192 Haverstock Hill, NW3 2AJ

One Dimensional Basement Heave Calculations

Revision 01 February 2016

Job No 13358

Introduction

The re-development of No. 192 Haverstock Hill will include the excavation of a 4m basement.

Approximately 12m to the south of the site are the lift and stair shafts to Belsize Park Underground station. Extending north from the station at both its front and rear are the platform and deep storage tunnels respectively. London Underground asset records show;

i. The crown of the nearest platform tunnel is 7m outside the front of the site at depth of 30m BGL.

ii. The crown of the western deep storage tunnel is 7m inside the rear of the site at a depth of 35m BGL; the eastern deep storage tunnel is outside the footprint of the basement.

iii. The crown of the eastern deep storage tunnel is below the rear of the site.

See attached section drawing 13358_101 & 102.

Given the position of these tunnels and lift shaft relative to the development site, a one dimensional heave assessment of the basement excavation has been completed.

1. Soil Data

1.1 Investigation Data

Two boreholes were sunk as part of the investigations establishing that the site is founded on London Clay.

The London Clay was proved to a depth of 20m.

1.2 Strength and Stiffness Parameters

The undrained strength/depth profile for the London Clay has been taken from the boreholes based on Stroud correlation of C_u = 5.5 x SPT Value.

This gives a C_u value at the top of the clay = 100 kN/m^2 and 200kN/m^2 at a depth of 20m. The maximum cohesion has been taken as 200kN/m^2, without further increase in strength.

The undrained stiffness of London Clay ranges typically from 40MN/m^2 to over 160MN/m^2 and suggested correlations between undrained cohesion, C_u, and undrained Youngs Modulus, E_u, range between E_u = 400C_u to 600 C_u.

A value of E_u = 400 C_u has been adopted in the current analysis of the heave.

2. Analysis

The analysis is based on Boussinesq elastic stress distribution utilising Newmark Charts to give the stress below the corner of a rectangle.

Two metre thick ground layers were considered with the tunnels the accumulative movement up to the crown calculated. For the vertical shaft the total accumulative heave to ground level is to be calculated.

The four locations considered are:

i. The basement footprint which coincides with the crown of the Eastern deep storage tunnel which is 35m BGL.

ii. The crown of the Western deep storage tunnel to the rear which has been taken as 35m BGL;

iii. The crown of the platform tunnel to the front of the site which has been taken as 30m BGL;

iv. The vertical access shaft which included the lift and emergency stairs :

The Newmark Rectangles are shown on drawing 13358_103.

No allowance has been made for the reinforcing effect of the piles, which will reduce the heave through adhesion.

2.1 Analysis Cut Off

In theory the Boussinesq elastic stress distribution, extends to infinity. In practice the Newmark curves used to find the coefficients stop when the depth is more than 10 times the narrowest rectangle dimension.

The analyses were stopped when either:

i. The change in stress due to the excavation was less than 1/200 of the overburden stress;
ii. The heave was less than 0.1mm on a 2m slice.

2.2 Drained Parameters

Drained heave results would be higher than the undrained values, but would take a greater time to achieve the necessary pore water pressure equilibrium. Given that the basement box construction will commence as soon as the excavation is complete the net reduction in overburden will be reduced and any drained results would relate to the completed frame.

3. Results

Four analyses were completed.

3.1 Eastern Deep storage tunnel

The movement at the mid-point of the short side of the basement was calculated. Splitting the site in half, this required one coefficient which was doubled for symmetry.

At 37m BGL, the stress changes were down to 0.5% of the overburden and at 39m BGL the ground movements were found to be less than 0.1mm for a 2m thick slice. The eastern Deep Storage Tunnel is just outside the basement with the cumulative heave to the crown of this tunnel being 0.3mm

3.2 Western Deep Storage Tunnel

The movement over the deep storage tunnel towards the rear of the site was calculated assuming symmetrical rectangles across the width of the site.

At a depth of 43m BGL the change in stress was less than 0.5% of the overburden and at 45m BGL the ground movements were less than 0.1mm for a 2m thick slice. Extrapolating the heave to 49m BGL, the accumulative heave to the crown of the tunnel was 0.8mm.

3.3 Platform Tunnel

The ground movement over the nearest platform tunnel at the front of the site was calculated. This was achieved by extending the 4m excavation to the platform tunnel with superposition of "filling" of the 7m outside the basement box to give the required profile.

At a depth of 33m BGL, the change in stress was less than 0.5% of the overburden and the ground movements were less than 0.1mm for a 2m thick slice. Extrapolating the heave to 41m BGL, the accumulative heave to the crown of the tunnel was 0.4mm.

3.4 Vertical Access Shaft

Similarly to the Platform Tunnel, the effect of the excavation on the vertical shaft within the station was considered by superposition of fill outside the basement on the larger excavation area.

With the distance from the basement, the heave was small, with the stress less than 0.5% of the overburden at a depth of 37m BGL. The accumulative heave at ground level was 1.7mm on a shaft that is over 30mm deep.

No allowance has been made for the self-weight of the shaft or the superstructure of the station building; the 1.7mm heave is an upper bound value. To place this in context, this is equivalent to a 4 degC change in temperature on a 30m tall concrete shaft.

4. Conclusion

For the three tunnel locations, the accumulative heave to the crown of the tunnel was found to be less than 1mm. Movements of this magnitude are not considered an issue by London Underground.

The heave of the vertical shaft, at 1.7mm is an upper bound value and is not considered an issue.

192 Haverstock Hill NW3 2AJ
Heave beneath 4m Basement Excavation
Eastern Deep Storage Tunnel

Building: 30 m 7 m Soil Density kN/m^3 20

Depth of basem't BGL m: 4.0

Newmark Rectangles 30 m x 3.5 m Overburden removed -80 kN/m^2

	Depth BGL	AOD	Depth below Base	Av below Base	Newm'k Rect'gle Coeffs	Coeff Total	Overburden Orig	Re-moved	After Excav-ation	% Chan-ge	Layer Thick m	C_u kN/m^2	E_u= 400C_u MN/m^2	Heave mm	Acc to top of Tunnel
Ground	0	69.0													
Basem't	4	65.0	0				80.0					100			
				1	0.250	0.500	100.0	-40.0	60.0		2.00	105	42.00	-1.90	
	6	63.0	2.0												
				3	0.215	0.430	140.0	-34.4	105.6	24.6%	2.00	115	46.00	-1.50	
	8	61.0	4.0												
				5	0.175	0.350	180.0	-28.0	152.0	15.6%	2.00	125	50.00	-1.12	
	10	59.0	6.0												
				7	0.137	0.274	220.0	-21.9	198.1	10.0%	2.00	135	54.00	-0.81	
	12	57.0	8.0												
				9	0.115	0.230	260.0	-18.4	241.6	7.1%	2.00	145	58.00	-0.63	
	14	55.0	10.0												
				11	0.095	0.190	300.0	-15.2	284.8	5.1%	2.00	155	62.00	-0.49	
	16	53.0	12.0												
				13	0.080	0.160	340.0	-12.8	327.2	3.8%	2.00	165	66.00	-0.39	
	18	51.0	14.0												
				15	0.067	0.134	380.0	-10.7	369.3	2.8%	2.00	175	70.00	-0.31	
	20	49.0	16.0												
				17	0.062	0.124	420.0	-9.9	410.1	2.4%	2.00	185	74.00	-0.27	
	22	47.0	18.0												
				19	0.057	0.114	460.0	-9.1	450.9	2.0%	2.00	195	78.00	-0.23	
	24	45.0	20.0												
				21	0.048	0.096	500.0	-7.7	492.3	1.5%	2.00	200	80.00	-0.19	
	26	43.0	22.0												
				23	0.044	0.088	540.0	-7.0	533.0	1.3%	2.00	200	80.00	-0.18	
	28	41.0	24.0												
				25	0.040	0.080	580.0	-6.4	573.6	1.1%	2.00	200	80.00	-0.16	
Platform	30	39.0	26.0												
Tunnel				27	0.037	0.074	620.0	-5.9	614.1	1.0%	2.00	200	80.00	-0.15	
Crown	32	37.0	28.0												
				29	0.033	0.066	660.0	-5.3	654.7	0.8%	2.00	200	80.00	-0.13	
	34	35.0	30.0												
				31	0.029	0.058	700.0	-4.6	695.4	0.7%	2.00	200	80.00	-0.12	
Deep	36	33.0	32.0												
Storage				33	0.028	0.056	740.0	-4.5	735.5	0.6%	2.00	200	80.00	-0.11	-0.31
Tunnel	38	31.0	34.0												
				35	0.025	0.050	780.0	-4.0	776.0	0.5%	2.00	200	80.00	-0.10	
	40	29.0	36.0												
				37	0.024	0.048	820.0	-3.8	816.2	0.5%	2.00	200	80.00	-0.10	

192 Haverstock Hill NW3 2AJ
Heave beneath 4m Basement Excavation
Western Deep Storage Tunnel

Building:	30 m	7 m	Soil Density kN/m^3	20		
Newmark Rectangles	23 m x	3.5 m	Depth of basem't BGL m:	4.0		
	7 m x	3.5 m	Overburden removed	-80	kN/m^2	

	Depth BGL	AOD	Depth below Base	Av below Base	Newmark Rectangle Coeffs 1	2	Coeff Total	Overburden Orig	Re-moved	After Excav-ation	% Chan-ge	Layer Thick m	C_u kN/m^2	E_u= 400C_u MN/m^2	Heave mm	Acc to top of tunnel
Ground	0	69.0														
Basem't	4	65.0	0					80.0					100			
				1	0.250	0.247	0.994	100.0	-79.5	20.5	80%	2.00	105	42.00	-3.79	
	6	63.0	2.0													
				3	0.210	0.210	0.840	140.0	-67.2	72.8	48%	2.00	115	46.00	-2.92	
	8	61.0	4.0													
				5	0.170	0.163	0.666	180.0	-53.3	126.7	30%	2.00	125	50.00	-2.13	
	10	59.0	6.0													
				7	0.135	0.120	0.510	220.0	-40.8	179.2	19%	2.00	135	54.00	-1.51	
	12	57.0	8.0													
				9	0.110	0.090	0.400	260.0	-32.0	228.0	12%	2.00	145	58.00	-1.10	
	14	55.0	10.0													
				11	0.093	0.067	0.320	300.0	-25.6	274.4	8.5%	2.00	155	62.00	-0.83	
	16	53.0	12.0													
				13	0.080	0.055	0.270	340.0	-21.6	318.4	6.4%	2.00	165	66.00	-0.65	
	18	51.0	14.0													
				15	0.067	0.040	0.214	380.0	-17.1	362.9	4.5%	2.00	175	70.00	-0.49	
	20	49.0	16.0													
				17	0.060	0.035	0.190	420.0	-15.2	404.8	3.6%	2.00	185	74.00	-0.41	
	22	47.0	18.0													
				19	0.050	0.026	0.152	460.0	-12.2	447.8	2.6%	2.00	195	78.00	-0.31	
	24	45.0	20.0													
				21	0.045	0.024	0.138	500.0	-11.0	489.0	2.2%	2.00	200	80.00	-0.28	
	26	43.0	22.0													
				23	0.040	0.019	0.118	540.0	-9.4	530.6	1.7%	2.00	200	80.00	-0.24	
	28	41.0	24.0													
				25	0.037	0.017	0.108	580.0	-8.6	571.4	1.5%	2.00	200	80.00	-0.22	
Platform	30	39.0	26.0													
Tunnel				27	0.033	0.015	0.096	620.0	-7.7	612.3	1.2%	2.00	200	80.00	-0.19	
Crown	32	37.0	28.0													
				29	0.030	0.012	0.084	660.0	-6.7	653.3	1.0%	2.00	200	80.00	-0.17	
	34	35.0	30.0													
				31	0.026	0.011	0.074	700.0	-5.9	694.1	0.8%	2.00	200	80.00	-0.15	
Deep	36	33.0	32.0													
Storage				33	0.025	0.010	0.070	740.0	-5.6	734.4	0.8%	2.00	200	80.00	-0.14	-0.79
Tunnel	38	31.0	34.0													
				35	0.023	0.009	0.064	780.0	-5.1	774.9	0.7%	2.00	200	80.00	-0.13	
	40	29.0	36.0													
				37	0.022	0.0085	0.061	820.0	-4.9	815.1	0.6%	2.00	200	80.00	-0.12	
	42	27.0	38.0													
				39	0.020	0.008	0.055	860.0	-4.4	855.6	0.5%	2.00	200	80.00	-0.11	
	44	25.0	40.0													
				41	0.019	0.007	0.052	900.0	-4.2	895.8	0.5%	2.00	200	80.00	-0.10	
	46	23.0	42.0													
				43	0.018	0.007	0.049	940.0	-3.9	936.1	0.4%	2.00	200	80.00	-0.10	
	48	21.0	44.0													
				45	0.017	0.006	0.046	980.0	-3.7	976.3	0.4%	2.00	200	80.00	-0.09	

192 Haverstock Hill NW3 2AJ
Heave beneath 4m Basement Excavation
Platform Tunnel

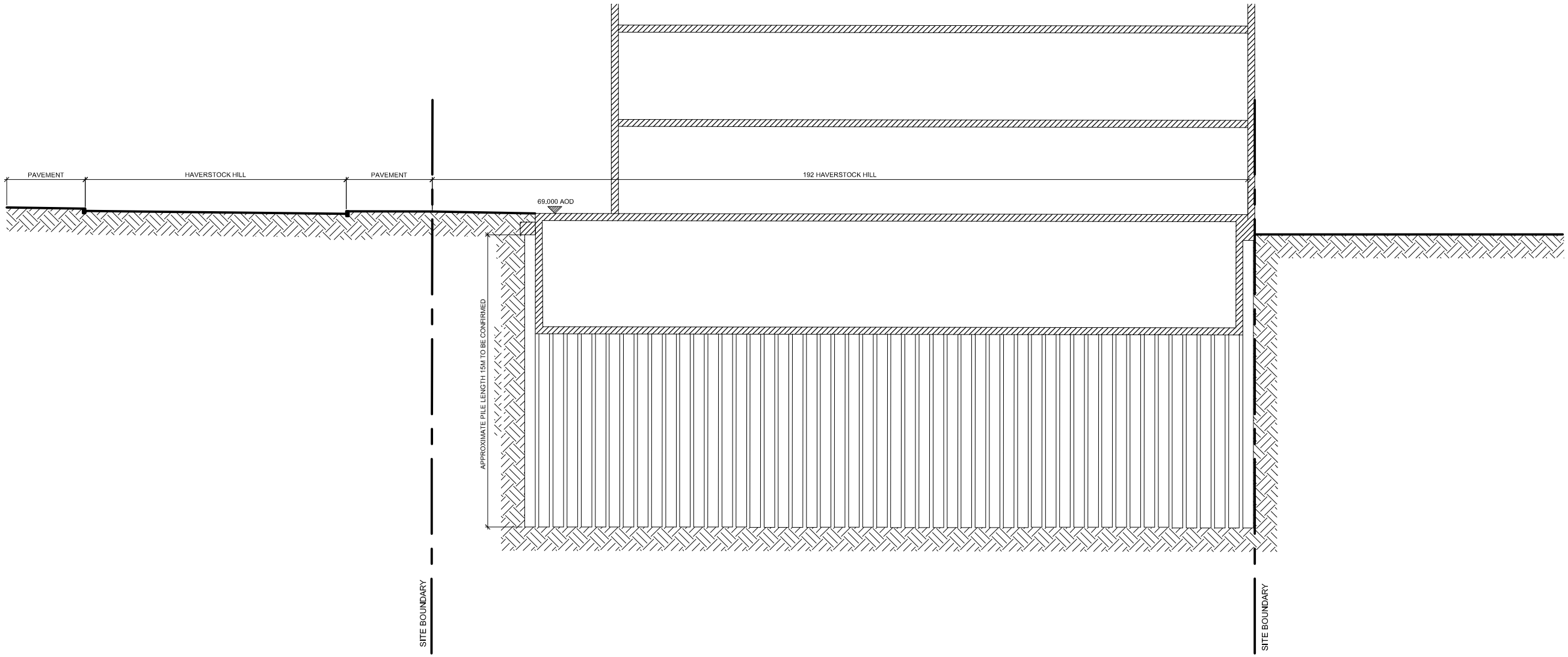
Building:	30	m	7	m	Soil Density kN/m^3	20	
Newmark Rectangles	37	m x	3.5	m	Depth of basem't BGL m:	4.0	
	7	m x	3.5	m	Overburden removed	-80	kN/m^2

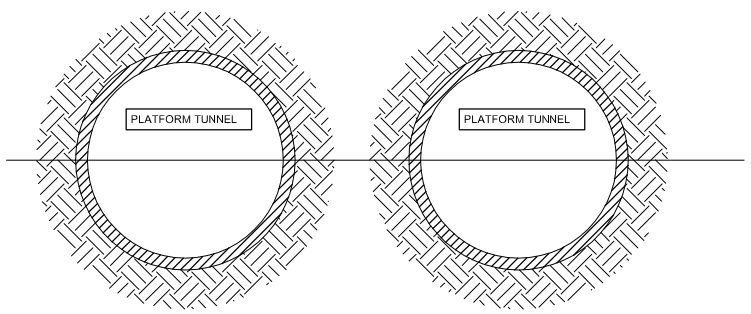
	Depth BGL	AOD	Depth below Base	Av below Base	Newmark Rectangle Coeffs 1	2	Coeff Total	Overburden Orig	Remov	After Excav-ation	% Chan-ge	Layer Thick m	C_u kN/m^2	E_u= 400C_u MN/m^2	Heave mm	Acc to top of tunnel
Ground	0	69.0														
Basem't	4	65.0	0					80.0					100			
				1	0.250	0.247	0.006	100.0	-0.5	99.5		2.00	105	42.00	-0.02	
	6	63.0	2.0													
				3	0.250	0.210	0.080	140.0	-6.4	133.6	4.6%	2.00	115	46.00	-0.28	
	8	61.0	4.0													
				5	0.173	0.163	0.020	180.0	-1.6	178.4	0.9%	2.00	125	50.00	-0.06	
	10	59.0	6.0													
				7	0.137	0.120	0.034	220.0	-2.7	217.3	1.2%	2.00	135	54.00	-0.10	
	12	57.0	8.0													
				9	0.113	0.090	0.046	260.0	-3.7	256.3	1.4%	2.00	145	58.00	-0.13	
	14	55.0	10.0													
				11	0.095	0.067	0.056	300.0	-4.5	295.5	1.5%	2.00	155	62.00	-0.14	
	16	53.0	12.0													
				13	0.080	0.055	0.050	340.0	-4.0	336.0	1.2%	2.00	165	66.00	-0.12	
	18	51.0	14.0													
				15	0.070	0.040	0.060	380.0	-4.8	375.2	1.3%	2.00	175	70.00	-0.14	
	20	49.0	16.0													
				17	0.065	0.035	0.060	420.0	-4.8	415.2	1.1%	2.00	185	74.00	-0.13	
	22	47.0	18.0													
				19	0.055	0.026	0.058	460.0	-4.6	455.4	1.0%	2.00	195	78.00	-0.12	
	24	45.0	20.0													
				21	0.052	0.024	0.056	500.0	-4.5	495.5	0.9%	2.00	200	80.00	-0.11	
	26	43.0	22.0													
				23	0.045	0.019	0.052	540.0	-4.2	535.8	0.8%	2.00	200	80.00	-0.10	
	28	41.0	24.0													
				25	0.042	0.017	0.050	580.0	-4.0	576.0	0.7%	2.00	200	80.00	-0.10	
Platform	30	39.0	26.0													
Tunnel				27	0.038	0.015	0.046	620.0	-3.7	616.3	0.6%	2.00	200	80.00	-0.09	
Crown	32	37.0	28.0													
				29	0.034	0.012	0.044	660.0	-3.5	656.5	0.5%	2.00	200	80.00	-0.09	-0.41
	34	35.0	30.0													
				31	0.032	0.011	0.042	700.0	-3.4	696.6	0.5%	2.00	200	80.00	-0.08	
Deep	36	33.0	32.0													
Storage				33	0.031	0.010	0.042	740.0	-3.4	736.6	0.5%	2.00	200	80.00	-0.08	
Tunnel	38	31.0	34.0													
				35	0.030	0.009	0.042	780.0	-3.4	776.6	0.4%	2.00	200	80.00	-0.08	
	40	29.0	36.0													
				37	0.026	0.009	0.035	820.0	-2.8	817.2	0.3%	2.00	200	80.00	-0.07	

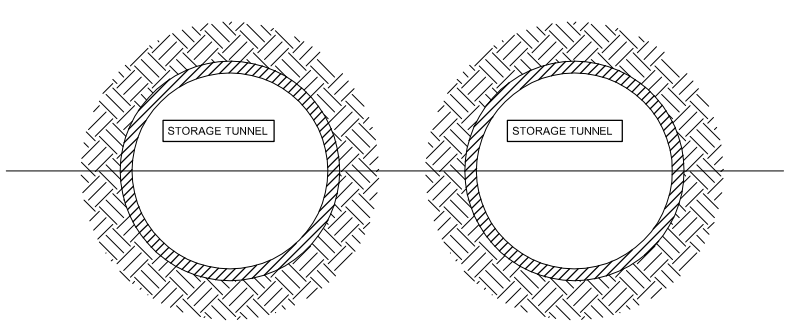
192 Haverstock Hill NW3 2AJ
Heave beneath 4m Basement Excavation
Vertical Access shaft

Building:	30	m	7	m	Soil Density kN/m^3	20	
Newmark Rectangles	18	m x	15.0	m	Depth of basem't BGL m:	4.0	
	11	m x	15.0	m	Overburden removed	-80	kN/m^2

	Depth BGL	AOD	Depth below Base	Av below Base	Newmark Rectangle Coeffs 1	2	Coeff Total	Overburden Orig	Re-moved	After Excav-ation	% Chan-ge	Layer Thick m	C_u kN/m^2	E_u= 400C_u MN/m^2	Heave mm	Acc
Ground	0	69.0														
Basem't	4	65.0	0					80.0					100			
				1	0.250	0.250	0.000	100.0	0.0	100.0		2.00	105	42.00	0.00	0.0
	6	63.0	2.0													
				3	0.249	0.247	0.003	140.0	-0.2	139.8	0.1%	2.00	115	46.00	-0.01	-0.01
	8	61.0	4.0													
				5	0.245	0.240	0.010	180.0	-0.8	179.2	0.4%	2.00	125	50.00	-0.03	-0.04
	10	59.0	6.0													
				7	0.237	0.227	0.020	220.0	-1.6	218.4	0.7%	2.00	135	54.00	-0.06	-0.10
	12	57.0	8.0													
				9	0.227	0.203	0.048	260.0	-3.8	256.2	1.5%	2.00	145	58.00	-0.13	-0.23
	14	55.0	10.0													
				11	0.210	0.185	0.050	300.0	-4.0	296.0	1.3%	2.00	155	62.00	-0.13	-0.36
	16	53.0	12.0													
				13	0.195	0.165	0.060	340.0	-4.8	335.2	1.4%	2.00	165	66.00	-0.15	-0.51
	18	51.0	14.0													
				15	0.180	0.153	0.054	380.0	-4.3	375.7	1.1%	2.00	175	70.00	-0.12	-0.63
	20	49.0	16.0													
				17	0.165	0.135	0.060	420.0	-4.8	415.2	1.1%	2.00	185	74.00	-0.13	-0.76
	22	47.0	18.0													
				19	0.154	0.122	0.064	460.0	-5.1	454.9	1.1%	2.00	195	78.00	-0.13	-0.89
	24	45.0	20.0													
				21	0.142	0.110	0.064	500.0	-5.1	494.9	1.0%	2.00	200	80.00	-0.13	-1.02
	26	43.0	22.0													
				23	0.128	0.095	0.066	540.0	-5.3	534.7	1.0%	2.00	200	80.00	-0.13	-1.15
	28	41.0	24.0													
				25	0.120	0.087	0.066	580.0	-5.3	574.7	0.9%	2.00	200	80.00	-0.13	-1.28
Platform	30	39.0	26.0													
Tunnel				27	0.105	0.076	0.058	620.0	-4.6	615.4	0.7%	2.00	200	80.00	-0.12	-1.40
Crown	32	37.0	28.0													
				29	0.100	0.070	0.060	660.0	-4.8	655.2	0.7%	2.00	200	80.00	-0.12	-1.52
	34	35.0	30.0													
				31	0.090	0.062	0.056	700.0	-4.5	695.5	0.6%	2.00	200	80.00	-0.11	-1.63
Deep	36	33.0	32.0													
Storage				33	0.080	0.055	0.050	740.0	-4.0	736.0	0.5%	2.00	200	80.00	-0.10	-1.73
Tunnel	38	31.0	34.0													
				35	0.075	0.053	0.044	780.0	-3.5	776.5	0.5%	2.00	200	80.00		
	40	29.0	36.0													
				37	0.070	0.048	0.045	820.0	-3.6	816.4	0.4%	2.00	200	80.00		







GENERAL NOTES:

DIMENSIONS ARE NOT TO BE SCALED FROM THIS DRAWING

ALL DIMENSIONS ARE TO BE CHECKED ON SITE PRIOR TO COMMENCEMENT OF ANY WORKS, AND ANY DISCREPANCIES REPORTED IMMEDIATELY TO THE ENGINEER.

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL OTHER DESIGN TEAM DETAILS AND SPECIFICATIONS.

Rev.	Description	By	Chkd.	Date
P2	PRELIMINARY ISSUE	AM	AM	26.02.16
P1	PRELIMINARY ISSUE	AM	AM	03.02.16

TRAIN AND KEMP
ENGINEERING BUSINESS SOLUTIONS
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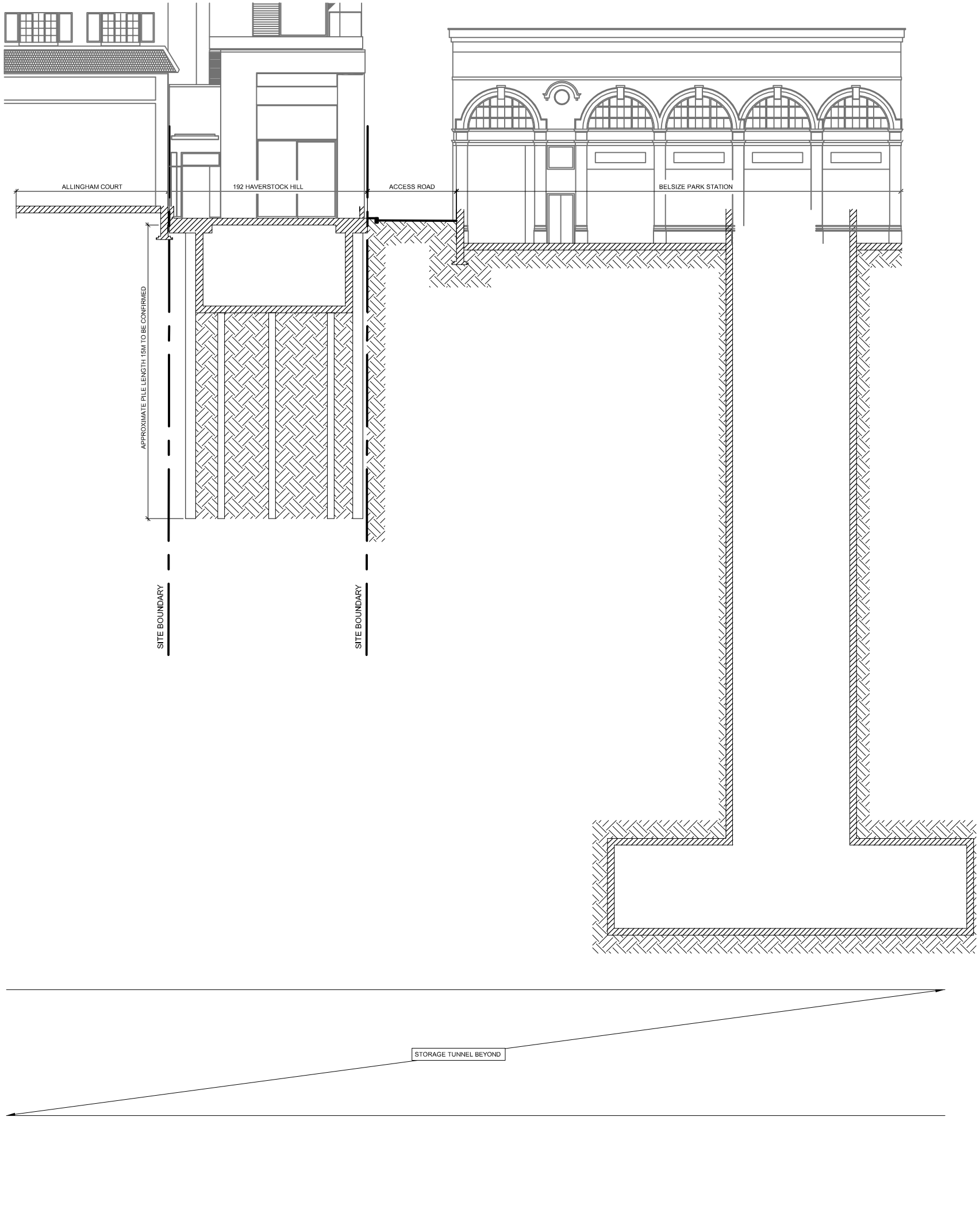
Client: CENTRAL REALITY LTD

Project: 192 HAVERSTOCK HILL

Title: SITE SECTION SHOWING ONE ESTIMATED TUNNEL POSITIONS

Drawing Status: FOR APPROVAL

Date:	JAN 2016	Drawing No.	Rev.
Scale:	1:100 ON A1	13358_101	P2
Drawn:	AM		
Chkd:	AM		



GENERAL NOTES:

DIMENSIONS ARE NOT TO BE SCALED FROM THIS DRAWING

ALL DIMENSIONS ARE TO BE CHECKED ON SITE PRIOR TO COMMENCEMENT OF ANY WORKS, AND ANY DISCREPANCIES REPORTED IMMEDIATELY TO THE ENGINEER.

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ALL OTHER DESIGN TEAM DETAILS AND SPECIFICATIONS.

Rev.	Description	By	Chkd.	Date
P2	PRELIMINARY ISSUE	AM	AM	26.02.16
P1	PRELIMINARY ISSUE	AM	AM	03.02.16

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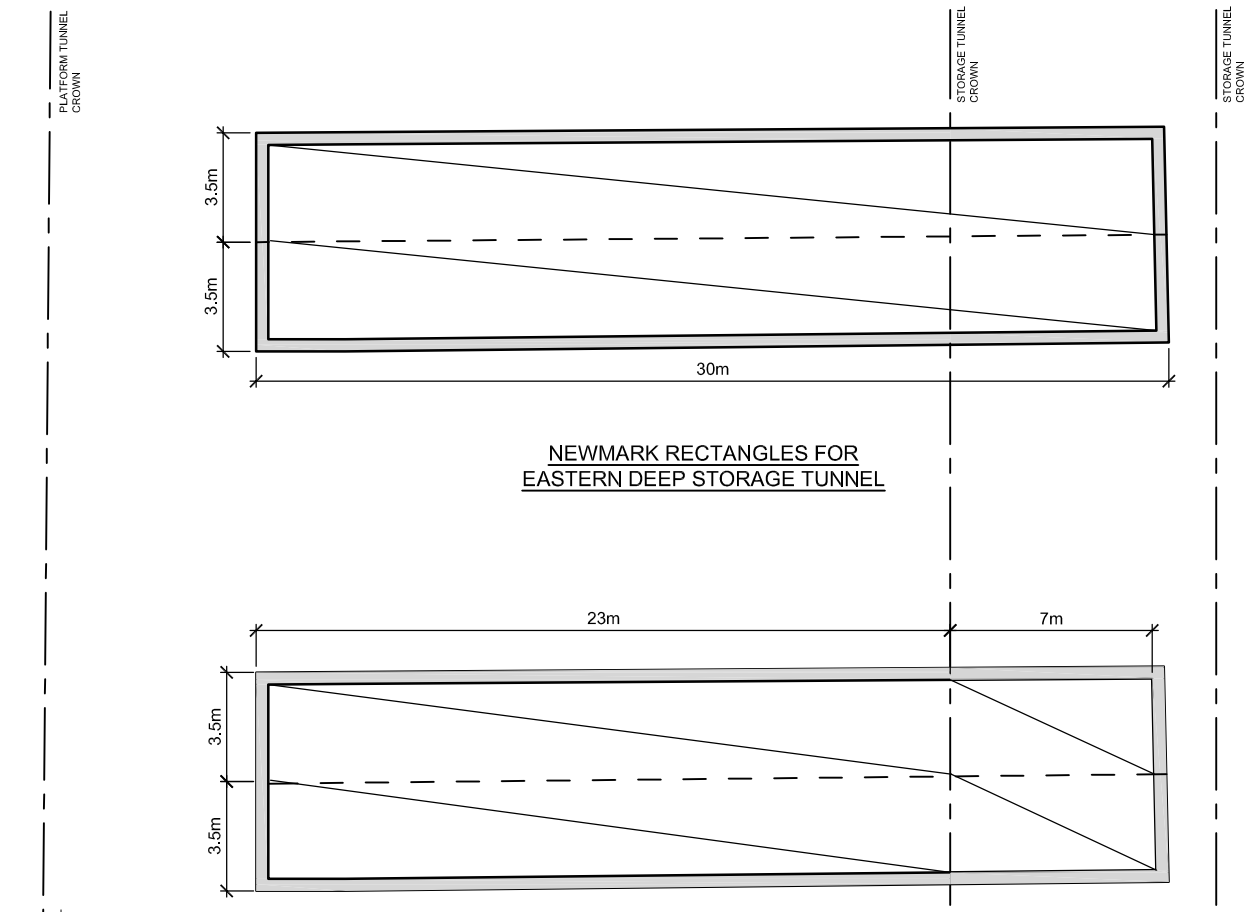
Title: SITE SECTION SHOWING TWO ESTIMATED TUNNEL POSITIONS

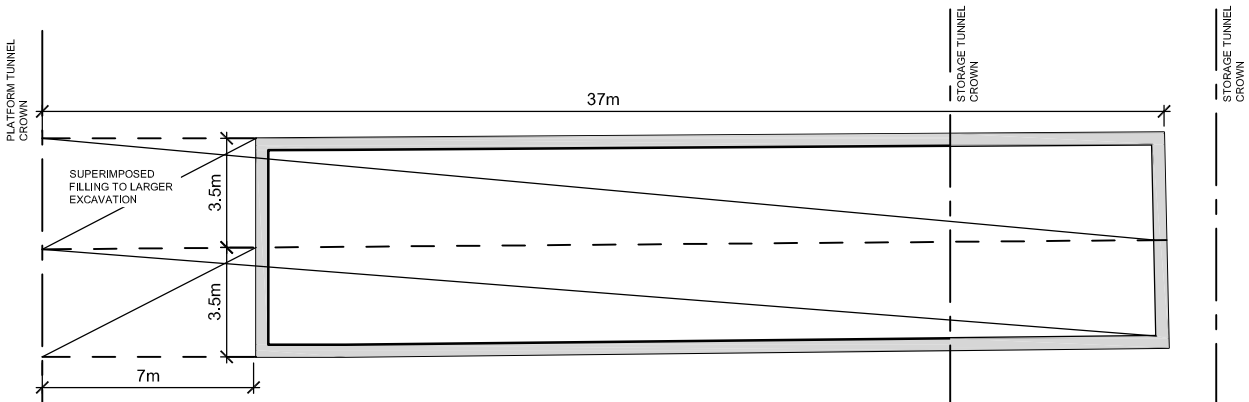
Drawing Status: PRELIMINARY

Date:	JAN 2016	Drawing No.	Rev.
Scale:	1:100 ON A1	13358_102	P2
Drawn:	AM		
Chkd:	AM		

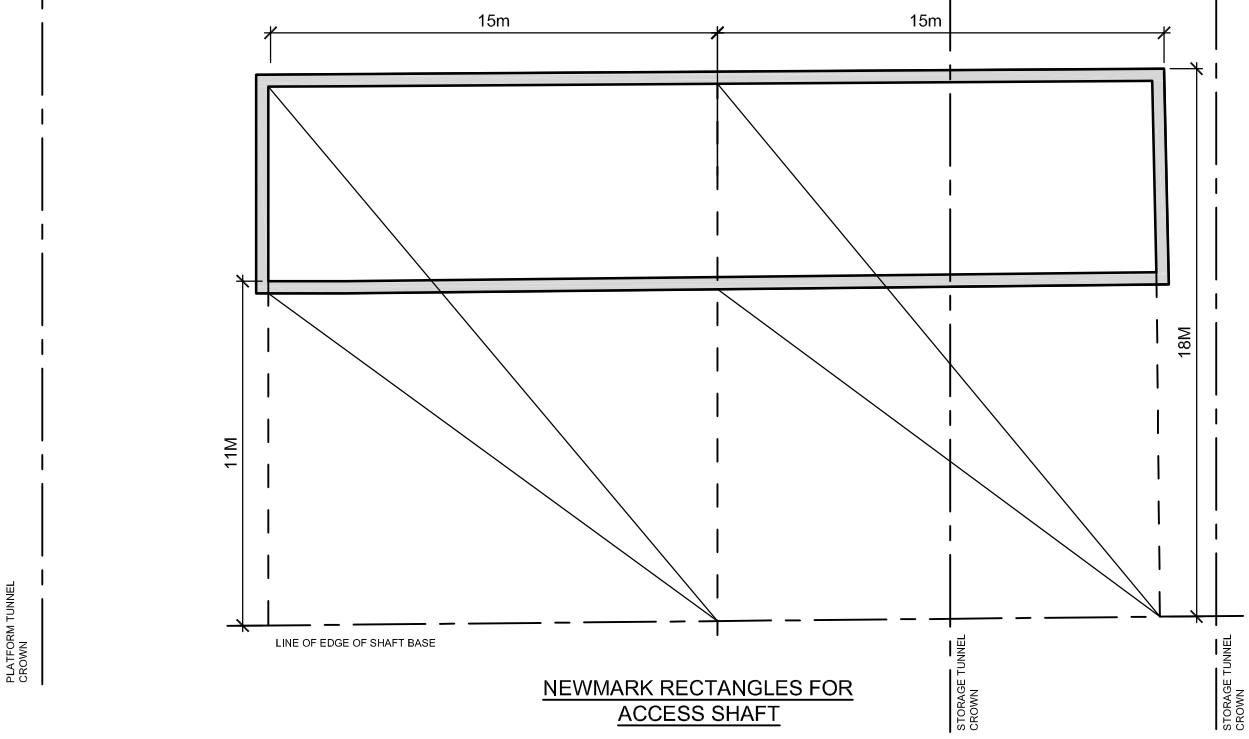


NEWMARK RECTANGLES FOR
EASTERN DEEP STORAGE TUNNEL

NEWMARK RECTANGLES FOR
WESTERN DEEP STORAGE TUNNEL



NEWMARK RECTANGLES FOR
PLATFORM TUNNELS



NEWMARK RECTANGLES FOR
ACCESS SHAFT

Rev.	Description	By	Chkd.	Date

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Client: CENTRAL REALITY

Project: 192 HAVERSTOCK HILL

Title: NEWMARK RECTANGLES FOR GROUND MOVEMENT ANALYSES

Drawing Status:

Date:	JAN 2016	Drawing No.	Rev.
Scale:	NTS	13358_103	
Drawn:	AM		
Chkd:	AM		