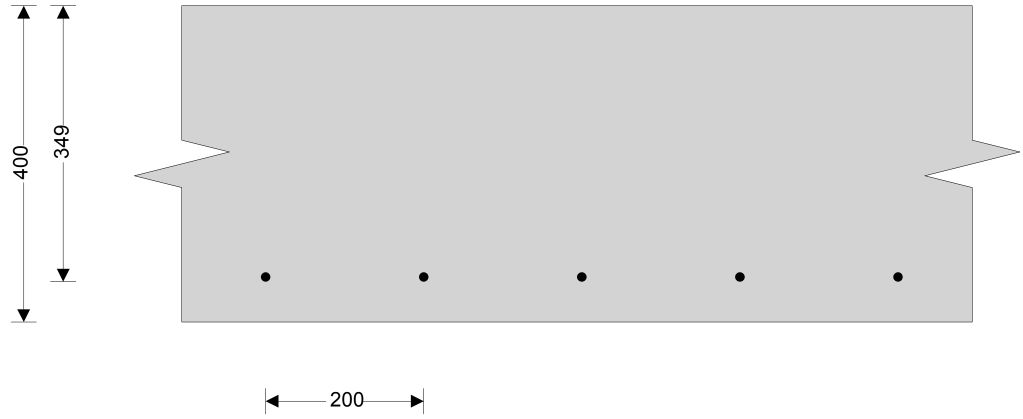
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{102.4}\ kN/m$

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{56.7}\ kNm/m$

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{4.4}\ kNm/m$

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{52.3}\ kNm/m$



Check toe in bending

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

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{349.0}\ mm$

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.011}$

Compression reinforcement is not required

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

$z_{toe} = \mathbf{332}\ mm$

Area of tension reinforcement required $As_{toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{363}\ mm^2/m$

Minimum area of tension reinforcement $As_{toe\_min} = k \times b \times t_{base} = \mathbf{520}\ mm^2/m$

Area of tension reinforcement required $As_{toe\_req} = \max(As_{toe\_des}, As_{toe\_min}) = \mathbf{520}\ mm^2/m$

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $As_{toe\_prov} = \mathbf{565}\ mm^2/m$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.294** 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_toe} = **0.417** N/mm²

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

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

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm²

Characteristic strength of reinforcement f_y = **500** N/mm²

Wall details

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

Cover to reinforcement in stem c_{stem} = **45** mm

Cover to reinforcement in wall c_{wall} = **45** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **84.4** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **2.1** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **22.3** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **36.1** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **46.4** kN/m

Calculate shear for stem design

Surcharge $V_{s\_sur\_f} = 5 \times F_{s\_sur\_f} / 8$ = **52.8** kN/m

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **0.3** kN/m

Moist backfill below water table $V_{s\_m\_b\_f} = F_{s\_m\_b\_f} \times (8 - (n^2 \times (4 - n))) / 8$ = **16** kN/m

Saturated backfill $V_{s\_s\_f} = F_{s\_s\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **30.7** kN/m

Water $V_{s\_water\_f} = F_{s\_water\_f} \times (1 - (a_l^2 \times ((5 \times L) - a_l) / (20 \times L^3)))$ = **39.5** kN/m

Total shear for stem design $V_{stem} = V_{s\_sur\_f} + V_{s\_m\_a\_f} + V_{s\_m\_b\_f} + V_{s\_s\_f} + V_{s\_water\_f}$ = **139.2** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times L / 8$ = **34.8** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **0.4** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times a_l \times (2 - n)^2 / 8$ = **10.4** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **15.9** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times a_l \times ((3 \times a_l^2) - (15 \times a_l \times L) + (20 \times L^2)) / (60 \times L^2)$ = **20.4**
kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **81.8** kNm/m

Calculate moment for wall design

Surcharge $M_{w\_sur} = 9 \times F_{s\_sur\_f} \times L / 128$ = **19.6** kNm/m

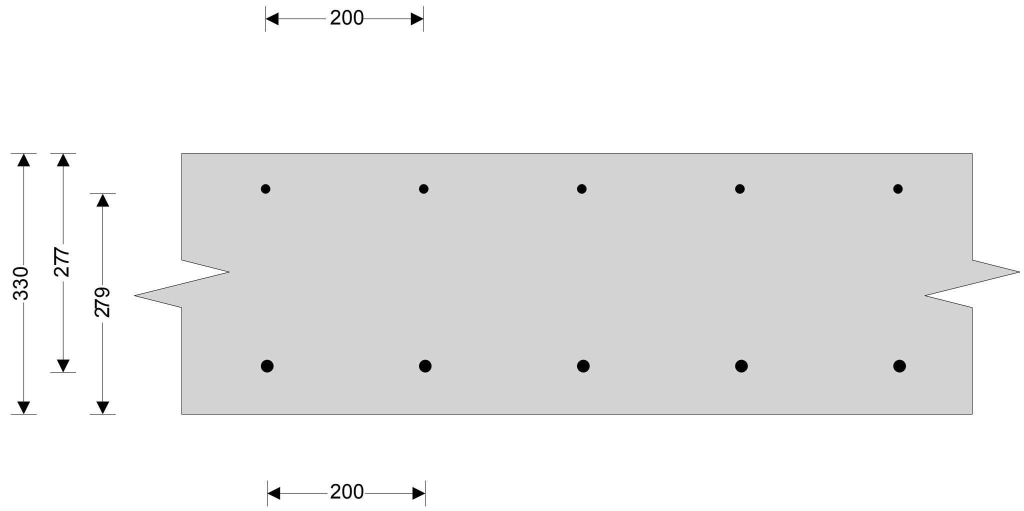
Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2)/(5 \times L^3) - 0.577^2/3]$ = **0.5**
kNm/m

Moist backfill below water table $M_{w\_m\_b} = F_{s\_m\_b\_f} \times a_l \times [((8 - n^2 \times (4 - n))^2 / 16) - 4 + n \times (4 - n)]/8$ = **5.7** kNm/m

Saturated backfill $M_{w\_s} = F_{s\_s\_f} \times [a_l^2 \times x \times ((5 \times L) - a_l)/(20 \times L^3) - (x - b_l)^3 / (3 \times a_l^2)]$ = **6.6** kNm/m

Water — $M_{w\_water} = F_{s\_water\_f} \times [a_l^2 \times x \times ((5 \times L)-a_l)/(20 \times L^3)-(x-b_l)^3 /(3 \times a_l^2)]$ = **8.5** kNm/m

Total moment for wall design — $M_{wall} = M_{w\_sur} + M_{w\_m\_a} + M_{w\_m\_b} + M_{w\_s} + M_{w\_water}$ = **40.8** kNm/m



Check wall stem in bending

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

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **277.0** mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.027**

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} = **263** mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **715** mm²/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **429** mm²/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **715** mm²/m

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

Area of reinforcement provided — $A_{s\_stem\_prov}$ = **1005** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.503** 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} = **0.578** N/mm²

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

Check mid height of wall in bending

Depth of reinforcement — $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **279.0** mm

Constant — $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu})$ = **0.013**

Compression reinforcement is not required

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

z_{wall} = **265** mm

Area of tension reinforcement required — $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall})$ = **354** mm²/m

Minimum area of tension reinforcement — $A_{s\_wall\_min} = k \times b \times t_{wall}$ = **429** mm²/m

Area of tension reinforcement required $A_{s\_wall\_req}$ = Max($A_{s\_wall\_des}$, $A_{s\_wall\_min}$) = **429** mm^2/m

Reinforcement provided **12 mm dia.bars @ 200 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov}$ = **565** mm^2/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 $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **237.1** N/mm^2

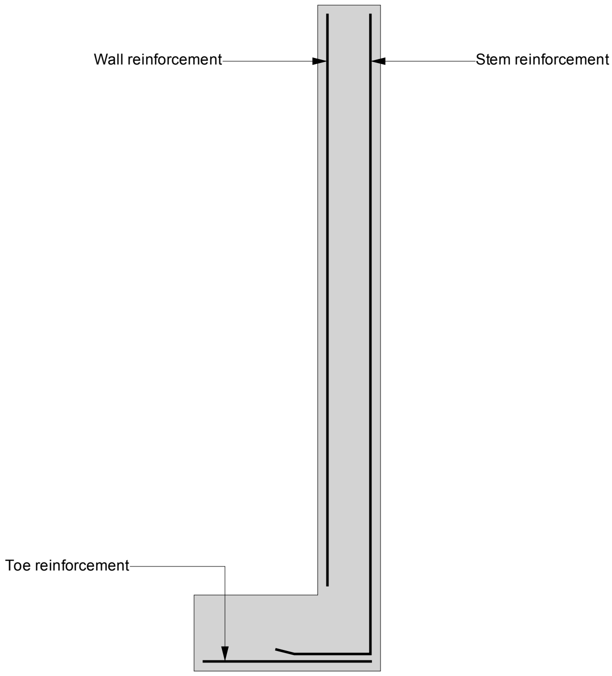
Modification factor $factor_{tens} = \min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.57**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **31.33**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **11.19**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Wall bars - 12 mm dia.@ 200 mm centres - (565 mm^2/m)
Stem bars - 16 mm dia.@ 200 mm centres - (1005 mm^2/m)

Annex A - Structural methodology

Introduction

This document sets out the structural methodology for the construction of the basement at 10, Downside Crescent.

Details of the stages

This methodology includes the drawings 1411-31 which is included in the drawings package. Reference should also be made to the other drawings in the contract.

PRE SITE START

1. Install monitoring positions on walls and do baseline survey. Monitoring to be carried out in accordance with movement monitoring specification thereafter, during structural works.

STAGE 1

2. Saw cut any existing ground floor screed, where it is present, to its full depth parallel to the party wall with No.8 as close to it as feasible and remove the portion against the party wall to limit vibration born noise through the party wall during demolition.

3. Demolish side infill with party wall toward No.12, observing the main house walls for any movement as demolition proceeds.

STAGE 2

4. Install underpinning to the party wall with No.8 and under main building walls where indicated on plan, in an agreed sequence.

5. Only ASUC registered underpinning specialists to be used to carry out the work.

6. Excavate for the pin, each excavation to be no more than 1 m wide. Excavations to be temporarily shored as they progress down in accordance with good practice. The line of the rear face of the excavation under the party wall is to be carefully set out to be at the face of the adjoining owner's wall above (allowing for the corbel to overhang). The rear face is to be shored with sacrificial cement board shutters. A lean mix cementitious grout is to be poured down the back of these boards as they are placed to fill any voids.

7. Carefully remove any existing mass concrete footing if present, clean off the underside of the existing original footing and repair any damaged brickwork.

8. Clean and blind the base of the excavation, put in the reinforcement and cast the toe and kicker of the pin with continuity reinforcement pushed into the surrounding soil to give the required lap for the next pins or using couplers.

STAGE 3

9. To allow for continuity of the reinforced concrete in the wall and suspended slab, carefully saw cut a section of the brickwork vertically on the line of the party wall boundary at the centre of the wall. The use of percussion tools to remove the brickwork will not be permitted.

10. Reinforce the pin and cast the wall up to 75mm below the footing level or underside of prepared brickwork, with continuity reinforcement or couplers as for its toe.

11. Dry pack the back half of the pin to the underside of the brickwork.

12. Cast the small remaining section of the front half of the pin.

13. Dry pack the front half of the pin to the underside of the cut brickwork.

14. Leave excavation to pin fully shored and proceed with the next pin in the sequence.

STAGE 4

15. Excavate trench for basement rear wall. Excavations to be temporarily shored as they progress down in accordance with good practice.

16. Clean and blind the base of the excavation, put in the reinforcement and cast the toe and kicker of the pin with continuity reinforcement pushed into the surrounding soil to give the required lap for the base slab and returning walls or using couplers.

17. When the concrete has gained sufficient strength place reinforcements and cast the wall up to the underside of the future ground floor slab.

STAGE 5

18. For the side walls of the new basement under the rear extension install first temporary sheet piles to secure excavation and adjoining walls at No. 12.

19. Prop top of piles, over future ground floor slab level, using horizontal waling beam and soldiers.

20. Dig trenches supported by shoring and cast side walls toe and stem first.

21. When the concrete has gained sufficient strength place reinforcements and cast the walls up to the underside of the future ground floor slab.

22. Install temporary needles and steelwork to support back and internal walls of the main building prior to commencing excavation of basement area. Dig local pit or trenches if necessary to allow construction of temporary pad or strip foundation at basement level to support temporary props. Excavations to be temporarily shored as they progress down in accordance with good practice.

STAGE 6

23. Excavate to 1000mm below existing ground floor level removing the top level of shoring to the underpinning and main retaining walls.

24. Install propping and waling beams at high level, just below the level of the proposed concrete ground floor slab, resin anchored to retaining walls. NOTE - Contractor to set out and split the beams, providing robust end plate and bolted splice connections to suit their manual handling requirements.

STAGE 7

25. Excavate inside the basement to 1000mm above proposed concrete slab removing the shoring down to the level of the excavation only, keeping the bottom shoring in place.

26. Locally excavate trenches max 400mm wide to the top of slab level across the building. Put low level propping to the underpinned wall within the trenches, just above the proposed slab level. NOTE - Contractor to set out and split the beams, providing robust end plate and bolted splice connections to suit their manual handling requirements.

STAGE 8

27. Complete excavation inside to basement slab formation level.

28. Lay blinding concrete, place reinforcement, and wall starter bars.

29. Cast basement slab with any drainage channels if necessary.

30. When basement slab concrete has reached strength, remove the low level propping and waling beams.

31. Place reinforcement, formwork and cast the reinforced concrete walls

32. Place soffit formwork and supporting temporary works, place reinforcement and cast ground floor slab, with boxouts for the temporary steelwork.

33. Remove high level propping in basement, when concrete reaches strength.

34. Dry-pack under the existing walls to the building where they will be supported on the concrete superstructure.

35. Remove temporary needles and steel work supporting structure, and fill in the boxouts.

36. Install drained cavity.

37. Construct rear extension.

38. Complete the construction and fitting out.

Annex B – Movement monitoring specification

1. Introduction

The purpose of this specification is to outline the requirements for a movement monitoring system that will measure movements during underpinning and basement excavation works. Movements of the owners' property and the neighbouring property, No.8 Downside Crescent and No.12 Downside Crescent will be monitored.

2. Installation

2.1. Control

Monitoring control stations are to be established around the site perimeter from which the monitoring targets can be surveyed. Additional control survey targets are to be placed outside the site's zone of influence and accurately fixed in 3 dimensions. These targets will be used to establish station coordinates prior to each survey.

2.2. Reflective targets

Monitoring points are to be installed as per the attached sketches. Exact locations are to be adjusted to ensure line of sight from survey stations. Targets are to be attached to walls using epoxy adhesive.

2.3. Tilt meters

Wireless high precision tilt sensors transmit data to the monitoring provider's office over an internet connection and can be published to a web portal with automatic alerts to the contractor at trigger levels. No tilt meters on party walls are suggested.

2.4. Precise levels

Precise level monitoring points are to be installed below each tilt-meter to monitor precise vertical movement. These are to be done head ball studs resin anchored into the wall.

3. Monitoring

3.1. Reflective Targets

These are to be surveyed using two rounds of angles for each survey point and recorded. Any large deviations are to be immediately reported to the contractor.

3.2. Precise levels

Precise levelling points are to be levelled based on benchmarks and levelling runs should be based on closed loops. Any closures greater than 1mm will require measurements to be repeated.

4. Monitoring frequency

Monitoring is to commence during site establishment. The initial set of baseline readings should be taken minimum 1 month before commencement of any significant structural works and then a first set of readings should be taken immediately prior to the start of any groundworks.

Thereafter monitoring should be carried out weekly during underpinning, excavation, temporary shoring, and concrete basement box construction. Once basement works are complete including the removal of all temporary works a set of readings should be taken followed by 3 more sets at intervals of 1 month.

5. Trigger values

Trigger levels for neighbouring property and party wall monitoring are set as follows;

Vertical settlement

Threshold value is 75% of trigger value – Report to all parties. Contractor to check walls in the vicinity of the monitoring point and report any new cracking. If cracks are evident, then crack monitors are to be installed and reported on weekly. Engineer to check relative settlement from neighbouring monitoring points and determine if any further action is required.

Action values are reported in the attached plan – Stop work and report to all parties. Contractor to check walls in the vicinity of the monitoring point and report on any cracking. Engineer to check relative settlement from neighbouring monitoring points and determine what action is required.

Tilt

Threshold alert value 1/500 – Automatic alert issued to contractor who is to alert all parties. Contractor to check party wall for any visible defects. Engineer to determine if any further action is required.

Threshold alert value 1/350 – Automatic alert issued to contractor who is to alert all parties and stop work. Contractor to check party wall for any visible defects. Engineer to determine what further action is required.

Trigger levels for areas other than the neighbouring property and party wall are set as follows;

Vertical settlement

Threshold value 4mm – Report to all parties. Contractor to check walls in the vicinity of the monitoring point and report any new cracking. If cracks are evident, then crack monitors are to be installed and reported on weekly. Engineer to check relative settlement from neighbouring monitoring points and determine if any further action is required.

Action value 6mm – Stop work and report to all parties. Contractor to check walls in the vicinity of the monitoring point and report on any cracking. Engineer to check relative settlement from neighbouring monitoring points and determine what action is required.

Horizontal movement

Threshold value 4mm – Report to all parties. Contractor to check walls in the vicinity of the monitoring point and report any new cracking. If cracks are evident, then crack monitors are to be installed and reported on weekly. Engineer to check relative movement from neighbouring monitoring points and determine if any further action is required.

Action value 6mm – Stop work and report to all parties. Contractor to check walls in the vicinity of the monitoring point and report on any cracking. Engineer to check relative movement from neighbouring monitoring points and determine what action is required.

6. Reporting

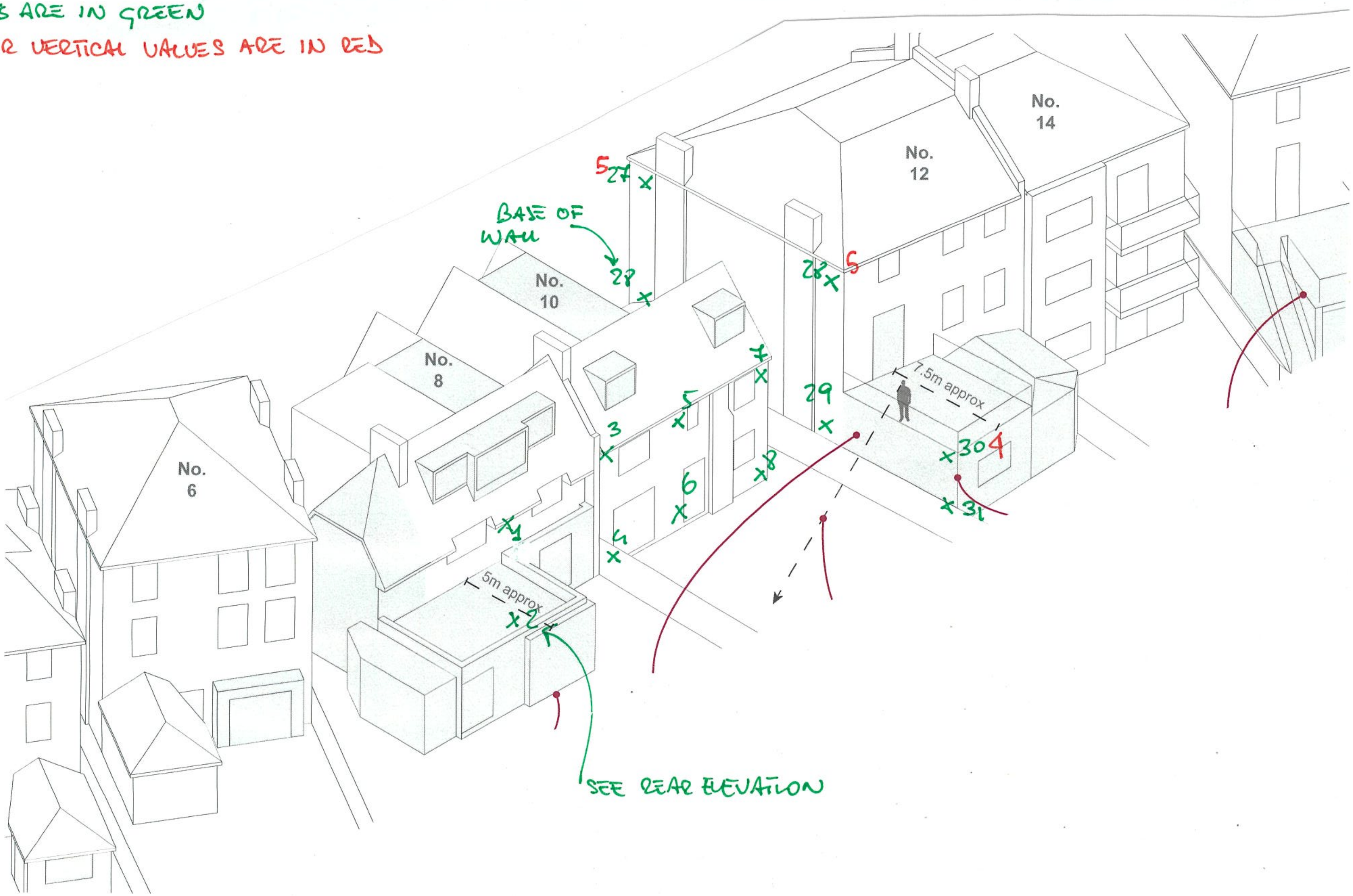
The reporting will be provided in PDF format.

Each report will contain the following information:

- Executive Summary
- Date of survey,
- Weather conditions during survey,
- Surveyor responsible for the survey.
- Applicable notes and accuracies
- Tabular data highlighting exceeding specified trigger limits.
- Graphs showing vertical and horizontal movements with time.
- Location plans

TARGETS ARE IN GREEN

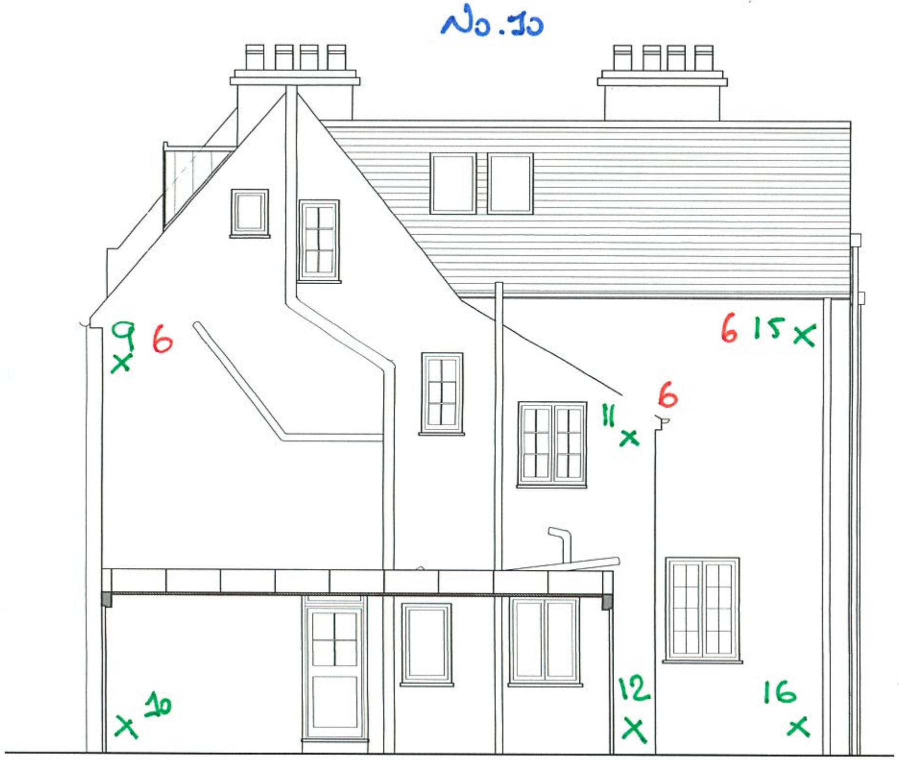
TRIGGER VERTICAL VALUES ARE IN RED



TARGETS ARE IN GREEN

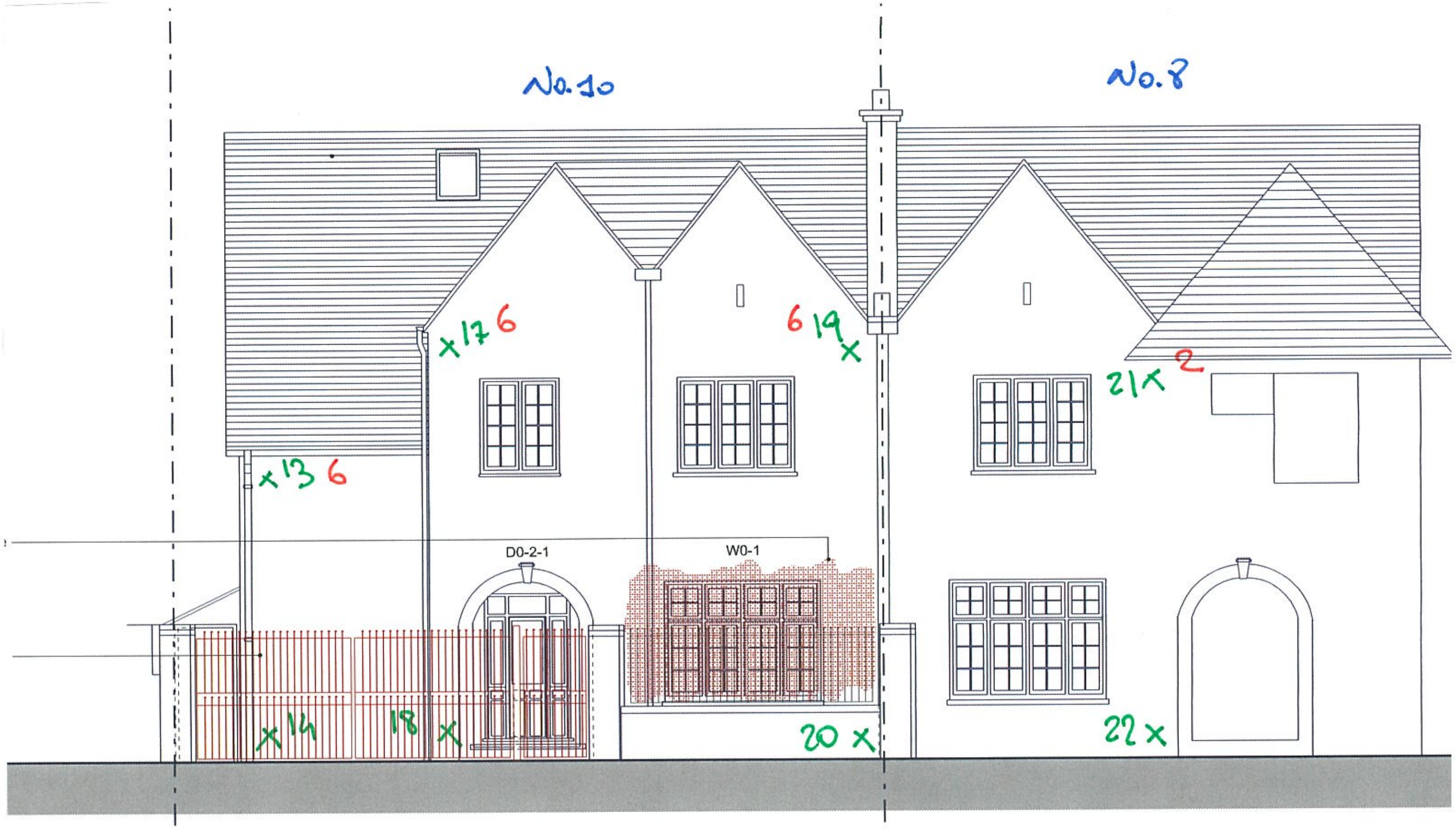
TRIGGER VERTICAL VALUES ARE IN RED

Existing Rear Elevation



EXISTING
Side Elevation
SCALE 1:100@A3 EX-02

TARGETS ARE IN GREEN
TRIGGER VERTICAL LEVEL ARE IN RED



Existing Front Elevation

EXISTING GROUND FLOOR