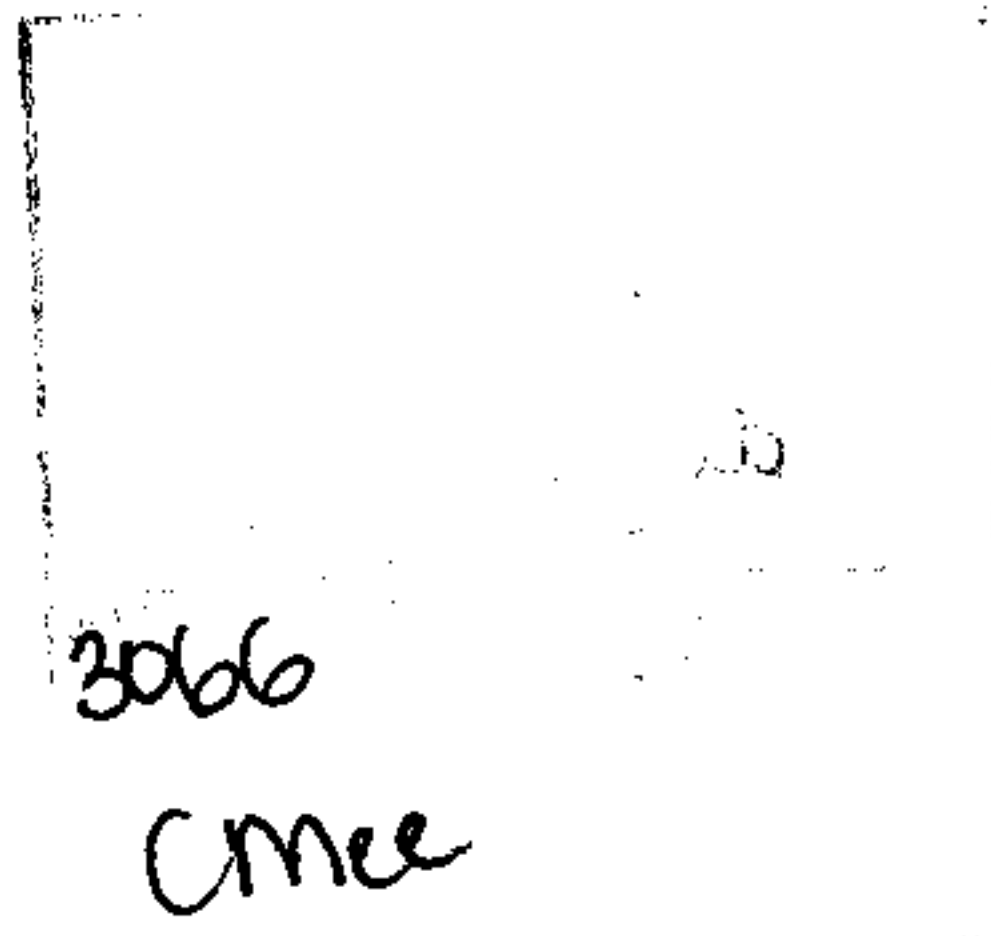


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UCL ANTHROPOLOGY BUILDING

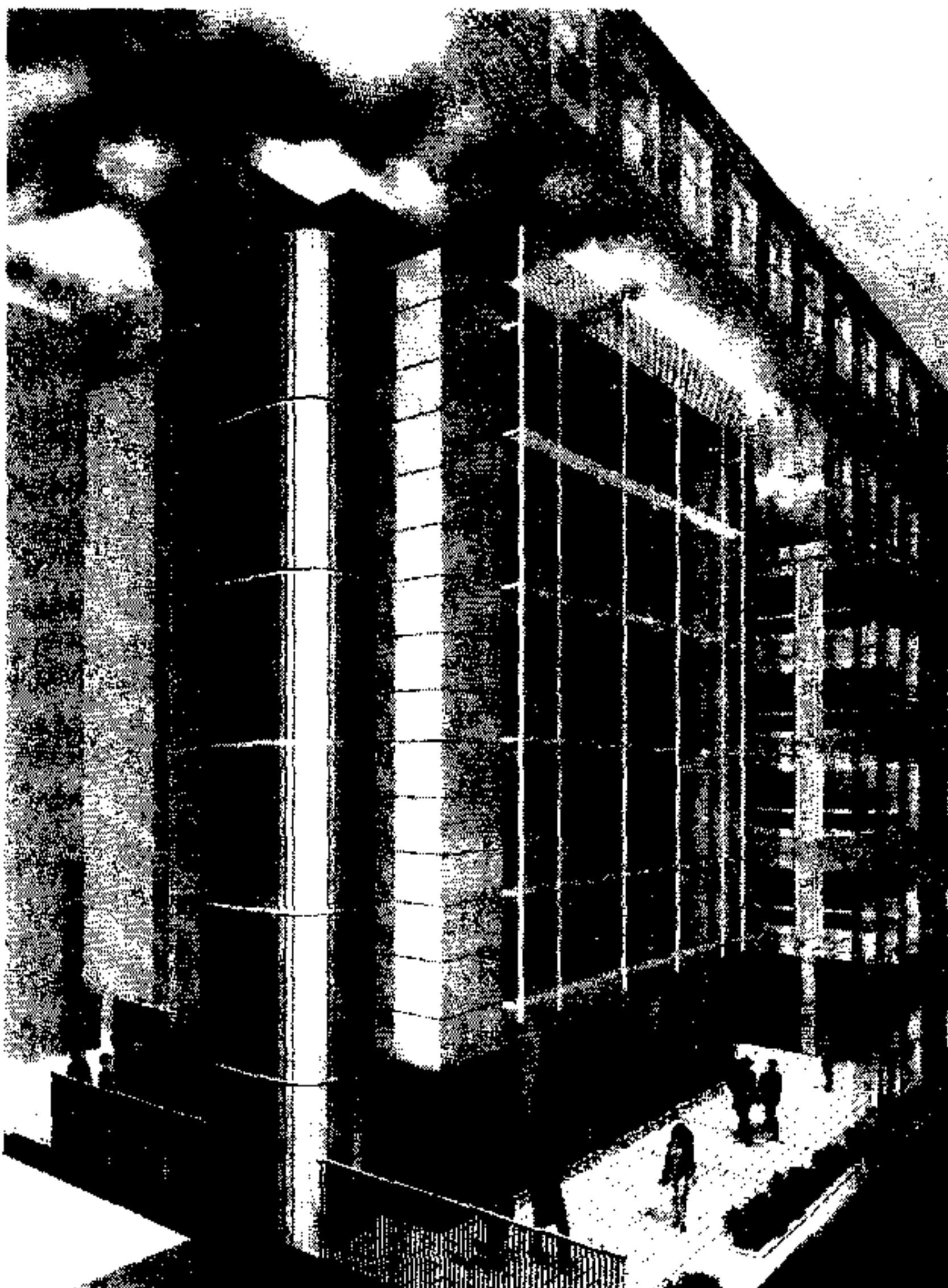
Effects of Construction of Crossrail Tunnels

for

Mansell Construction Services Limited

March 2005

project no. 3517



whitbybird

60 Newman Street
London W1T 3DA

tel 020 7631 5291
fax 020 7323 4645
london@whitbybird.com

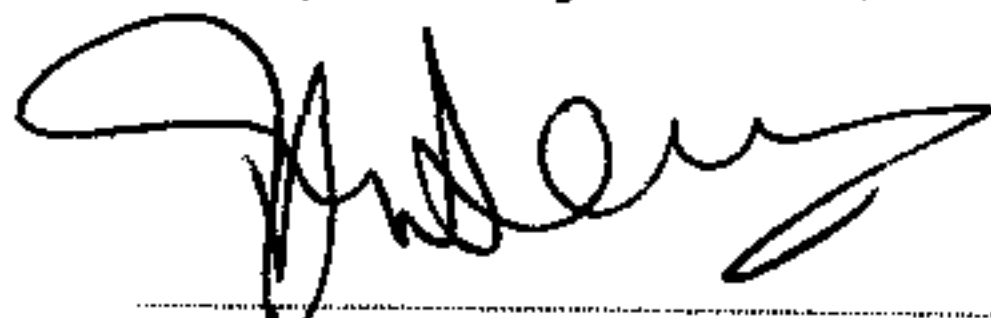
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Prepared by:



Khoshhal Azeemi
Design Engineer

Reviewed by



Dr Zed M Nyirenda
Senior Geotechnical Engineer

Approved by



Dr Mohsen Vaziri
Director

1 INTRODUCTION

A new building for the Anthropology Department of University College London (UCL) is being constructed by Mansell Construction Services Limited. The new structure is supported by two groups of 18 piles. The piles are 450mm diameter and 24m long when measured from the top of the pile cap.

The protected route of Crossrail Line 2 tunnels passes through the site. Therefore it was necessary to assess the impact of the construction of these tunnels on the displacements of the new building.

In the early stages of the design development Geotechnical Consulting Group (GCG), commission by Martin Stockley Associates on behalf of UCL, undertook a similar assessment of impact of the proposed Crossrail tunnels construction on the new UCL Anthropology building

This analysis is therefore an independent check of the work carried out by GCG, which was a result of reviewing their earlier report.

2 KEY AVAILABLE INFORMATION

2.1 Ground Conditions

Ground level at road level on site is approximately +24.6 mOD but the level of the top of the pile cap in the basement is about 21m OD. One borehole was drilled at the location of each of the two pile caps and the results are given in the factual report by STATS, (Stats 2004). The site investigation shows Made Ground over Terrace gravels and London Clay. The top of London Clay averaged at +18.5 mOD. The average thickness of the London Clay was 12.3 and the Lambeth Group was proven to an average thickness of 17.5m. Thanet Sand beneath over the Chalk is around 5m thick. The ground stratigraphy is represented in Figure 1 below.

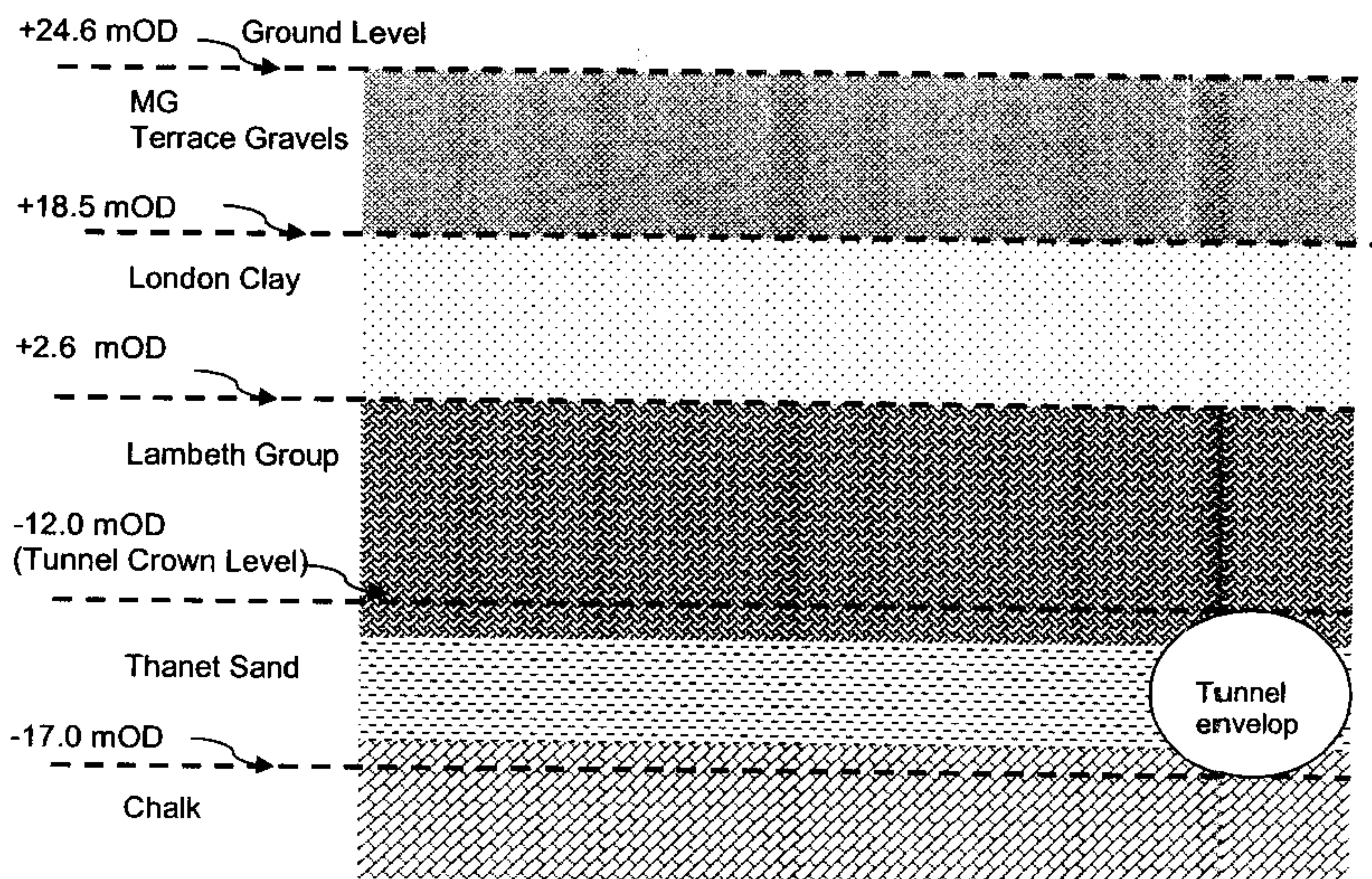


Figure 1 Schematic ground stratigraphy showing the cross rail tunnel at the top of construction tolerance zone at UCL Department of Anthropology

2.2 Proposed Structure

The proposed structure is an exam building of the department of Anthropology. It is a four storey building whose foundations comprise two pile groups of 450mm diameter piles constructed from the existing basement level. The pile caps, which are 13m apart, are approximately 5m square and 1.5m thick.

2.3 Crossrail's Tunnels Construction

The two tunnels forming the north and south bound running tunnels are assumed to be constructed at some time in the future following the completion of the building. Each tunnel will have an outside diameter of 7m. Settlement predictions in the analysis assume a volume loss of 1.7% due the construction of the tunnels. This value is within the range proposed by Crossrail and has been used to coincide with the earlier calculations by GCG (Martin Stockley 2002)

Figure 2 shows locations of the tunnels in relation to the two pile caps. The western tunnel will run directly beneath the centre of the eastern pile cap and some 7m east of the eastern pile cap's centre. The eastern tunnel is about 30m away from the centre of the eastern pile cap and 37m from the western pile cap.

Level information for the tunnels in the vicinity of the development is given in a copy of an e-mail from Crossrail reproduced in Appendix 1. The proposed crown level is at -17 mOD (some 42m below ground level). However, as Appendix 1 shows, the top construction tolerance is -12m OD, i.e. a deviation of 5m vertically, therefore the piles can only go down to -6m OD to allow for the 6m vertical exclusion zone (Figure 3). The horizontal tolerance is 3.5m in either direction.

3 METHOD OF ANALYSIS

Settlements due to Tunnel construction have been computed using the method described in Mair et al (1996), which is also outlined in Crossrail's information for developers, January 2001, 'Crossrail Line 2, Chelsea-Hackney Line'. Settlements ahead of the tunnels face, were assessed as described in Attewell and Yeates (1984).

Despite the fact that the tunnels will either be constructed in the Chalk or Thanet Sands, it has been assumed for the purposes of calculation that the settlements will be those appropriate for clay.

The effects of individual tunnels and the two tunnels together during and post construction were calculated on each pile cap. Then differential movements between the centres of the caps were deduced.

Settlements at the level of top of the pile cap (+21mOD), 16m below the top of pile cap, equivalent raft level (+5mOD) and base of the piles (-3mOD) have been examined. However, we concur with GCG that the most appropriate level to estimate settlement of the group of piles is at 'equivalent raft level' which is at a depth of 2/3 of the pile depth ($=2/3 \times 24 = 16\text{m}$, 5mOD). The various levels used in the analysis are shown in Figure 3.

4 RESULTS AND CONCLUSIONS

The hand calculations carried out for this exercise are attached in Appendix 2. Results of calculations at the (5.0 m OD) are summarised below:

- Maximum settlement of the pile group nearest to the eastern tunnel post construction would be less than 26mm
- Maximum settlement of foundation due to the construction of the western tunnel would be 21mm
- Maximum differential settlement between the two foundations during construction of the western tunnels would be 10mm.
- Maximum permanent differential would be less than 5mm.

At its nearest point the tunnels would be 9m below the bottom of pile group and their construction would not significantly affect the capacity of the piles.

As our findings are similar to those of GCG, we concur with their conclusion as in:

- The affect of the differential settlement due to the advance of the tunnel would be to cause the frame to tilt towards the tunnel as it advanced by less than 20mm.
- Since the new structure is steel frame on the two pile caps, the differential movements of the above magnitude will be accommodated by the frame

From the above, it is not concluded that we agree with the predictions made by GCG in their report, reproduced here in Appendix 3.

5 REFERENCES

Attewell P. B and Yeates J. (1984). Tunnelling in soil. Chapter 6 of Ground Movements and their effects on Structures. Attewell and Taylor (eds). Surrey University Press (1984) pp 133-215.

Crossrail(2001). Crossrail Line 2, Chelsea-Hackney Line'

Mair R.J., Taylor R.N. and Burland J.B (1996) Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. Geotechnical Aspects of Underground construction in Soft Ground, Mair and Taylor (Eds). 1996 Balkeema.pp 713-718.

STATS (2004). Report for Mansell Construction Services Limited, Factual report on Site Investigation

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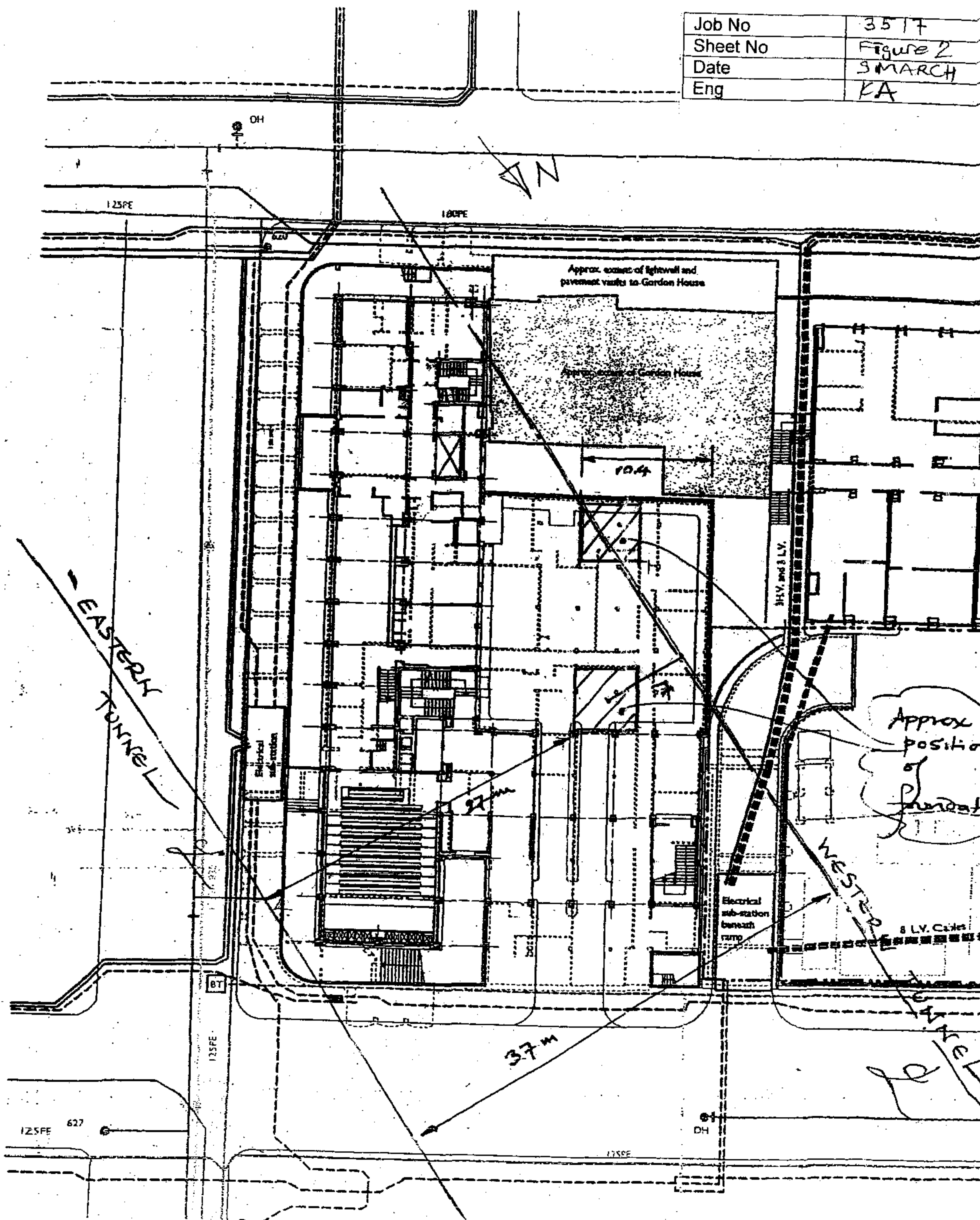
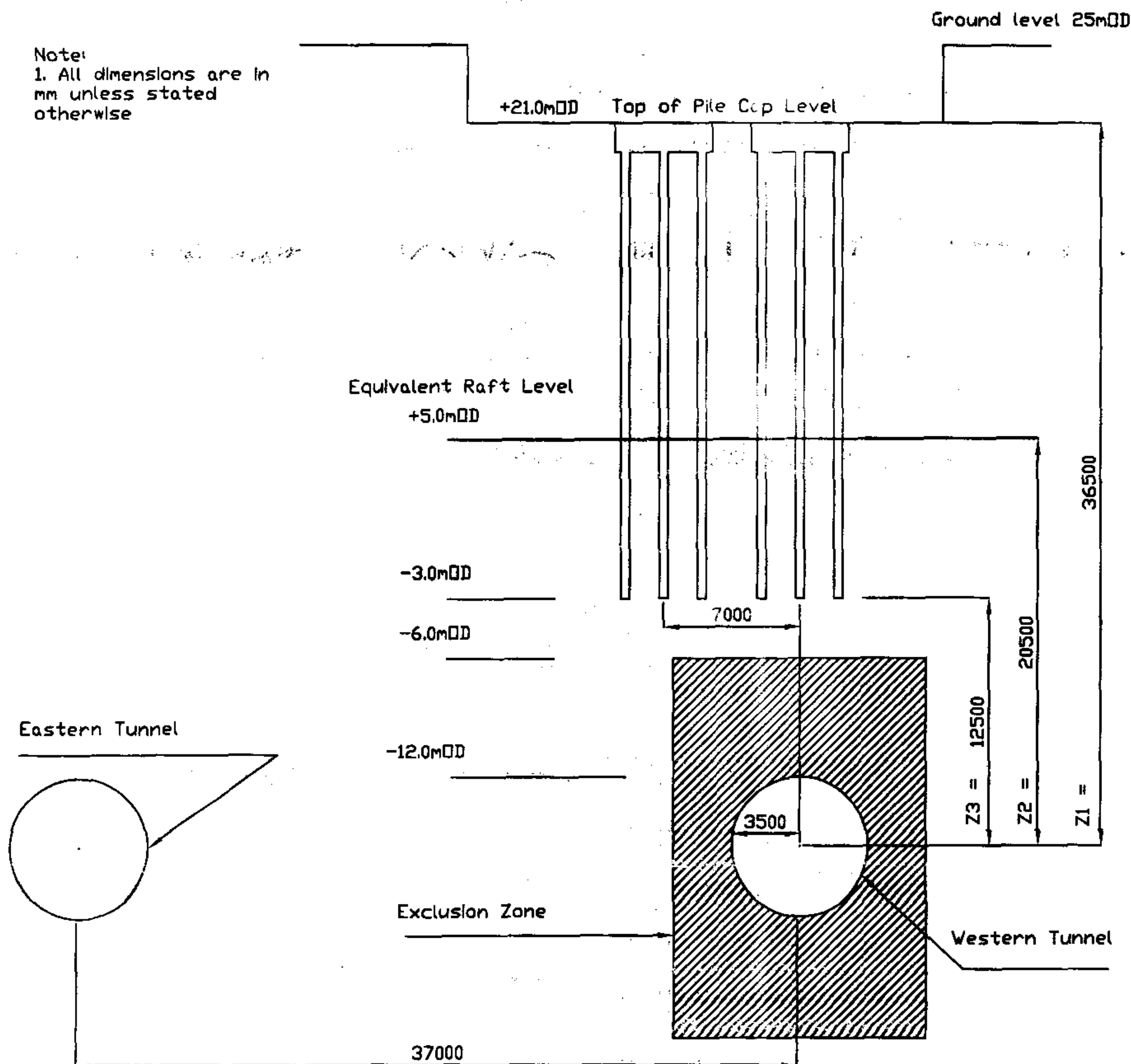


FIGURE 2:

Approximate location of tunnel centre lines relative to building footprint.

Figure 3: Worst Case Alignment of Grossrail's Tunnels in Relation to the Proposed Building



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ENGINEERS

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APPENDIX 1

Crossrail Tunnel level information

Trevor Sharrock

From: Trevor Sharrock
Sent: 24 June 2002 15:03
To: Julian Broster; Leena Dabee; Martin Stockley
Subject: FW: Taviton Street development

This information means we actually have an approximate piling zone of 27m below basement (say 26m below pile cap).

cc: file 188/01

-----Original Message-----

From: Black Mike [SMTP:MikeBlack@CrossRail.co.uk]
Sent: Monday, June 24, 2002 2:59 PM
To: Trevor Sharrock
Cc: Edwards Huw
Subject: Taviton Street development

Trevor,

Further to our meeting at Crossrail's offices last week, I am forwarding the level information in the vicinity of the proposed development as promised.

Tunnel Crown 83mTD (-17mOD)
Top of construction tolerance zone 88mTD (-12mOD)
Top of foundation clearance zone 94mTD (-6mOD)
Ground Level 125mTD (+25mOD)

These levels give a 31m deep possible construction zone between ground level and tunnel exclusion zone.

I hope this information is useful. If I can be of any further assistance, please do not hesitate to give me a call.

Regards,

Mike Black
Senior Geotechnical Design Manager
Crossrail

Tel. 020 7841 7664 (int.688 7664)
Fax. 020 7941 7703
E-mail. mikeblack@crossrail.co.uk
Web. <http://www.crossrail.co.uk>
Post. Cross London Rail Links Ltd
1 Butler Place
London SW1H 0PT

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This footnote also confirms that this email message has been swept

EMAIL SEND TO TREVOR
SHARROCK. [JUNE 2002]

APPENDIX 2

CALCULATIONS

SUMMARY

wb Results

Post Construction settlements (mm)

Levels	Tunnels	A*	B**	Differential
At top pile cap (+21mOD)	Eastern	1.8	3.7	1.9
	Western	14.3	13.3	1.0
	Total	16	17	0.9
At equivalent raft level (+5mOD)	Eastern	0.0	0.4	0.3
	Western	25.5	20.2	5.3
	Total	26	21	5.0
At base of the piles (-3mOD)	Eastern	0.0	0.0	0.0
	Western	41.8	22.3	19.5
	Total	42	22	19.5

* A - represent the centre of the western pile cap

** B - represent the centre of the eastern pile cap

During Construction Settlements (mm)

Level	Differential settlement
At top pile cap (+21mOD)	4.5
At equivalent raft level (+5mOD)	10.3
At base of the piles (-3mOD)	18.8

GCG Results

GCG results indicate a maximum settlement of 21mm at 6.7mOD and a maximum differential settlement of 9.3mm (advancing tunnels) at this level

Comparison

Settlement	GCG*	wb	Difference
Maximum Post Construction Settlement (mm)	21.0	25.5	4.5
Maximum During Construction Differential Settlement (mm)	9.3	10.3	1.0

* Please note that GCG value were computed at 6.7mOD compared to 5mOD by wb.

Conclusion

As the results of the our analysis and GCG are comparable and having reviewed their assumptions and the application of the method of analysis, we concur with their findings and conclusion.

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date	3 March 2008
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project UCL - Anthropology Department

Effects of Construction of Crossrail Tunnels

Introduction: A new building for the Anthropology Department of University College (UCL) is under construction. The new structure is supported on 24m long piles.

The proposed route of the Crossrail Line 2 tunnels pass under the site. Geotechnical Consulting Group (GCG) produced an impact assessment of the tunnels' construction on the proposed building in July 2004 for Martin Stockley Associates (MSA) on behalf of UCL.

Aim

The objective of this analysis is to predict the effect of construction of Crossrail tunnels and compare the results with those produced by GCG.

Method

The adopted method is outlined in

"Crossrail Line 2 - Chelsea - Hackney Line"

(Information for developers, updated January 2001)

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project UCL - Anthropology Department

- Key Assumptions:
- GCG assumptions were reviewed and were generally adopted in this analysis, except the pile length is 24m (as opposed 20m of GCG assumed).
(See Effects of Construction of Crossrail 2, July 2004)
 - The assumed tunnel positions/routes are shown in figures 1 & 2.
 - Settlements calculation points: centre of pile caps 7m apart. (A-B)
 - Volume loss = 1.7%
 - Assume cohesive (clay) soil below foundation containing tunnels (conservative as it ignores the presence of Thanet Sand and Chalk).

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project

Settlement calculation:

Input: Tunnel diameter = 7.0 m

Tunnel crown level = -12 mOD

Top of pile cap = +21 mOD

$$K = 0.5$$

$$V_L = 1.7\% = 0.017$$

Common Parameters:

$$Z = 21 + 12 + 7/2 = 36.5 \text{ m}$$

$$i = KZ = (0.5)(36.5) = 18.25$$

$$V_s = V_L \times \frac{\pi D^2}{4} = 0.017 \times \frac{\pi \times 7^2}{4} = 0.654 \text{ m}^3/\text{m}$$

$$S_{\max} = \frac{V_s}{\sqrt{2\pi} i} = \frac{0.654}{\sqrt{2\pi} 18.25} = 14.3 \text{ mm}$$

$$S_v = S_{\max} \exp\left[-\frac{y^2}{2i^2}\right]$$

Settlement Point A

Western tunnel contribution

Offset from tunnel axis = 0

Vertical settlement, $S_v = S_{\max} \exp\left[\frac{-y^2}{2i^2}\right]$

$$S_{v,A}^W = (14.3 \text{ mm})(1) = 14.3 \text{ mm}$$

$$S_{v,A}^W = 14.3 \text{ mm}$$

Eastern tunnel contribution

Offset from tunnel axis, $Y = 37 \text{ m}$

$$S_{v,A}^E = (14.3) \exp\left(\frac{-37^2}{2 \times 18.25^2}\right)$$

$$= (14.3)(0.128)$$

$$= 1.83 \text{ mm}$$

$$S_{v,A}^E = 1.83 \text{ mm}$$

Total settlement at A, $S_{v,A}^{WE} = S_{v,A}^W + S_{v,A}^E = 14.3 + 1.83 = 16.13 \text{ mm}$

project

Settlement Point B Western tunnel contribution

Offset from tunnel axis, $Y = 7.0 \text{ m}$

$$S_{V,B}^W = 14.3 \exp \left[\frac{-7^2}{2 \times 18.25^2} \right]$$

$$S_{V,B}^W = 13.29 \text{ mm}$$

Eastern tunnel contribution

Offset from tunnel axis, $Y = 30 \text{ m}$

$$S_{V,B}^E = 14.3 \exp \left[\frac{-30^2}{2 \times 18.25^2} \right]$$

$$S_{V,B}^E = 3.7 \text{ mm}$$

$$\text{Total settlement, } S_{V,B}^{W+E} = S_{V,B}^W + S_{V,B}^E$$

$$= 13.29 + 3.7$$

$$S_{V,B}^{W+E} \approx 17.0 \text{ mm}$$

Differential Settlements between A & B

i) When only Western tunnel is completed, $\delta = S_{V,A}^W - S_{V,B}^W$

$$= 14.3 - 13.3$$

$$\boxed{\delta = 1 \text{ mm}}$$

ii) When only Eastern tunnel is completed, $\delta = S_{V,A}^E - S_{V,B}^E$

$$= 18.3 - 3.7 \sim$$

$$\boxed{\delta = 2 \text{ mm}}$$

iii) When both tunnels completed, $\delta = S_{V,A}^{W+E} - S_{V,B}^{W+E}$

$$= 16.13 - 17 \sim$$

$$\boxed{\delta = 1 \text{ mm}}$$

Settlements at top of pile cap, equivalent raft level (2/3 pile length below pile cap) and base of piles are computed by a spread sheet and presented in next page.

Vertical Settlement (by O'Reilly and New, 1982 and 1991)

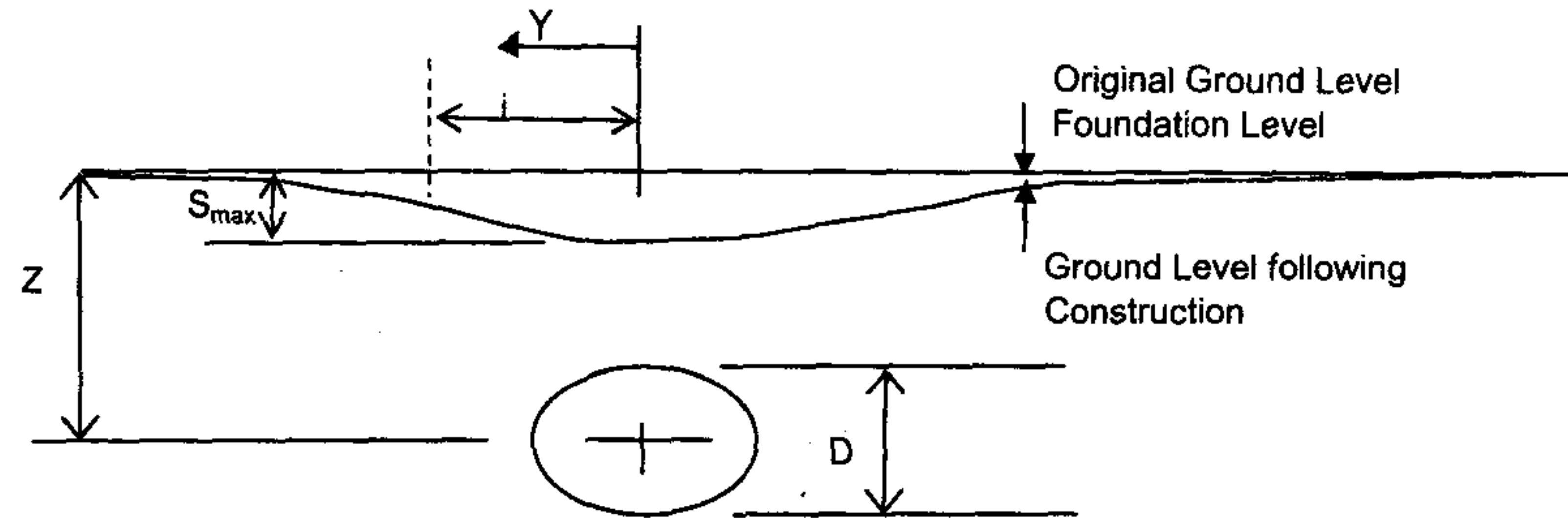
Area	38.485 m ²
------	-----------------------

$$i = k * z$$

$$V_s = V_i \left(\frac{\pi D^2}{4} \right)$$

$$S_{max} = \frac{V_s}{\sqrt{2\pi} i}$$

$$S_v = S_{max} \left[\exp \left(\frac{-Y^2}{2i^2} \right) \right]$$



Level	Point	Tunnels	Z	I	V _s	S _{max} (m)	Y (m)	Y ²	2i ²	(-Y ² /2I ²)	Sv (m)	Sv (mm)	S _{total} (mm)	Differential (mm)
At top of Pile cap (21.0mOD)	A	Eastern	36.5	18.25	0.65423667	0.01430152	37	1369	666.125	-2.05517	0.001831611	1.8	16	1
		Western	36.5	18.25	0.65423667	0.01430152	0	0	666.125	0	0.014301516	14.3		
	B	Eastern	36.5	18.25	0.65423667	0.01430152	30	900	666.125	-1.351098	0.003703461	3.7	17	
		Western	36.5	18.25	0.65423667	0.01430152	7	49	666.125	-0.07356	0.013287261	13.3		
At 2/3 pile length below ground level (5.0mOD)	A	Eastern	20.5	10.25	0.65423667	0.02546368	37	1369	210.125	-6.51517	3.77087E-05	0.0	26	5
		Western	20.5	10.25	0.65423667	0.02546368	0	0	210.125	0	0.025463675	25.5		
	B	Eastern	20.5	10.25	0.65423667	0.02546368	30	900	210.125	-4.283165	0.000351371	0.4	21	
		Western	20.5	10.25	0.65423667	0.02546368	7	49	210.125	-0.233195	0.020167218	20.2		
At toe of Piles (-3.0mOD)	A	Eastern	12.5	6.25	0.65423667	0.04176043	37	1369	78.125	-17.5232	1.02456E-09	0.0	42	19
		Western	12.5	6.25	0.65423667	0.04176043	0	0	78.125	0	0.041760427	41.8		
	B	Eastern	12.5	6.25	0.65423667	0.04176043	30	900	78.125	-11.52	4.1466E-07	0.0	22	
		Western	12.5	6.25	0.65423667	0.04176043	7	49	78.125	-0.6272	0.022303624	22.3		

project UCL - Anthropology Department

Advancing tunnel (by Peter Attwell and John Yeates, 1984)

$$i = 0.43(z_0 - z) + 1.1 \quad \text{at top of pile cap @ 21 m OD}$$

$$i = 0.43(21 + 12 + 1/2 - 0) + 1.1 =$$

$$i = 16.8 \text{ m}$$

$$V = 0.654 \text{ m}^3/\text{m}$$

$$(x - x_i) \rightarrow \infty \quad \text{and} \quad G\left(\frac{x - x_i}{i}\right) = 1$$

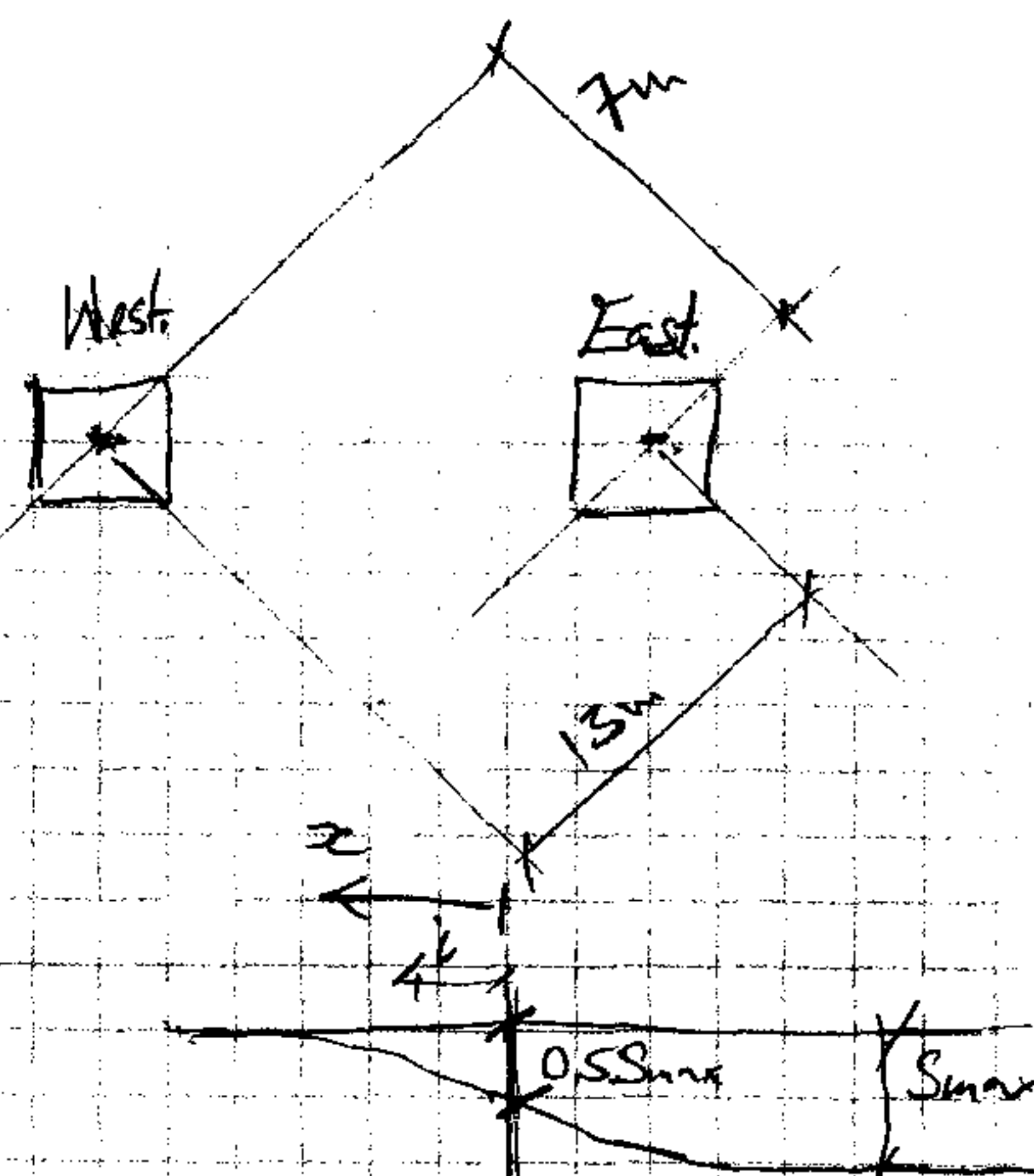
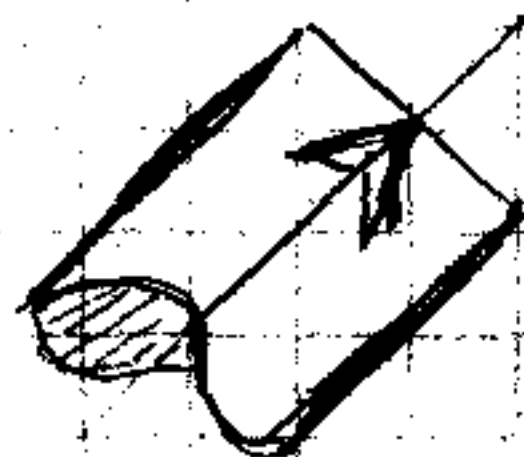
if the tunnel is directly under centre of western raft/pad then at

$$W = 0.5 S_{\text{max}} = 0.5(15.5) = 7.75 \text{ mm}$$

$$\text{at E, } (x - x_f) = 13 \text{ m}$$

$$y = 7 \text{ m}$$

Ref (pp 40)



$$G\left(\frac{x - x_f}{i}\right) = G(0.77) = 0.808 \quad (\text{Table 6.1})$$

settlement at 'E'

$$w = \frac{V}{\sqrt{2\pi}i} \exp\left[-\frac{y^2}{2i^2}\right] \left\{ G\left(\frac{x - x_i}{i}\right) - G\left(\frac{x - x_f}{i}\right) \right\}$$

$$= \frac{0.654}{\sqrt{2\pi}(16.8)} \exp\left[-\frac{7^2}{2 \times (16.8)^2}\right] \{ 1 - 0.808 \}$$

$$w = 3.2 \text{ mm}$$

$$\text{Differential settlement} = 7.75 - 3.2 = 4.5 \text{ mm}, \quad \boxed{\delta = 4.5 \text{ mm}}$$

for the remaining levels, please see attached spreadsheet.

Vertical Settlement ahead of Advancing Tunnel (by Peter Attewell and John Yeates)

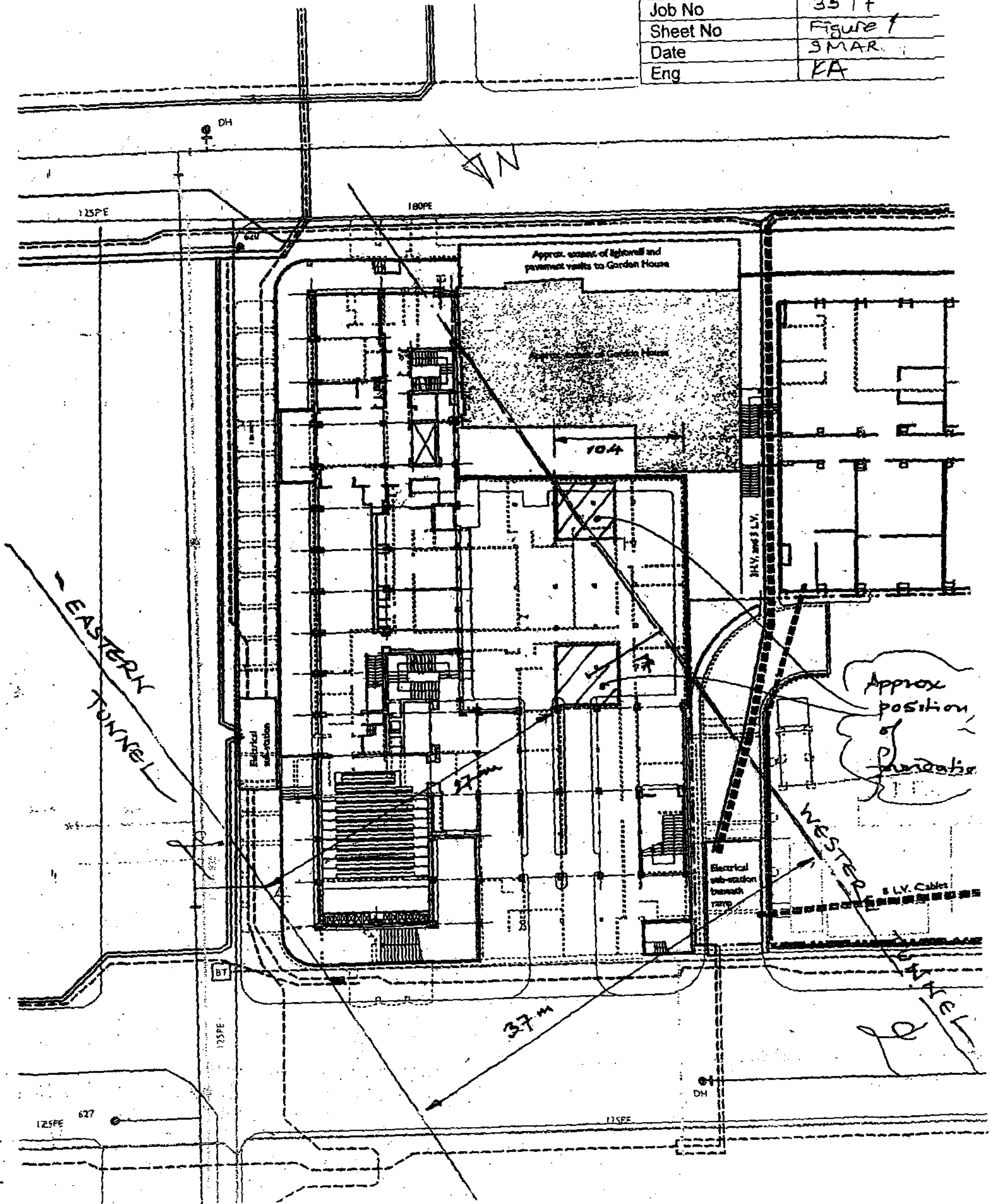
m
%
m
m

$$i = 0.43 * (Z_0 - Z) + 1.1$$

$$w = S_{\max} * \exp \left[\frac{-Y^2}{\sqrt{2\pi} i} \right] \left\{ G \left(\frac{x - x_i}{i} \right) - G \left(\frac{x - x_f}{i} \right) \right\}$$

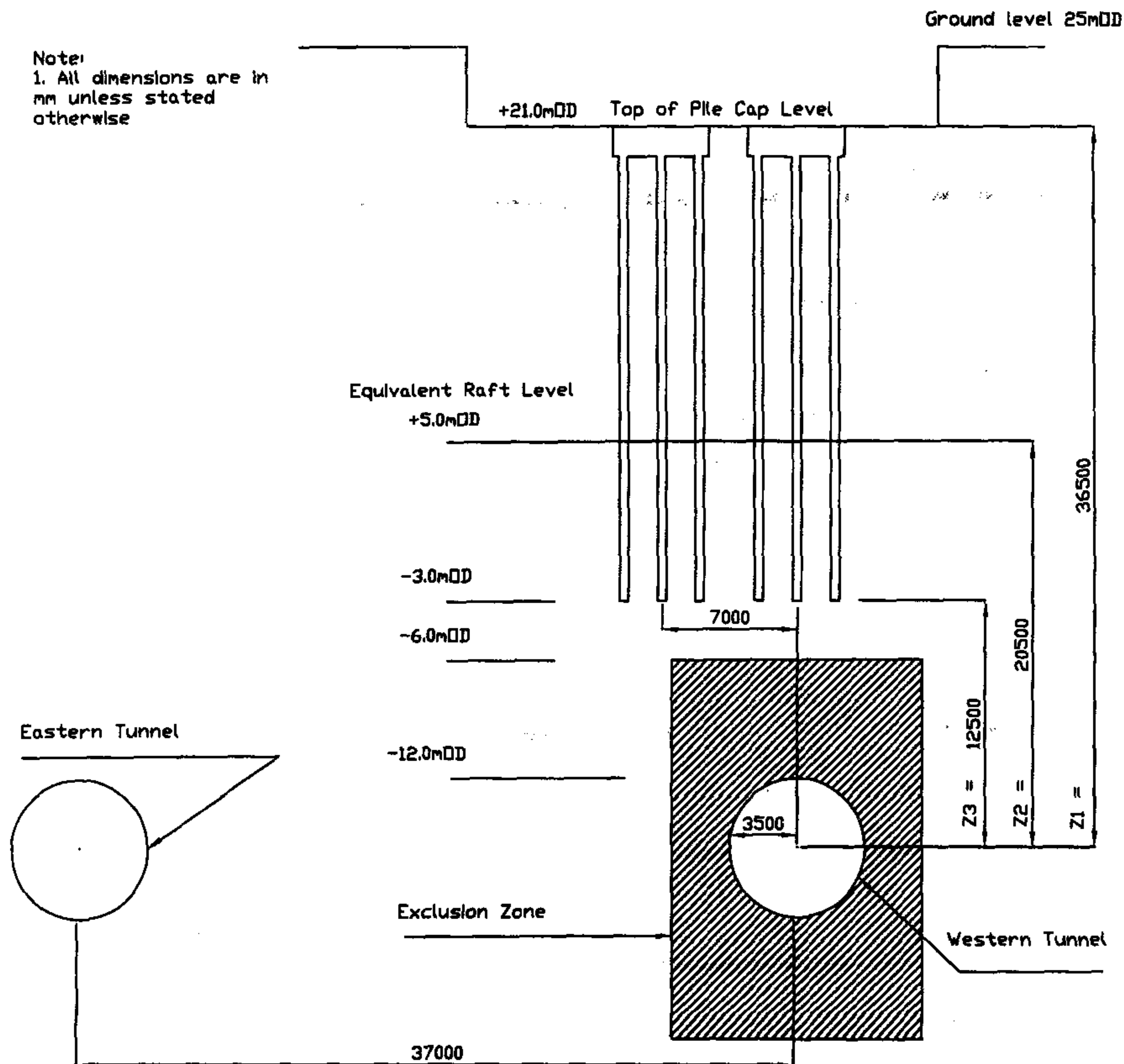
Level	Z (m)	Zo-Z (m)	i (m)	(X-Xf)/i	G((x-xf)/i)	V (m ³ /m)	S _{max} (mm)	Sv (mm)	Diff. (mm)
Top of Pile	0	36.5	16.795	0.774039893	0.808	0.65423667	15.5	3.3	4.5
2/3 of pile depth	16	20.5	9.915	1.31114473	0.915	0.65423667	26.3	2.9	10.3
Base of pile	24	12.5	6.475	2.007722008	0.981	0.65423667	40.3	1.4	18.8

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Approximate location of tunnel centre lines relative to building footprint.

Figure 2: Worst Case Alignment of Crossrail's Tunnels In Relation to the Proposed Building



APPENDIX 3

Original Report by GCG



Our Ref: 182/02/jgg

Richard Pope
Mansell Construction Services Ltd
Roman House
263-269 City Road
London
EC1V 1JX

20th July 2004

Dear Richard,

UCL Anthropology/SSEES - Exam Halls

We enclose a copy of the report carried by Geotechnical Consulting Group, on our behalf, which deals with the statutory requirements of the planning application. This is issued to you as a contract document.

Yours sincerely

Jaime Goma
for Martin Stockley Associates.

c.c. Bruce Lowrie - HLM Architects
 Phil Beeson - Turner and Townsend
 Angela Clemo - UCL

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UCL ANTHROPOLOGY BUILDING

**EFFECTS OF CONSTRUCTION
OF CROSSRAIL 2**

MARTIN STOCKLEY ASSOCIATES

JULY 2004



GEOTECHNICAL CONSULTING GROUP

1A Queensberry Place London SW7 2DL United Kingdom
Tel: +44 (0)20 7581 8348 Fax: +44 (0)20 7584 0157
Email: admin@gcg.co.uk Web Site: www.gcg.co.uk

High St. John.

**UCL ANTHROPOLOGY BUILDING
EFFECTS OF CONSTRUCTION
OF CROSSRAIL 2**

MARTIN STOCKLEY ASSOCIATES

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UCL ANTHROPOLOGY BUILDING

CHECK OF EFFECT OF FUTURE CONSTRUCTION OF CROSSRAIL 2 TUNNELS ON BUILDING

MARTIN STOCKLEY ASSOCIATES

July 2004

1. INTRODUCTION

It is proposed to construct a new building for the Anthropology Department of University College London (UCL) at the location in fig 1, adjacent to the SSEES building which is currently under construction. The building is to occupy the site of an existing basement (which is to be retained) and will rise to five levels above ground floor level. The construction will comprise a steel frame as shown in fig 2 supported on two pile caps constructed from within the basement using minipiles approximately 20 metres long. A plan of the foundations is shown in Appendix 1.

The protected route of the tunnels of the projected Crossrail Line 2 passes under the site. This route is shown in fig 3. The crown of the tunnels will be at a minimum depth of around 36 metres below the existing ground level.

GCG have been appointed by Martin Stockley Associates (MSA) on behalf of UCL to check the possible effects of the construction of the tunnels at some time after the completion of the building. MSA have supplied GCG with drawings of the proposed structure and tunnel alignment together with the information supplied by Transport for London (TfL) on the tunnel construction. MSA have also supplied copies of the site investigations carried out for this development and the adjacent development for the School of Slavonic and Eastern European Studies (SSEES) carried out by Stats.

2. GROUND AND WATER CONDITIONS

Ground level at the site (in Tiverton Street to the north east) is approximately +24.6 m OD. The site investigations show made ground over Terrace gravels and the London Clay. The surface of the London Clay is at approximately +18.1 mOD. The London Clay is between 12.3 and 15.5 metres thick. Below the London Clay is the Lambeth Group

which was proved to around 10 metres thick and was found to comprise very stiff clay. The information supplied by TfL suggests that the base of the Lambeth Group is at around -12 mOD, and the Thanet Sand beneath over the Chalk is around 5 metres thick. The TfL cross section shows the tunnel entirely in the Chalk.

- Information on the aquifer suggests that the water table in this area is at below the level of the surface of the chalk. There will be a perched water table in the Terrace Gravels. The borehole information suggests that this only amounts to a small head of water over the London Clay.

3. DESCRIPTION OF THE FOUNDATIONS AND STRUCTURE.

The foundations will comprise two groups of minipiles constructed from the existing basement level each incorporated in a pile cap approximately 5 metres square and 1.5 metres thick. This will support the frame of the structure on a number of columns forming the legs of the frame, as shown in fig 2. The centres of these pile caps are approximately 13 metres apart.

The existing basement is at approximately +21.5 m OD. It is assumed for the purposes of calculation that the tops of the piles are at +20 mOD.

- It has been assumed, for the purposes of calculation, that the piles are approximately 20 metres long.

4. TUNNEL CONSTRUCTION

The two tunnels forming the north and southbound running tunnels are assumed to be constructed at some time in the future following the completion of the building. Each tunnel will have an outside diameter of 7 metres. Settlements due to tunnelling are to be constructed assuming a volume loss of 1.7%.

Fig 4 shows a drawing of the approximate layout of the new and existing buildings together with the projected centrelines of the two tunnels. It can be seen that the easternmost is some 37 metres east of the western tunnel and passes some 27 metres from the nearest part of any foundation.

The tunnel crowns are to be at -17m OD, i.e more than 40 metres below existing ground level.

It is to be assumed that the tunnels may deviate by up to 5 metres vertically and 3.5 metres horizontally from the assumed alignment.

It is assumed for the purposes of calculation that the tunnels can be constructed in any order and can be driven in either direction.

5. DESCRIPTION OF CALCUALTIONS.

Tunnels settlements have been calculated using the method described in Mair et al (1996) and, for the purposes of assessing the effect of tunnel advance, as described in Attewell and Yeates (1984).

Although the tunnels will either be constructed in the Chalk or the Thanet Sands, the latter of which will be dry, it has been assumed for the purposes of calculation that, as the majority of the overburden is clay, the settlements will be those appropriate for clay. These calculations are likely to be conservative as tunnel volume losses are likely to be significantly less than the assumed 1.7 %.

The calculations have initially examined the effect of the furthest tunnel from the site (the eastern tunnel, and then looked at the one that passes directly under the site. It has been assumed that the worst condition occurs when the tunnel passes directly under the western foundation, since this is possible within the allowable deviation and this gives the largest settlement.

Settlements at the level of the tops and bases of the piles have been examined, but it has been assumed that the appropriate level to estimate settlements of the group is the level of the equivalent foundation which is at a depth of 67% of the pile depth.

The relative settlement of the pile groups and the existing basement have been estimated assuming that there is no linkage between them.

6. RESULTS AND CONCLUSIONS

The calculations are attached as Appendix 2.

The following results were obtained:

- Maximum settlement of the pile group nearest to the eastern tunnel during construction would be less than 2 mm.
- Maximum settlement of the basement slab would be 4 mm.
- Maximum settlement of the foundation due to construction of the western tunnel would be 21 mm.
- The basement slab would settle around 5 mm less than the pile group.
- Maximum differential settlement between the two foundations during construction of the western tunnel would be 9 mm.
- Maximum permanent differential would be around 5 mm.

At its nearest point the tunnels would be 12 metres below the pile groups and their construction would not affect the capacity of the piles.

The effect of the differential settlement due to the advance of the tunnel would be to cause the frame to tilt towards the tunnel as it advanced by around 20 mm at the top. The tilt would reduce as the tunnel passed.

As the new building is a steel frame supported on the two pile caps, the significance of the tilt caused by tunnel construction is minor, as the entire frame will rotate. The relative settlements between the basement slab and the new structure are small and are in any case exaggerated as the piles themselves will restrict movement in the immediate vicinity of the group.

Regarding damage, it is not appropriate to apply the usual criteria to classify damage in terms of strain. On the basis of the assessment of the potential differential settlements between the basement and the foundations it seems unlikely that this would give rise to anything other than fine cracks. This would put the damage category in the 'negligible to very slight' as defined in Table 1 of Mair et al (1996).

7. REFERENCES.

Mair R.J., Taylor R.N. and Burland J.B. (1996) Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. *Geotechnical Aspects of Underground Construction in Soft Ground*, Mair and Taylor (Eds). 1996 Balkema. Pp 713-718.

Attewell P.B. and Yeates J. (1984). Tunnelling in soil. Chapter 6 of *Ground Movements and their effects on Structures*. Attewell and Taylor (eds). Surrey University Press (1984) pp 132-215.

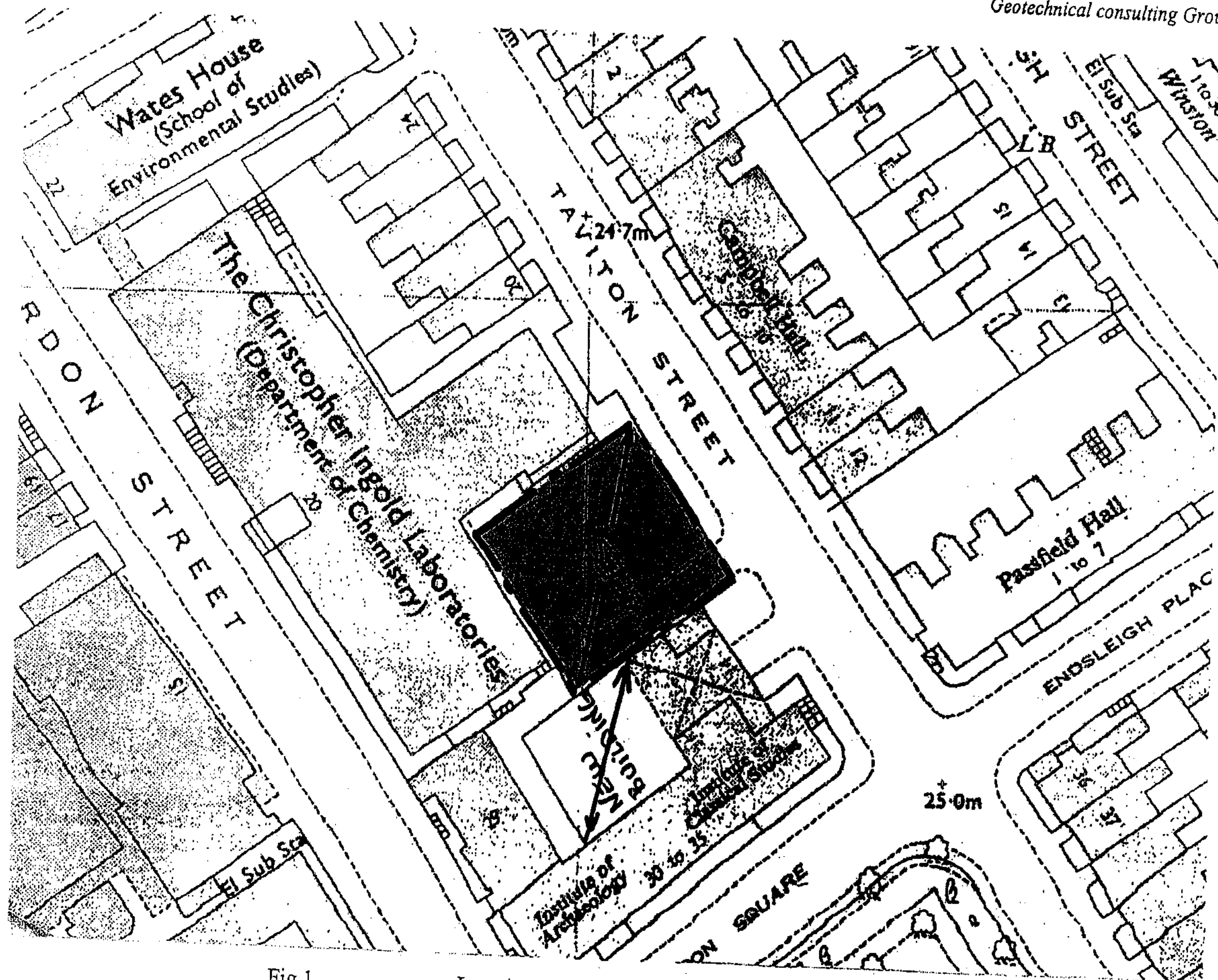
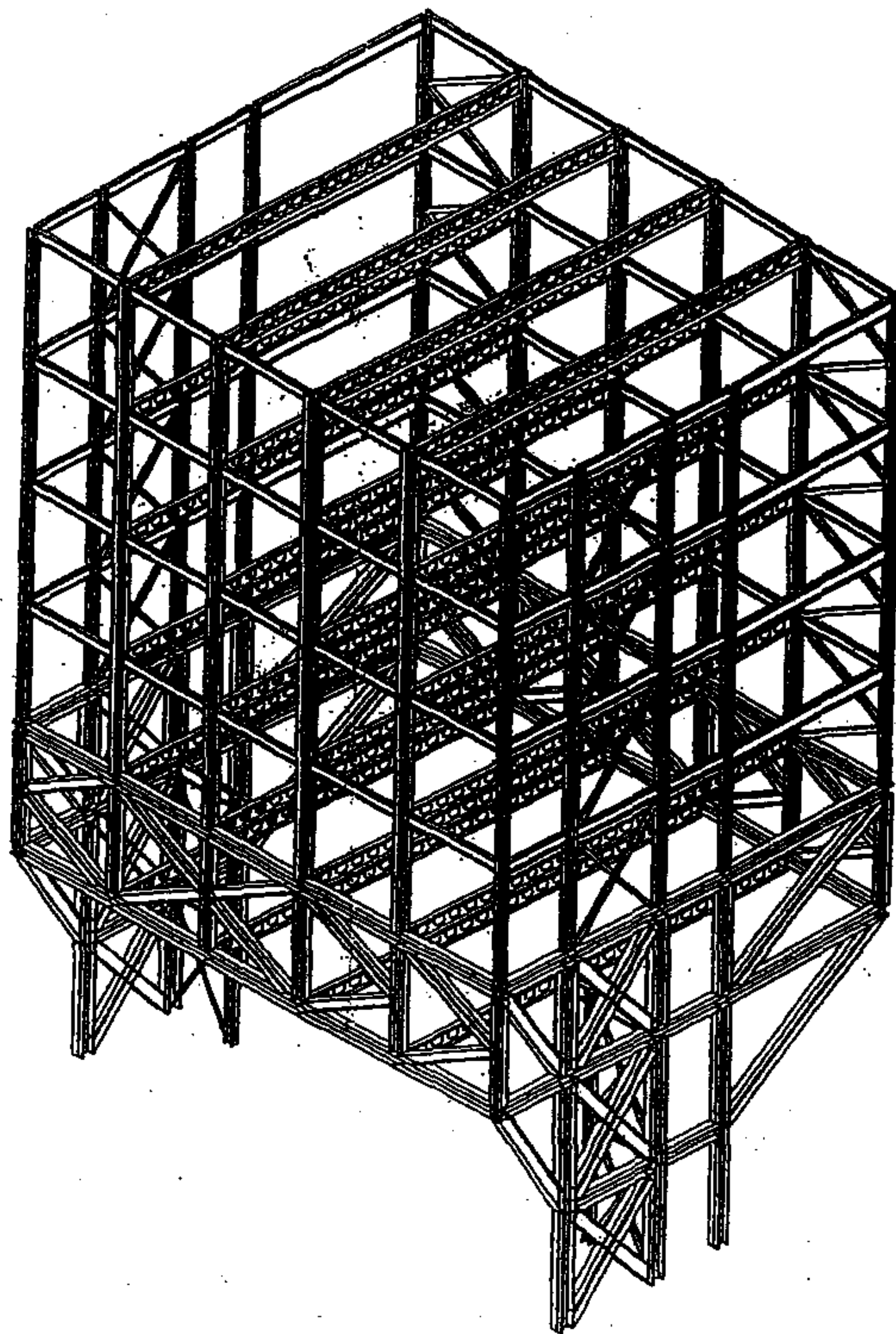


Fig 1.

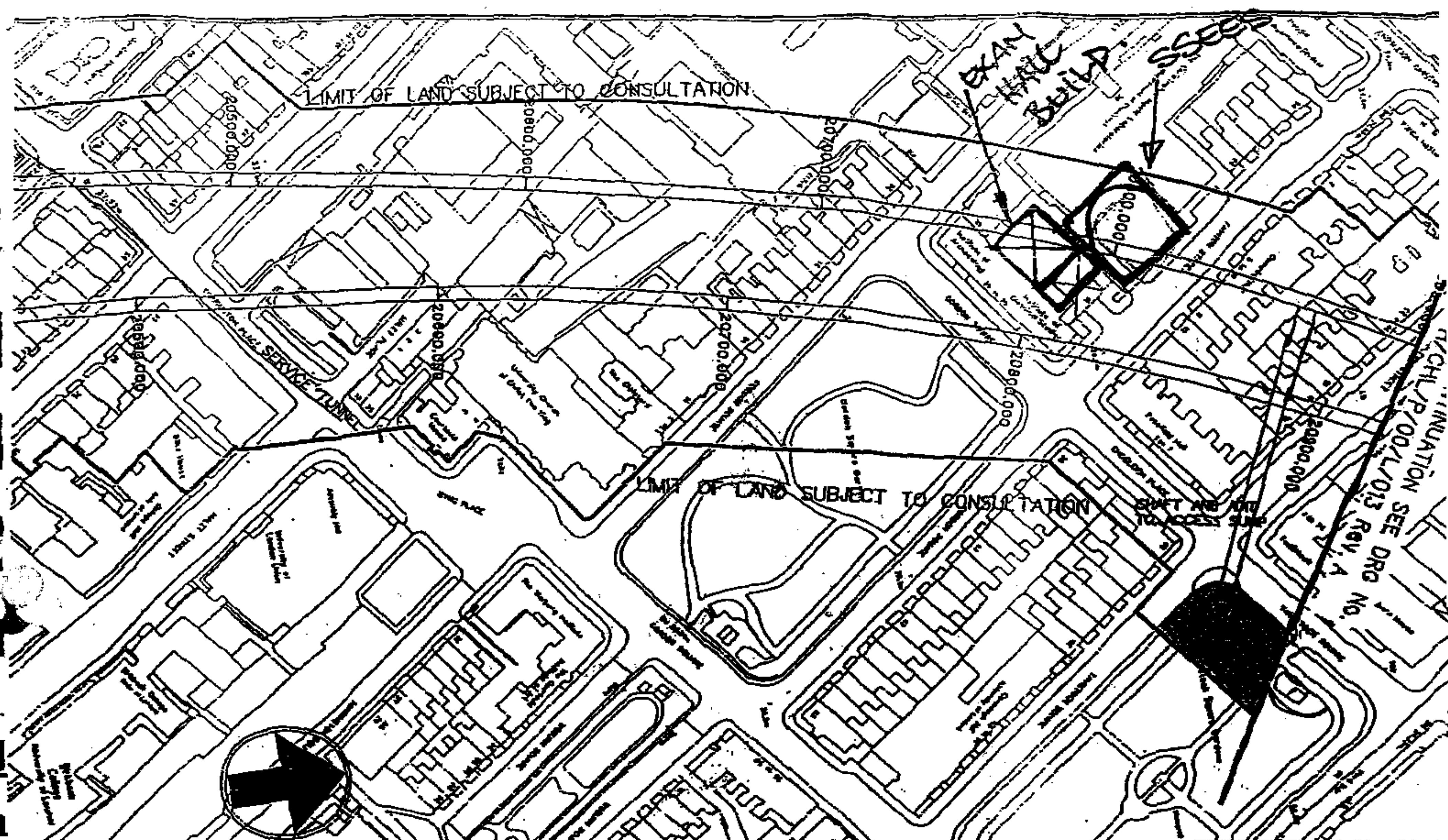
Location of the site.



Isometric View

Fig 2.

Isometric view of steel frame



PLAN

LONDON BOROUGH OF CAMDEN

DRAFT

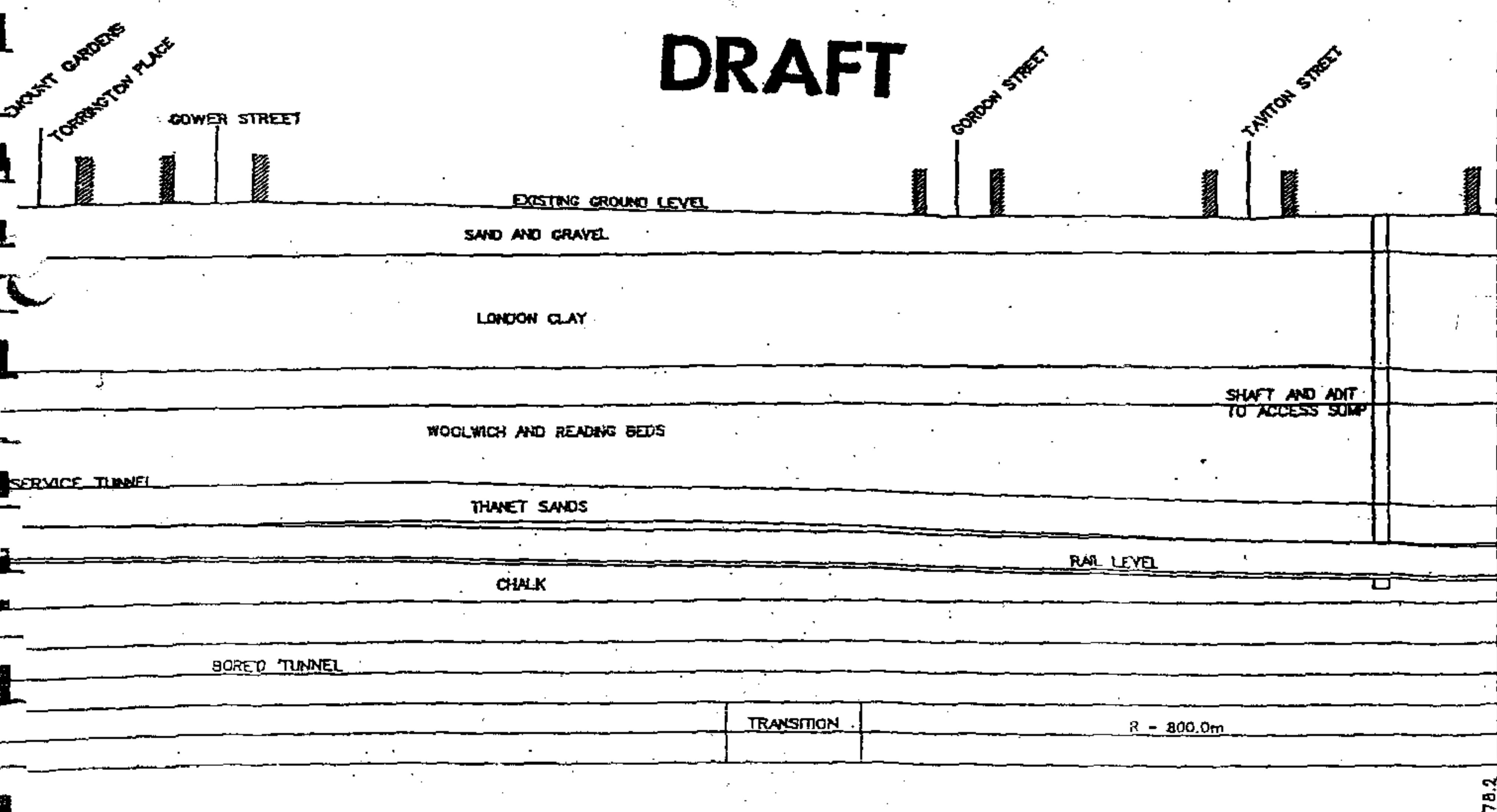


Fig 3.

Route of Crossrail 2

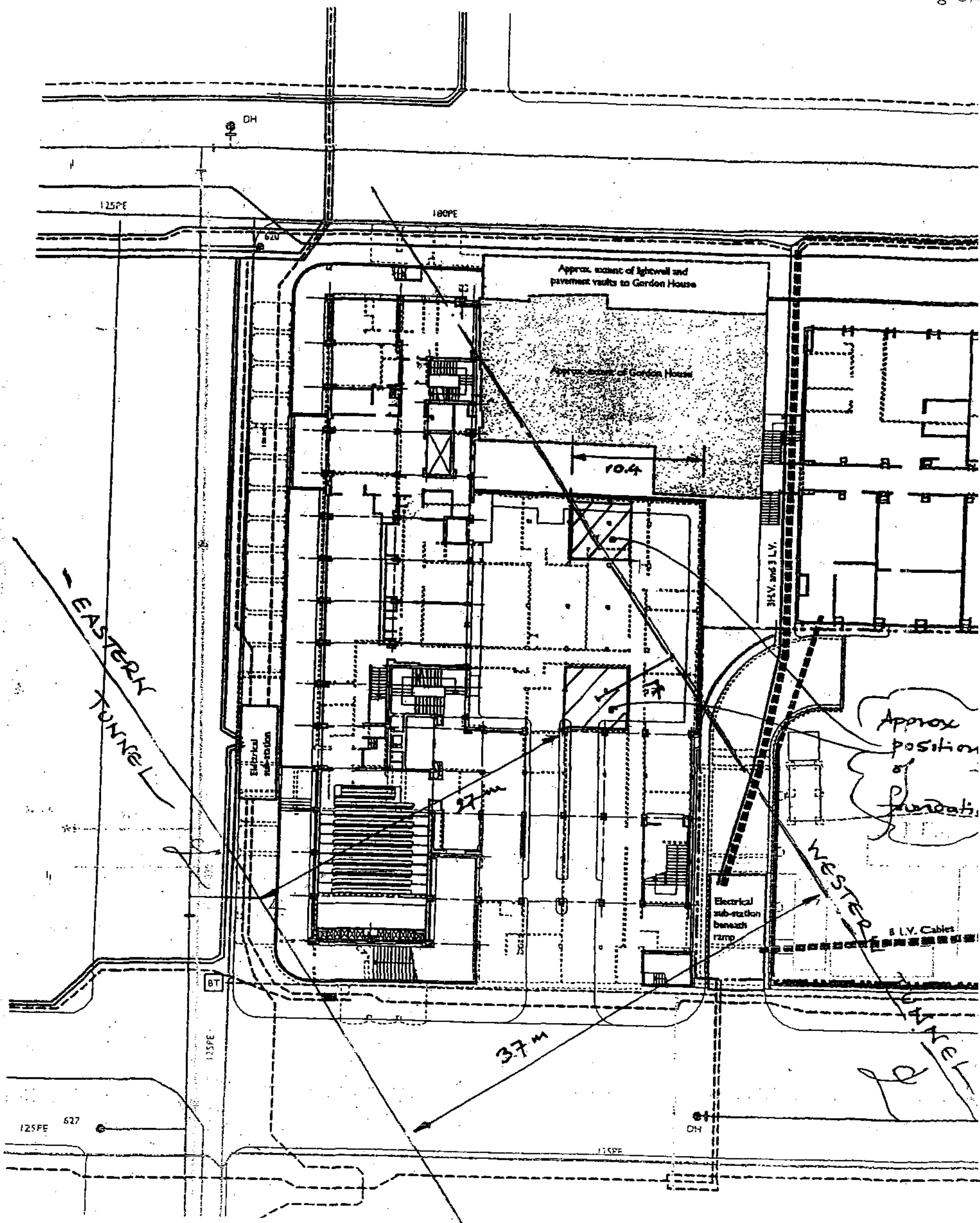


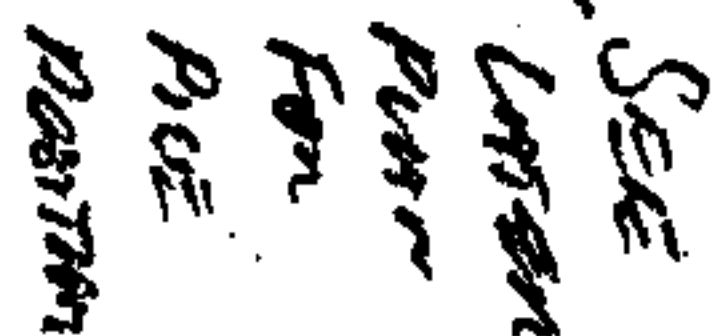
Fig 4

Approximate location of tunnel centre lines relative to building footprint.

APPENDIX 1

DRAWING OF FOUNDATIONS

32.11



UCL Anthropology. Tunnel settlements

APPENDIX 2

CALCUALTIONS OF SETTLEMENT

UCL ANTHROPOLOGY DEPT.

EFFECT OF TUNNELS FOR CROSSRAIL 2Assumptions

- Tunnel is 7 m OD
- Volume loss (winning tunnels) 1.7%
- Assumed crown level -17 m OD
- Allow ± 5 m vertical deviation
 ± 3.5 m horizontal deviation
- Assume tunnel calculations as for construction

in clay

- Ground surface +24.6 m OD

Use excavation method as Mair et al (1996)

Effect of eastern tunnel

$$\text{Least depth to tunnel axis} = 24.6 + 17 + 3.5 - 5 = 36.6 \text{ m}$$

$$z_0 = 0.5 z_a = 18.3 \text{ m}$$

At head of piles which are under pile cap, assume $z = 4.6$ m

ie top of piles at +20 m

$$y_{yz} = 0.175 z_0 + 0.325 (z_0 - z), \quad z_0 = 0.5 z_a$$

$$y_{yz} = 18.3 - 0.325 z = 16.8 \text{ m}$$

$$\text{Settlement } w_{yz} = w_{max} e^{-\frac{y^2}{2 y_z^2}} \quad (y = \text{horizontal offset})$$

$$w_{max} = 1.25 \times V_L \times R^2 = 15.5 \text{ mm}$$

$$y = 27 \text{ m}$$

$$w_{yz} = 15.5 \times e^{-\frac{27^2}{2(16.8)^2}} = 4.25 \text{ mm}$$

1A Queensberry Place, London SW7 2DL, United Kingdom.
 Tel: +44 (0)20 7581 8348
 Fax: +44 (0)20 7584 0157

Email: admin@gcg.co.uk
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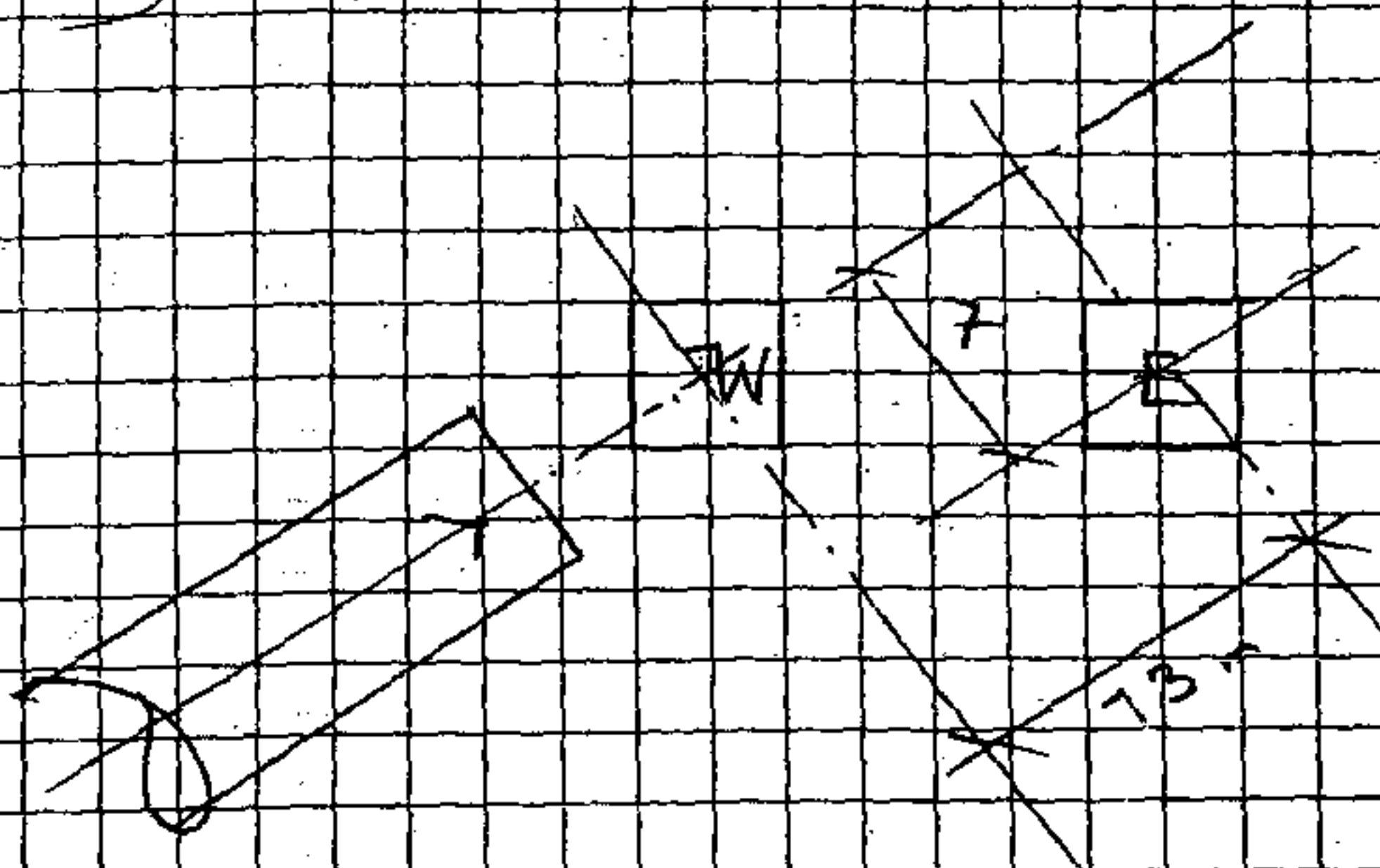
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UCL ANTHROPOLOGY DEPTH

B Effect of western tunnel

Given deviation worst condition would be tunnel passing directly under westernmost foundation, approaching from west



Maximum Settlements

Check settlements at top of piles, level of equivalent raft and base of piles
 ($z = 4.6, 18, 24.6 \text{ m}$)

for $z = 4.6$	$z_{yz} = 16.8 \text{ m}$
18	$z_{yz} = 12.45 \text{ m}$
24.6	$z_{yz} = 10.3 \text{ m}$

$w_{max}, z = 4.6 \text{ m}$	$= 15.5 \text{ mm}$
12.45	21 mm
24.6	25.3 mm

For a group offset at 7 m (group E)

$w_{yz} 4.6$	$= 14.2 \text{ mm}$
12.45	17.9 mm
24.6	20.7 mm

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Where 27 m is the distance from the tunnel to nearest part of any foundation

Over 5 m width of foundation, settlement differential

$$= W_{27, z} - W_{32, z}$$

$$\text{Where } W_{32, z} = 15.5 \times e^{-\frac{32^2}{2(16.8)}} = 2.5 \text{ mm}$$

$$\text{Differential} = 1.7 \text{ mm at pile cap underside.}$$

If piles are 20 m long, equivalent raft would be at 13.3 m

below pile cap underside. Estimate settlement at $z = 4.6 + 13.4 = 18 \text{ m}$

$$z_{yz} = 18.3 - 0.325 \times 18 = 12.45 \text{ m}$$

$$W_{max} = 1.25 \times 0.017 \times 3.5^2 = 21 \text{ mm}$$

At centre of pile group

$$W_{yz} = 21 \times e^{-\frac{29.5^2}{2 \times (12.45)^2}} = 1.3 \text{ mm}$$

Conclusion: effect of eastern tunnel on foundations is very small

There may be a small relative settlement between pile cap and basement slab (1 to 3 mm)

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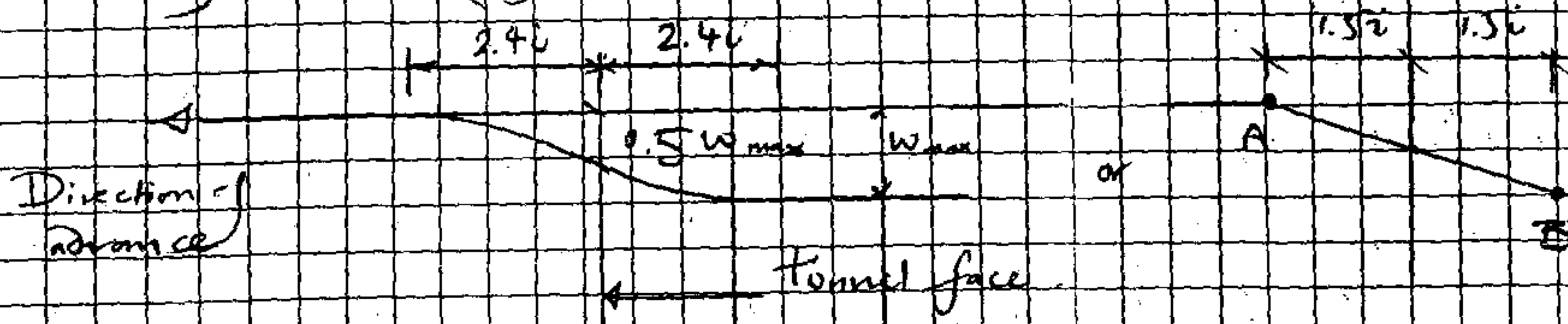
ii. Difference between foundations likely to be 4 to 5 mm

for completed tunnel

Mass settlement = 21 nm.

For advancing tunnel

Using Attenwell & Yates (1984), cumulative settlement curve



1- $v = 12.45 \text{ m}$ (for equivalent raft)

$$2.4 i = 29.9 m$$

$$1.52 = \sqrt{18.67} \text{ m}$$

If horizontal offset is 7 m and E is 13 m ahead of W

40 max. width = 21 mm

$LO_{MAX, East} = 17.9 \text{ mm}$

Approximately, if $W_{\text{max}} = 21 \text{ mm}$ (as tunnel passes point B)

$$W_{\text{rest}} = 179 - \frac{179 \times 13}{2 \times 1867} = 11,7 \text{ mm}$$

Differential = 2.3 mm (Between W and E)

As time passed, this world grew

1A Queensberry Place, London SW7 2DL, United Kingdom.
 Tel: +44 (0)20 7581 8348 Email: admin@gcg.co.uk
 Fax: +44 (0)20 7584 0157 Web: www.gcg.co.uk

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This suggests that the building would tilt towards the advancing tunnel. If the building height is approximately twice the distance between the footings, the horizontal movement of the top of the building, if it rotated rigidly, would be $\leq 20 \text{ mm}$.