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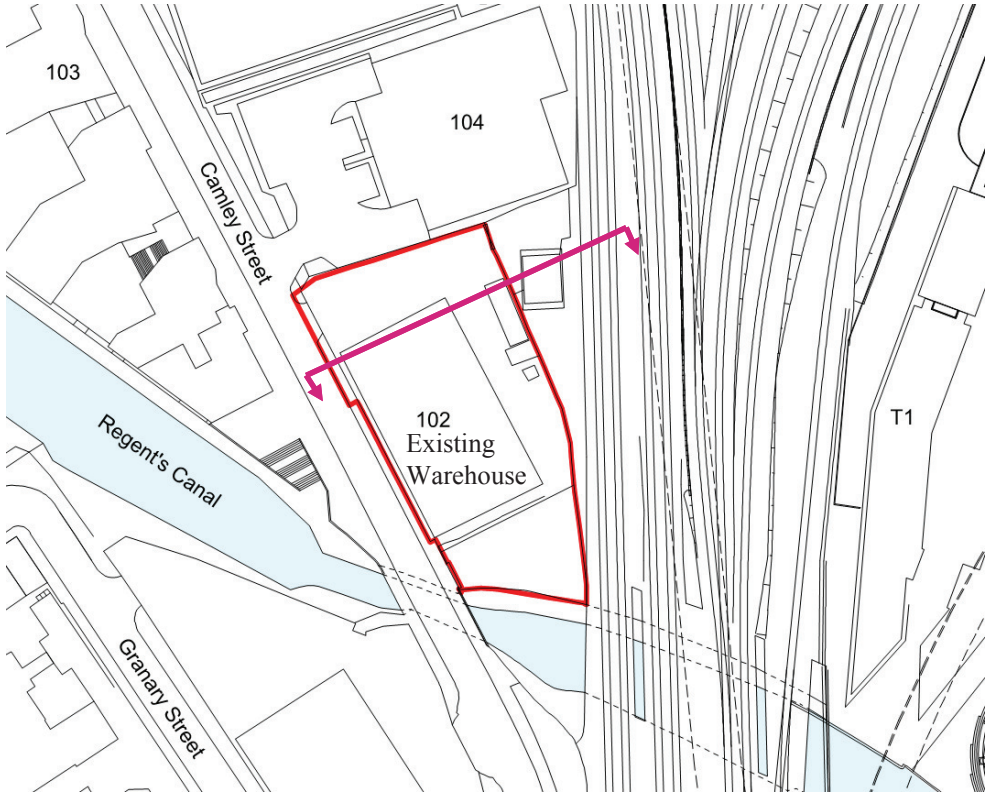
- Analysis of ground movement
- Ground movements summary
- Monitoring proposals and strategy
- Hydrogeological study

Site Location and Proposed Development



Proposed

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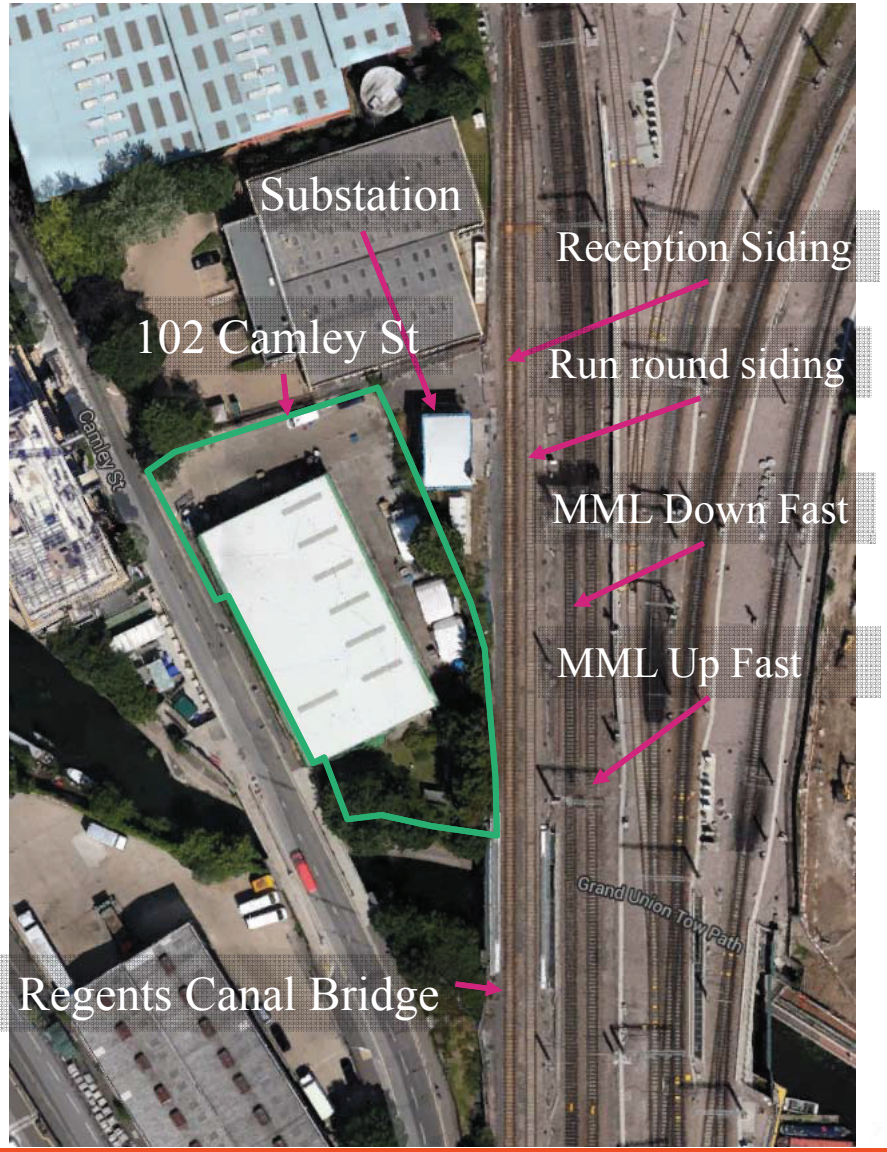
Network Rail Assets

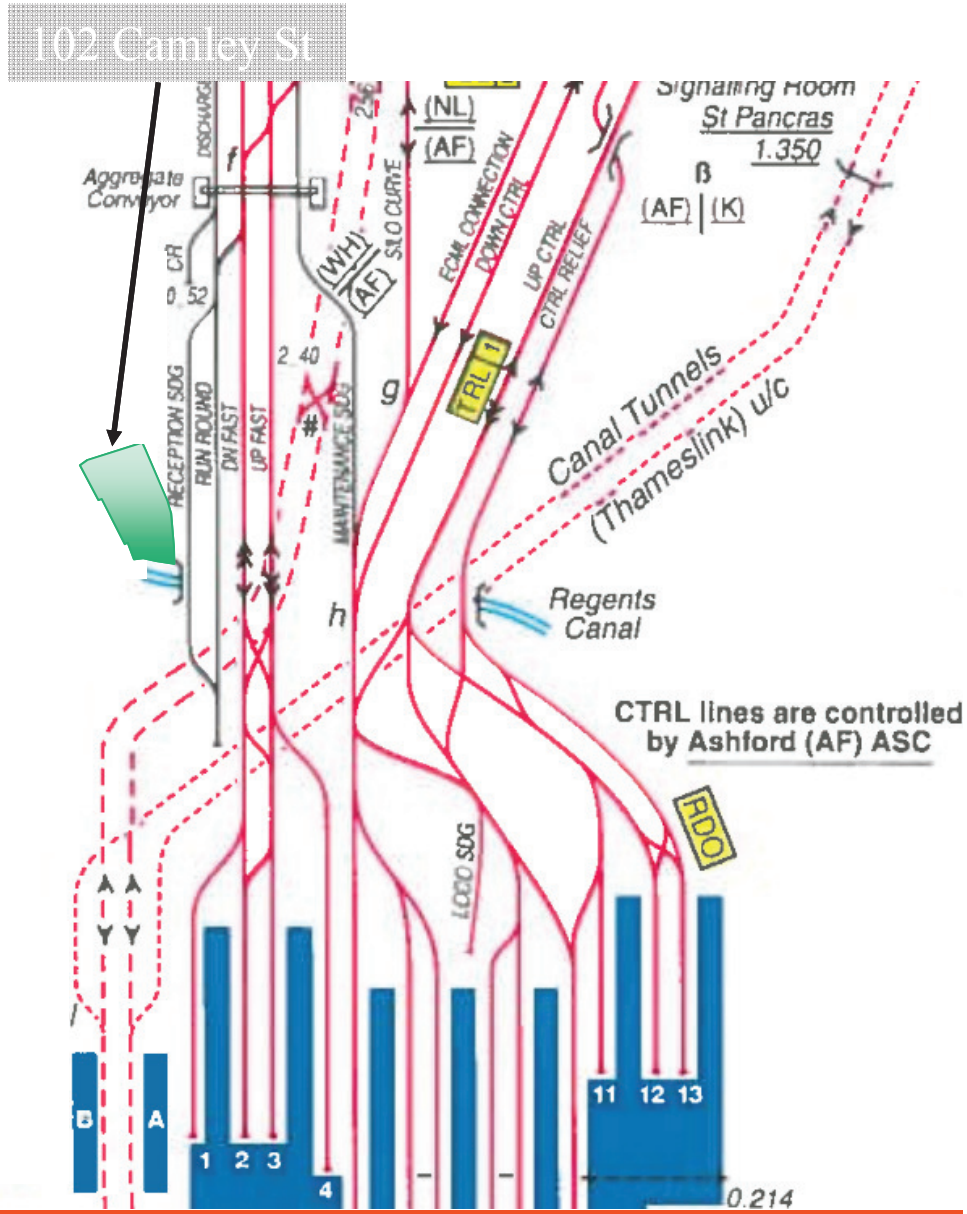
- Track
  - Reception siding
  - Run round siding
  - MML Down fast
  - MML Up fast
  - OLE equipment

- St. Pancras MML Substation No. 1

- Regents Canal Bridge (SPC1/8)

Network Rail Assets





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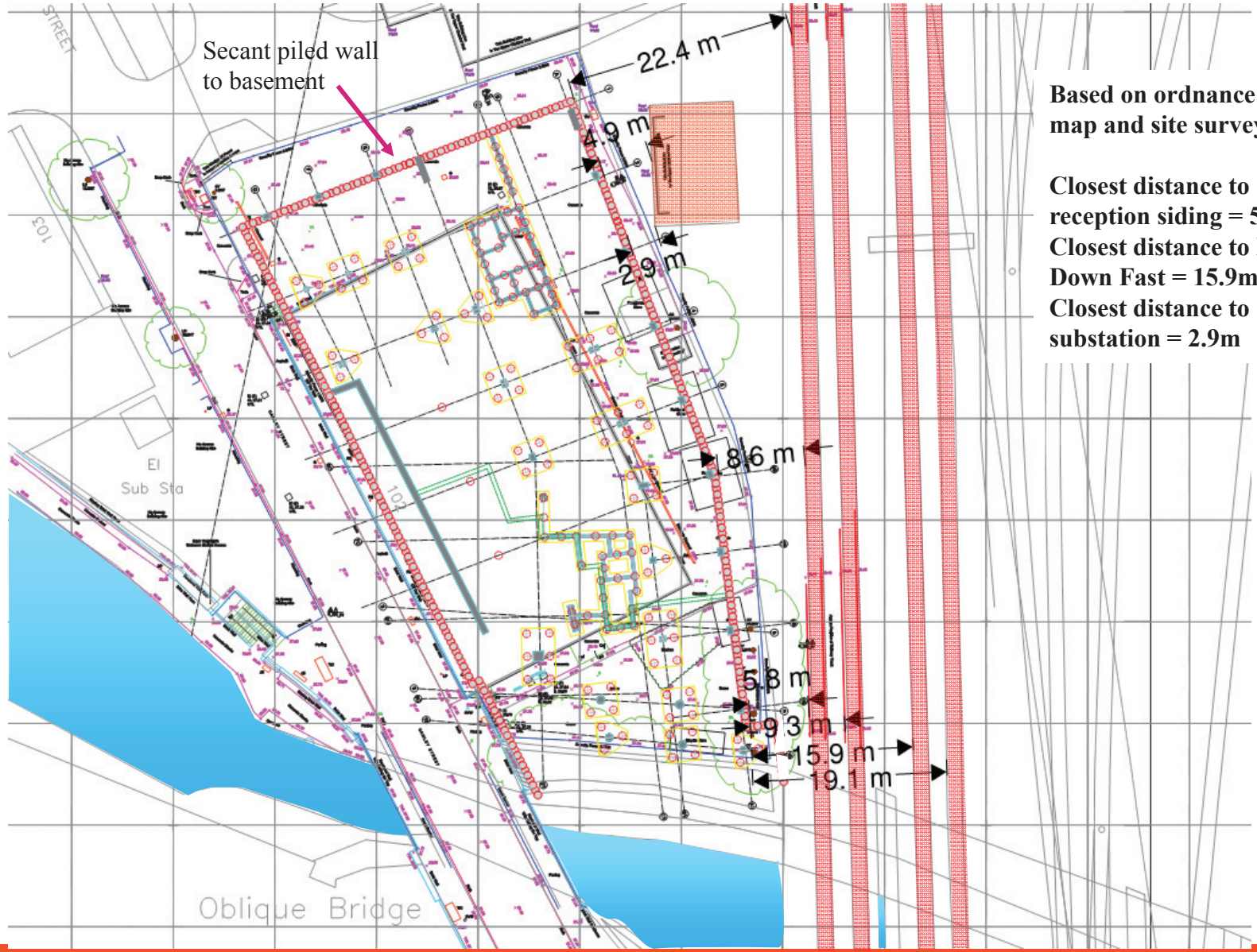
Network Rail Assets – distances from basement



Based on ordnance survey map and site survey:

Closest distance to reception siding = 5.8m
Closest distance to MML Down Fast = 15.9m
Closest distance to substation = 2.9m

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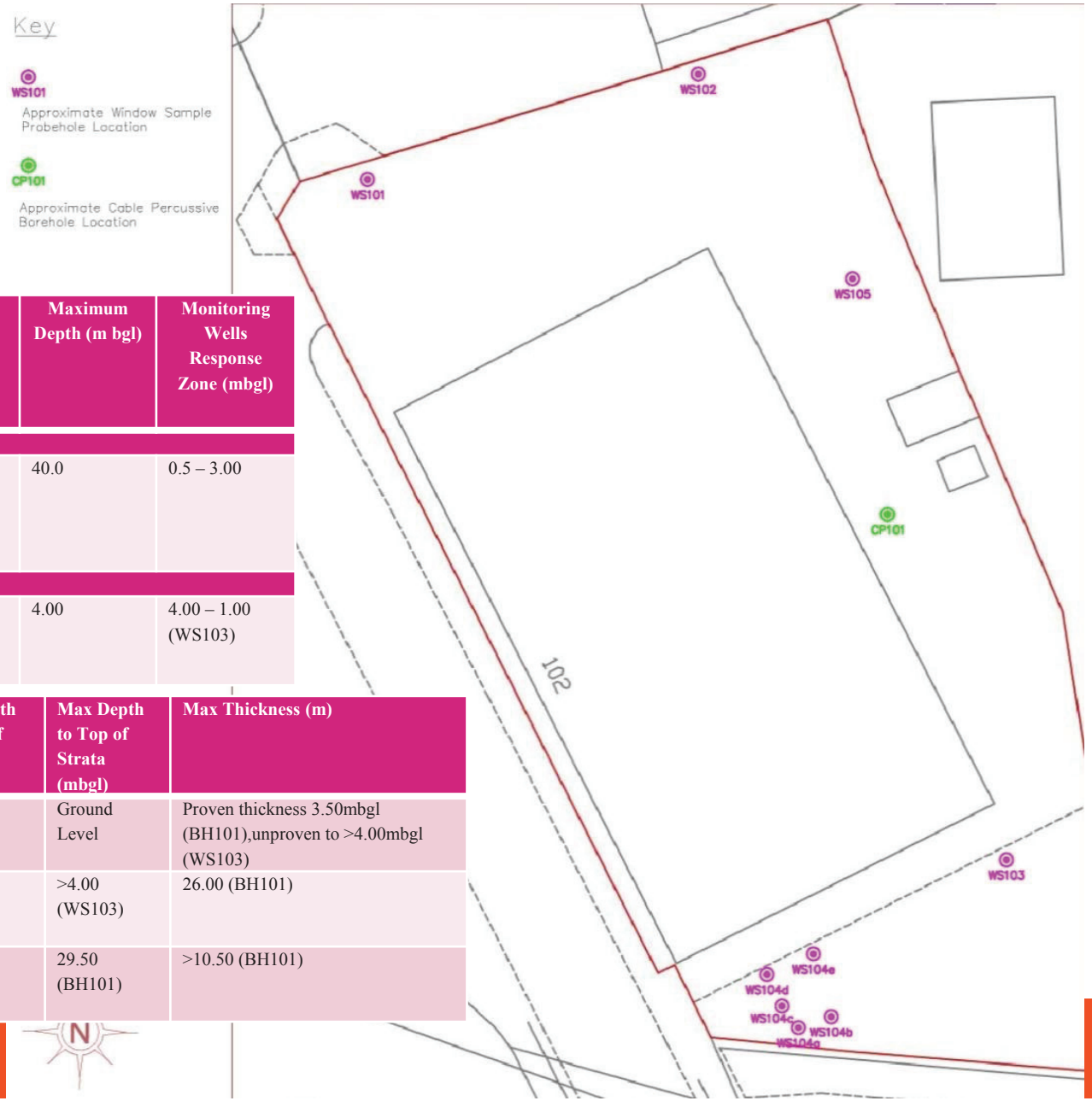
Ground investigation

- Site specific at 102 Camley Street
- CTRL investigation
- 103 Camley Street investigation

Ground investigation – 102 Camley St – Phase 1



Location Hole	Type	Maximum Depth (m bgl)	Monitoring Wells Response Zone (mbgl)
Cable Percussive Hole			
BH101	Cable Percussive Borehole	40.0	0.5 – 3.00
Window Sample Holes			
WS101 to 105	Window Sample Hole	4.00	4.00 – 1.00 (WS103)

Strata	Min Depth to Top of Strata (mbgl)	Max Depth to Top of Strata (mbgl)	Max Thickness (m)
Made Ground	Ground Level	Ground Level	Proven thickness 3.50mbgl (BH101),unproven to >4.00mbgl (WS103)
London Clay Formation (Bedrock)	3.50 (BH101)	>4.00 (WS103)	26.00 (BH101)
Lambeth Group (Woolwich and Reading Beds)	29.50 (BH101)	29.50 (BH101)	>10.50 (BH101)

Second Phase commencing with more window samples holes and 2 piezometers

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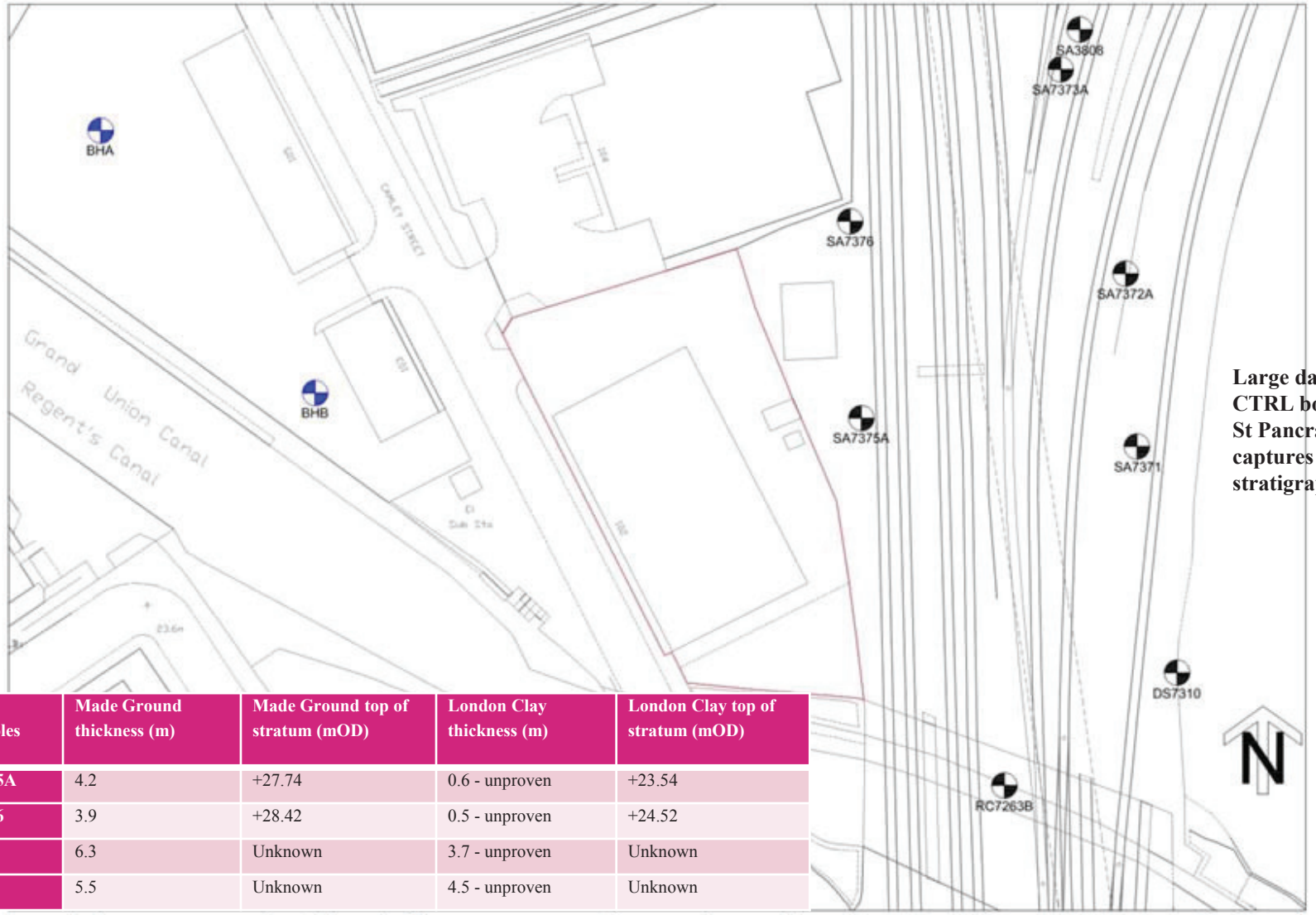
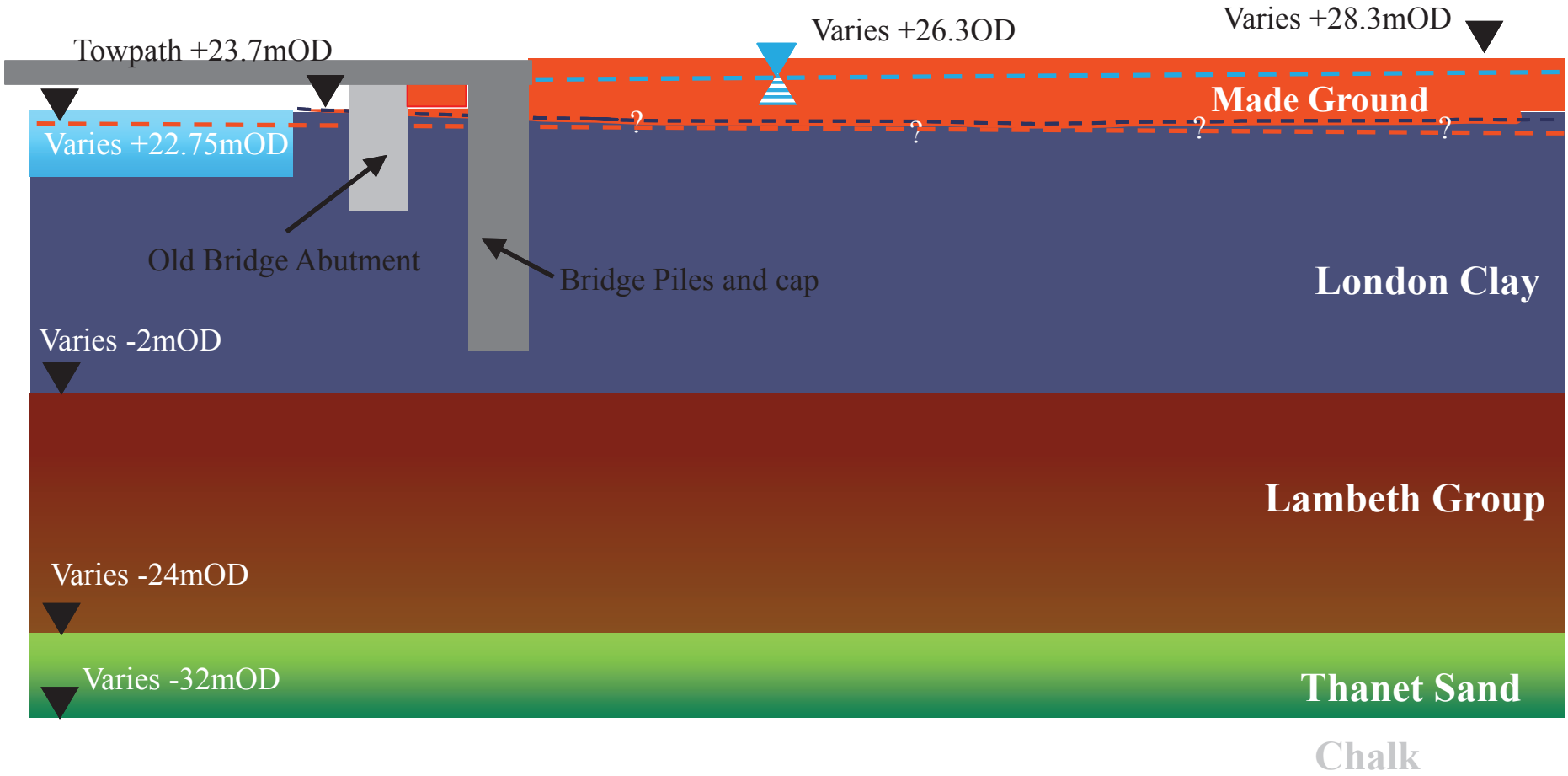
Ground investigation – 103 Camley St and CTRL



Closest Boreholes	Made Ground thickness (m)	Made Ground top of stratum (mOD)	London Clay thickness (m)	London Clay top of stratum (mOD)
SA7375A	4.2	+27.74	0.6 - unproven	+23.54
SA7376	3.9	+28.42	0.5 - unproven	+24.52
BHB	6.3	Unknown	3.7 - unproven	Unknown
BHA	5.5	Unknown	4.5 - unproven	Unknown

Large database of CTRL boreholes in St Pancras area captures deeper stratigraphy

Stratigraphy

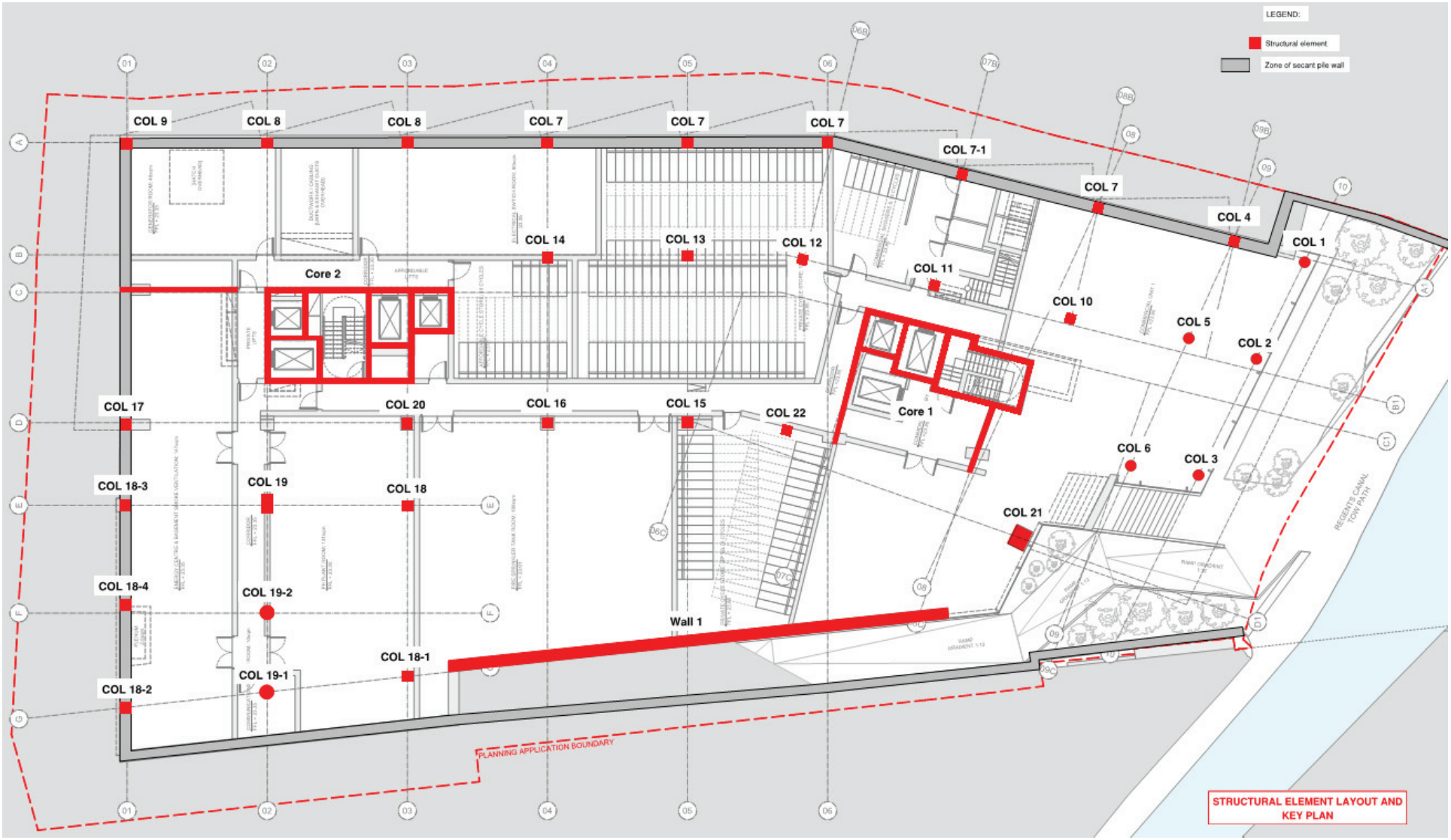


Soil parameters for design - based on CTRL and 102 Camley St

	Bulk density γ (kN/m^3)	Coefficient of Earth pressure at rest, K_0	Characteristic soil strength			Stiffness for Retaining wall analysis (MPa)	Stiffness for ground movement analysis (MPa)
			Undrained shear strength (kN/m^2)	Cohesion c' (kN/m^2)	Friction angle (°)		
Made Ground	19	0.58	-	0	25	E'=15 (beneath substation only) E'=8 (elsewhere)	E'=15 (beneath substation only) E'=8 (elsewhere)
London Clay	19	1.4	50+15z (z<3m)* 75+6.5z (z>3m)*	2	25	E_u=1000c_u E'=750c_u	E_u = 500c_u E'=400c_u
Lambeth Group	19	N/A	As LC	N/A	N/A	As LC	As LC
Upnor Formation/ Thanet Sands	19	N/A	N/A	N/A	N/A	N/A	E'=200

*where z is the depth below the top of London Clay

Load Distribution



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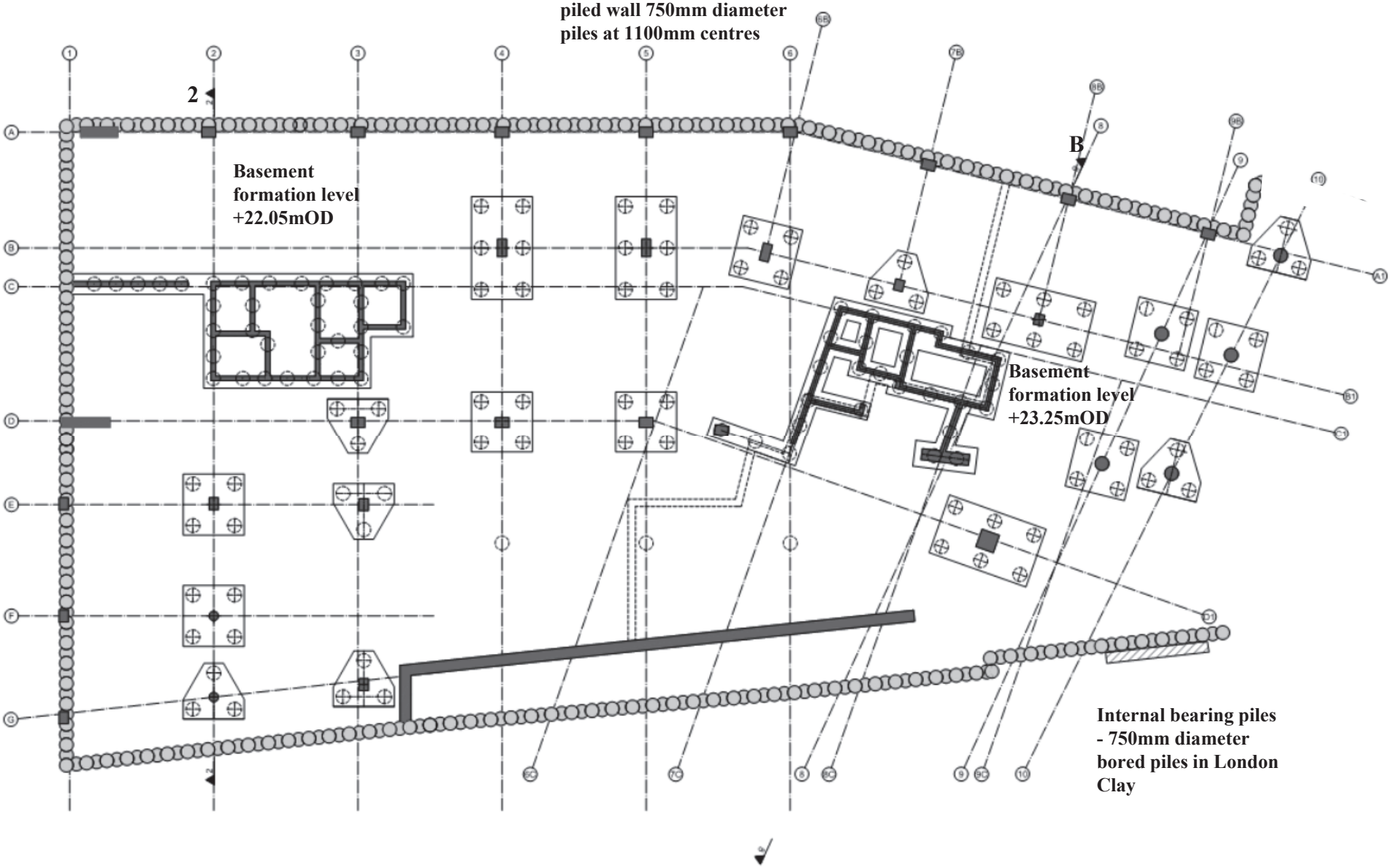
Piled Foundations



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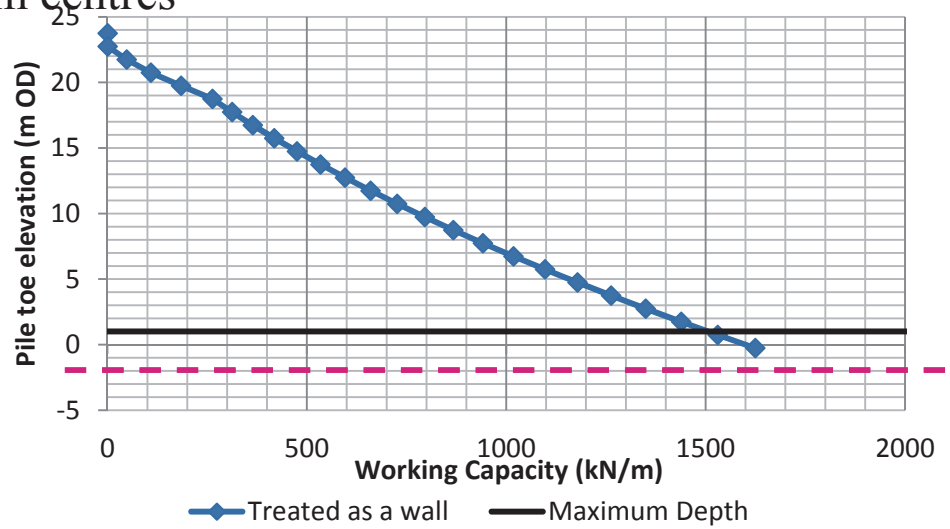
Retaining Wall

- Male piles of 750mm diameter at 1100mm centres
- 650mm without casing

  (below +21. 5mOD)
- Load bearing
- Toe level +2mOD to +5mOD

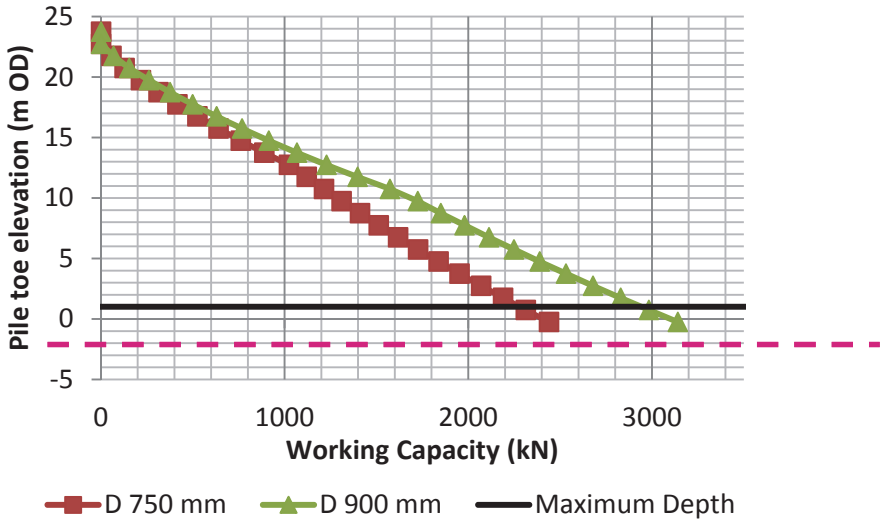
Base of London Clay -2mOD



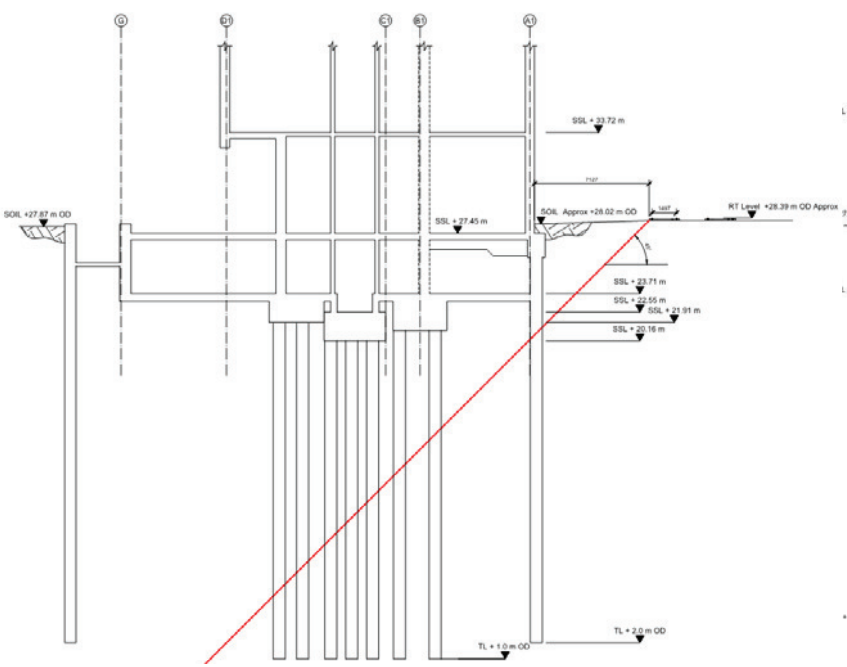
Bearing Piles

- Groups of 750mm diameter piles
- Toe level +1mOD

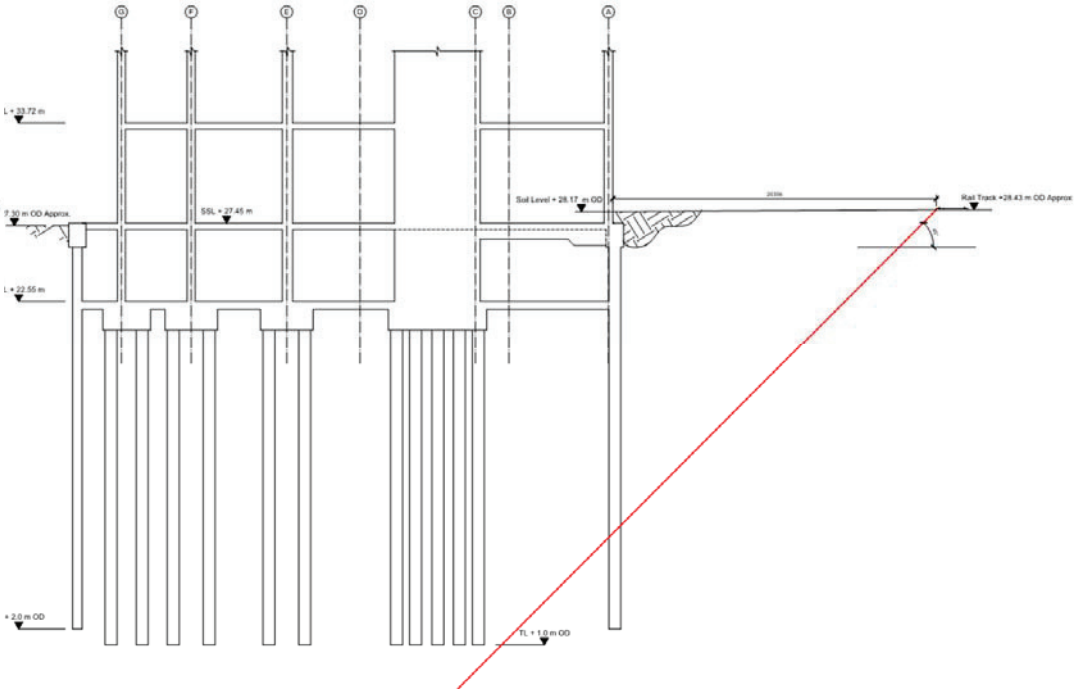
Base of London Clay -2mOD



Zone within line at 45 degrees to sleeper

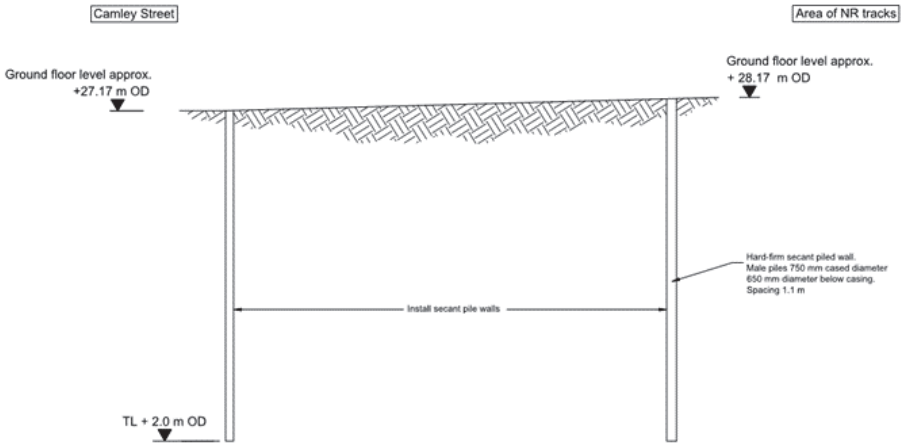


Section B – towards canal

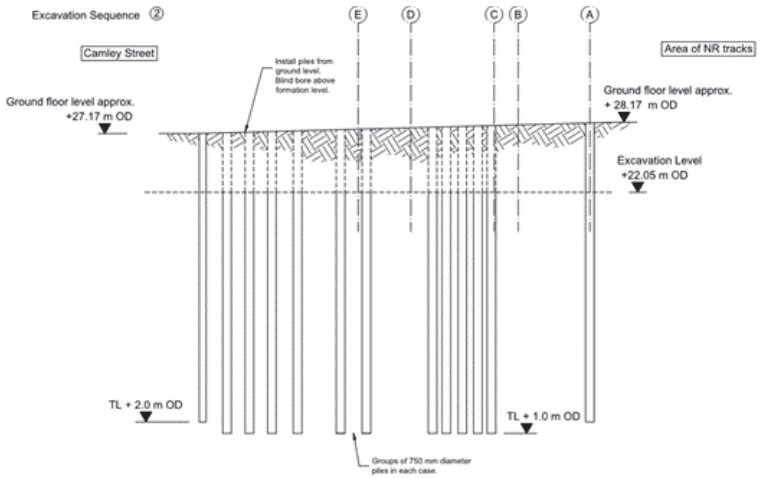


Section 2 – near substation

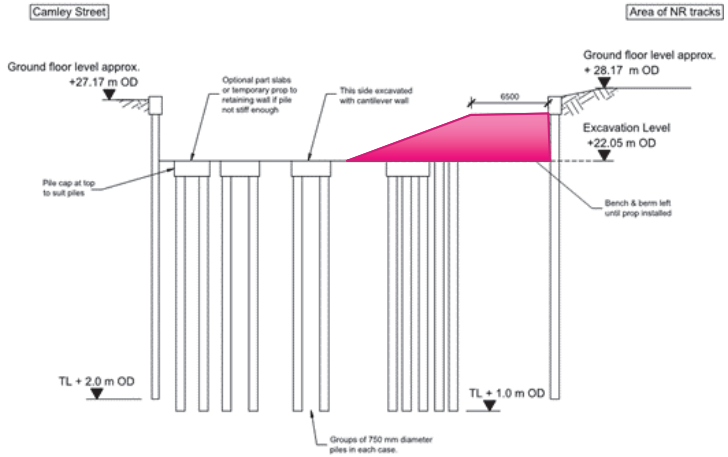
Basement Construction Sequence



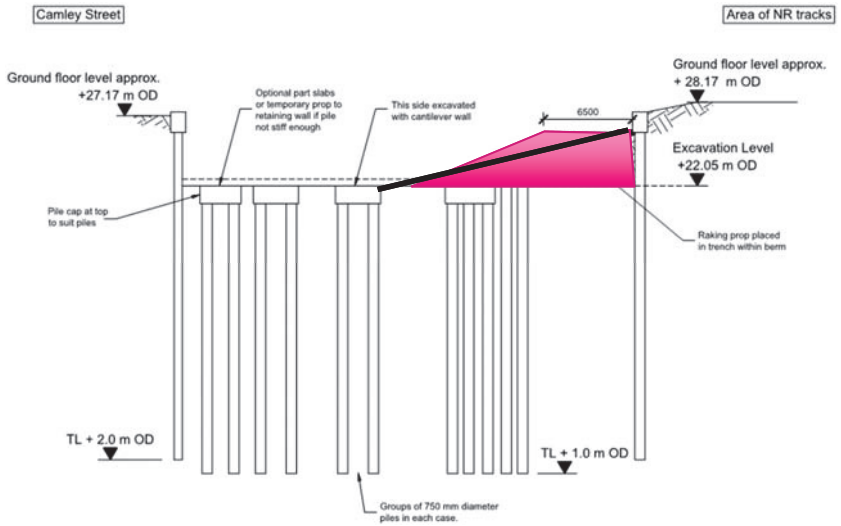
Stage 1 install secant piled walls



Stage 2 install bearing piles



Stage 3 excavate west side of basement leaving berm against east wall



Stage 4 install pile caps and raking prop off pile caps onto east wall

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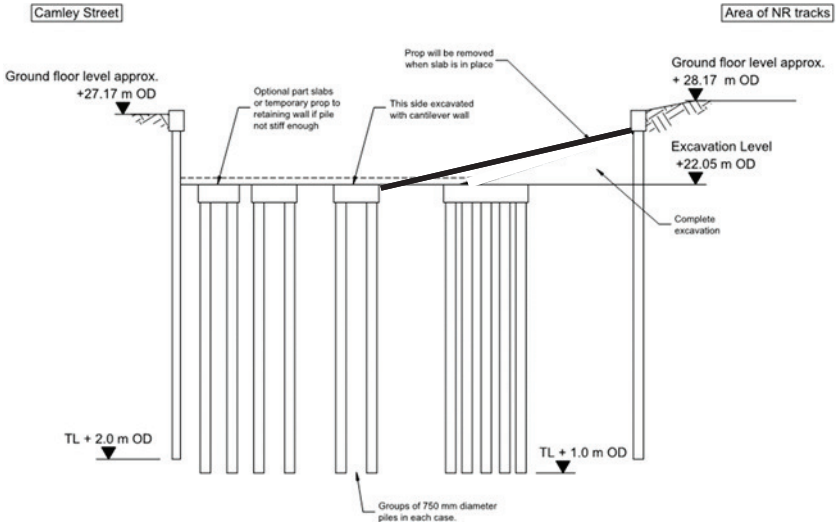
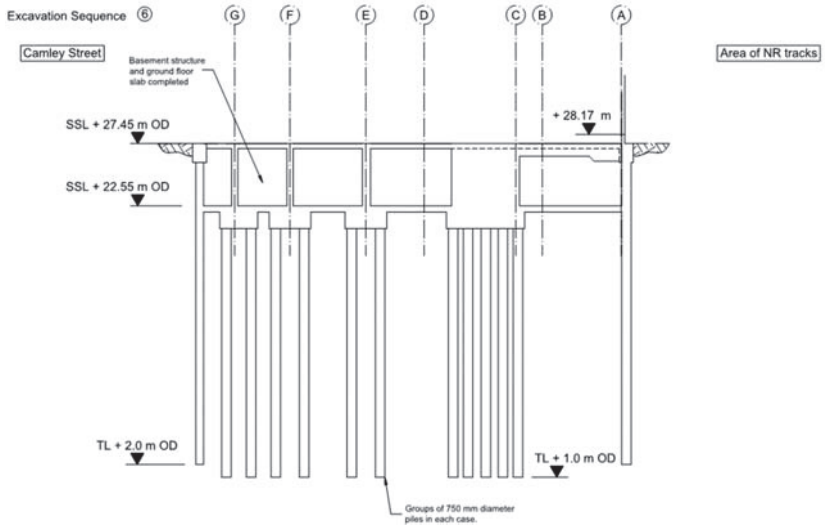


Stage 5 – excavate berm with inclined prop in place



Stage 6 – install base slab and ground floor slab and remove prop

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NR Guidance on potential acceptability of predicted movements

Fault	Trigger Level	Action
Level 1	Twist >1/300	Note
Level 2	Twist >1/200	Report Level 2 fault to Fault Control Centre (FCC). Instruct FCC to report fault to Track Section Manager immediately. The fault shall be rectified within 7 days.
Level 3	Twist >1/125	Report Level 3 fault to FCC. Instruct FCC to report fault to Track Section Manager immediately. The fault shall be rectified within 36 hours.
Level 4	Twist >1/90	Line shall be blocked with immediate effect because of a dangerous twist fault. Report Level 4 fault to FCC. Instruct FCC to report to Track Section Manager immediately. No rail traffic shall use the line until the fault has been corrected.
Cant variation	Changes in cant +/- 20mm or +/- 15mm*	Report fault to FCC. Instruct FCC to report fault to Track Section Manager for immediate inspection of track.
Displace-ment fault	25mm^{+} difference from the original	Report fault to FCC. Instruct FCC to report fault to Track Section Manager for immediate inspection of track.

Source: NR Letter of Instruction **NR/BS/LI/045 (Issue 3): Monitoring track over or adjacent to Civil Engineering works: procedure and intervention levels.**

*20mm for non-electrified lines and lines with standard electrification clearances, or +/- 15mm for lines with restricted electrification clearances.

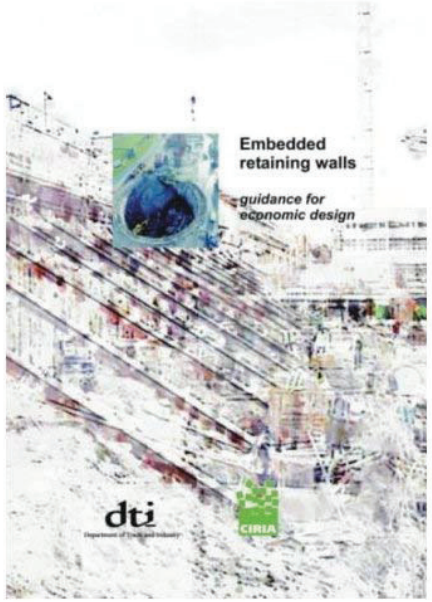
$^{+}$This may be reduced to 10mm where the length of track is subject to an Enhanced Permissible Speed or where a higher level of track quality is required.

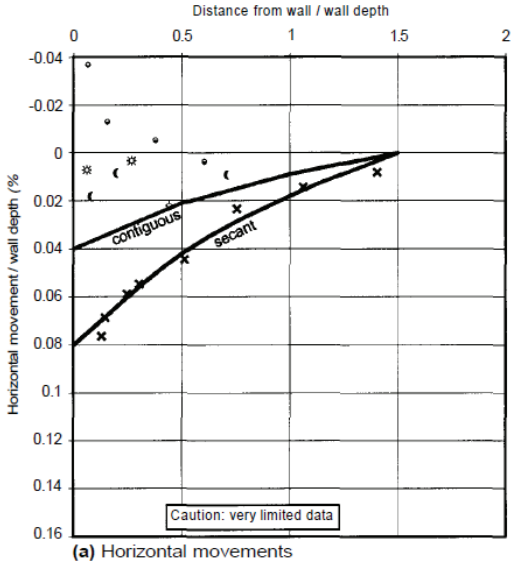
Components of Ground Movement

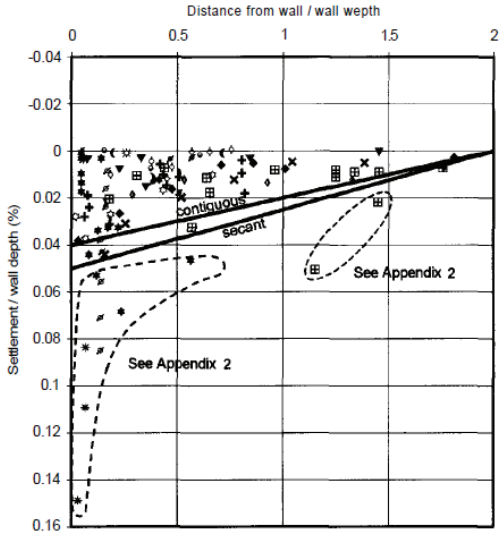
Stage	Component of ground movement	Analysis method
Demolition	vertical	Oasys Pdisp
Wall installation	vertical and horizontal	Empirical data (CIRIA C580)
Excavation	vertical and horizontal	Oasys Frew
Reloading (superstructure construction)	vertical	Data for ground settlement profile adjacent to loaded piles
Long term increment	vertical	Oasys Pdisp

Methods of analysis

Assessment of movement due to wall installation







Relationships derived from CIRIA C580 and contractor experience

Chosen - 0.015% * h/D, extending to 1.5D for vertical and horizontal movement
~ 4mm directly behind wall

Methods of analysis

Assessment of movement due to excavation of the railway embankment and basement

- *Oasys* FREW

Frew analyses the soil structure interaction of a flexible retaining wall, for example a sheet pile or diaphragm wall. The wall is represented as a line of nodal points and three stiffness matrices relating nodal forces to displacements are developed.

- *Oasys* Pdisp

Pdisp calculates the displacements (and stresses if required) within a linear elastic or non-linear soil mass, arising from uniform normal or tangential pressure, applied to rectangular and circular loaded planes.

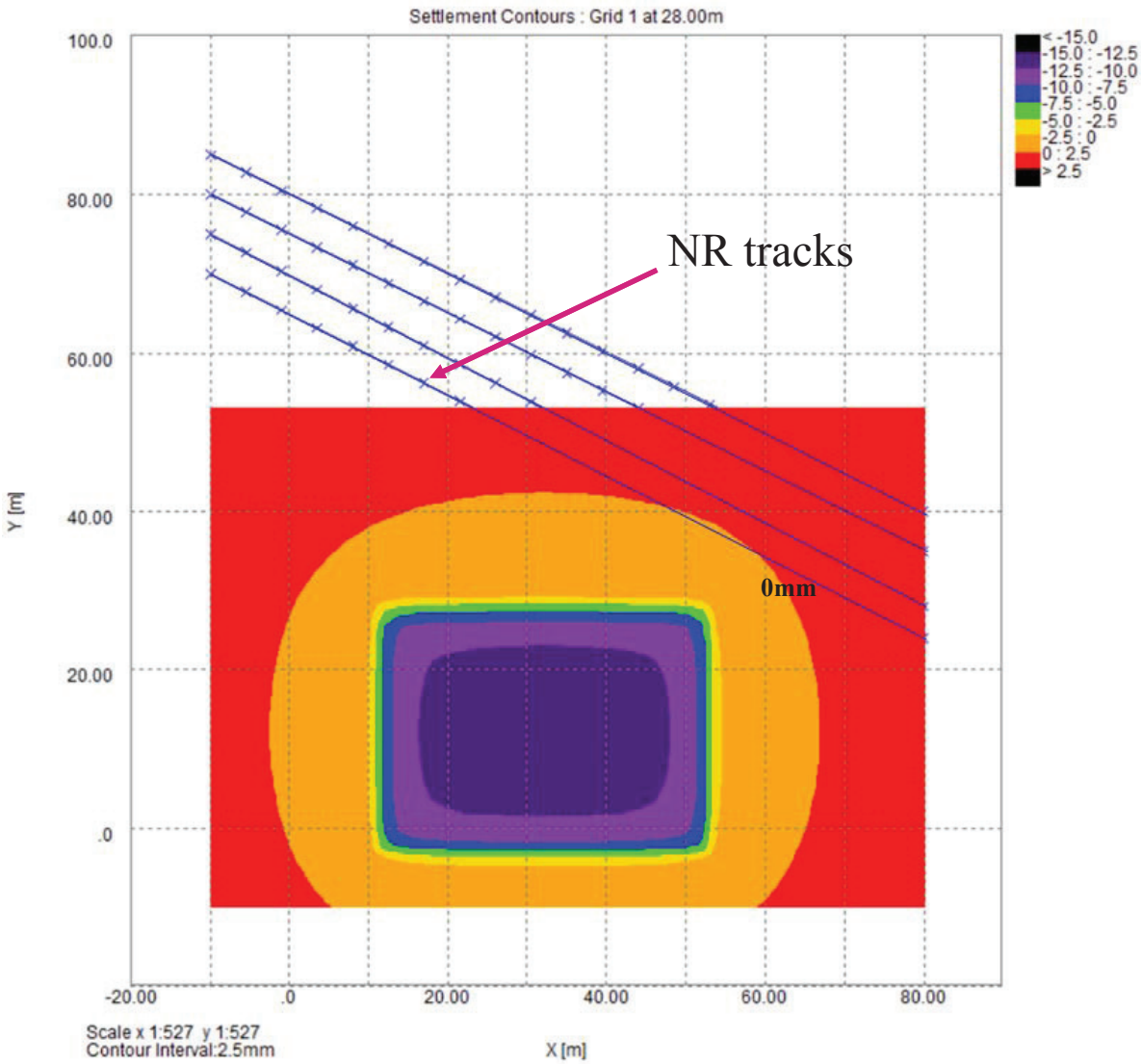
The program is ideal for predicting the displacements that may arise due to the action of several loads in a soil mass, and gives the user an understanding of the settlement pattern likely to arise both beneath and beyond the loaded area being analysed.

The analysis carried out uses a Boussinesq approximation

Ground movement analysis results

Results from demolition analysis

– vertical movements



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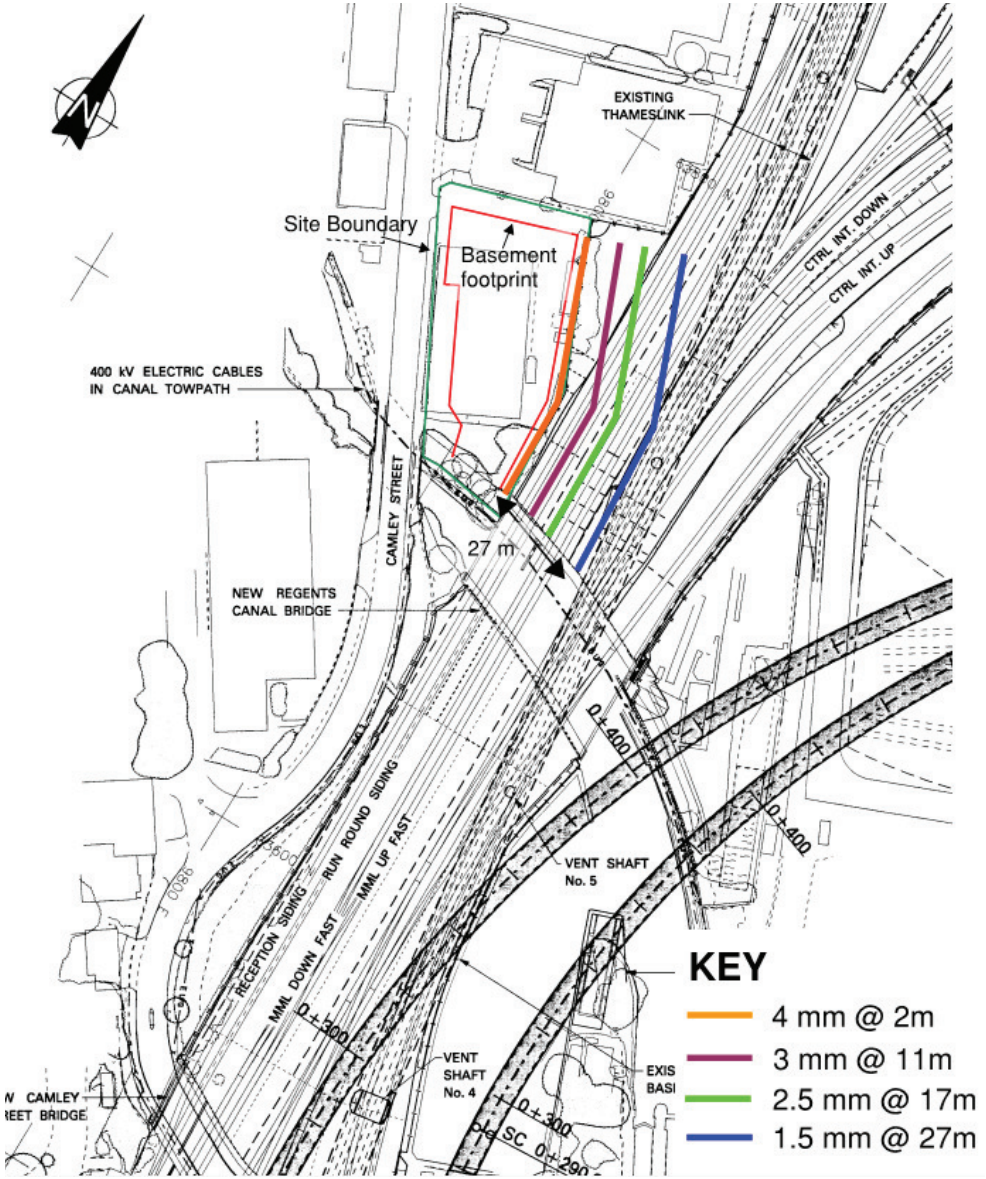
Ground movement analysis results

Results from wall installation analysis

– vertical and horizontal movement assumed equal



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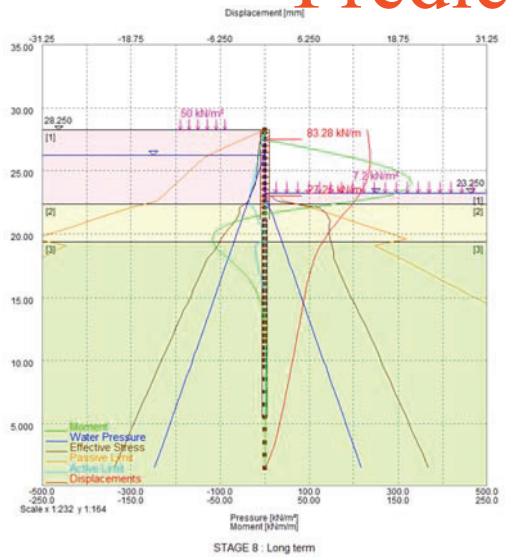
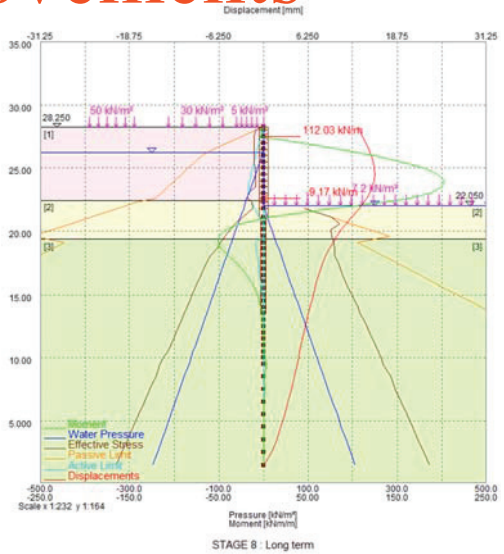
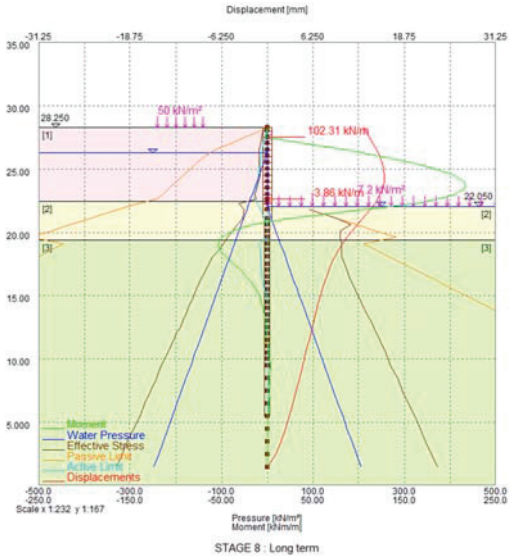
Predicted Wall movements



Section nearest Towpath



Section in front of substation

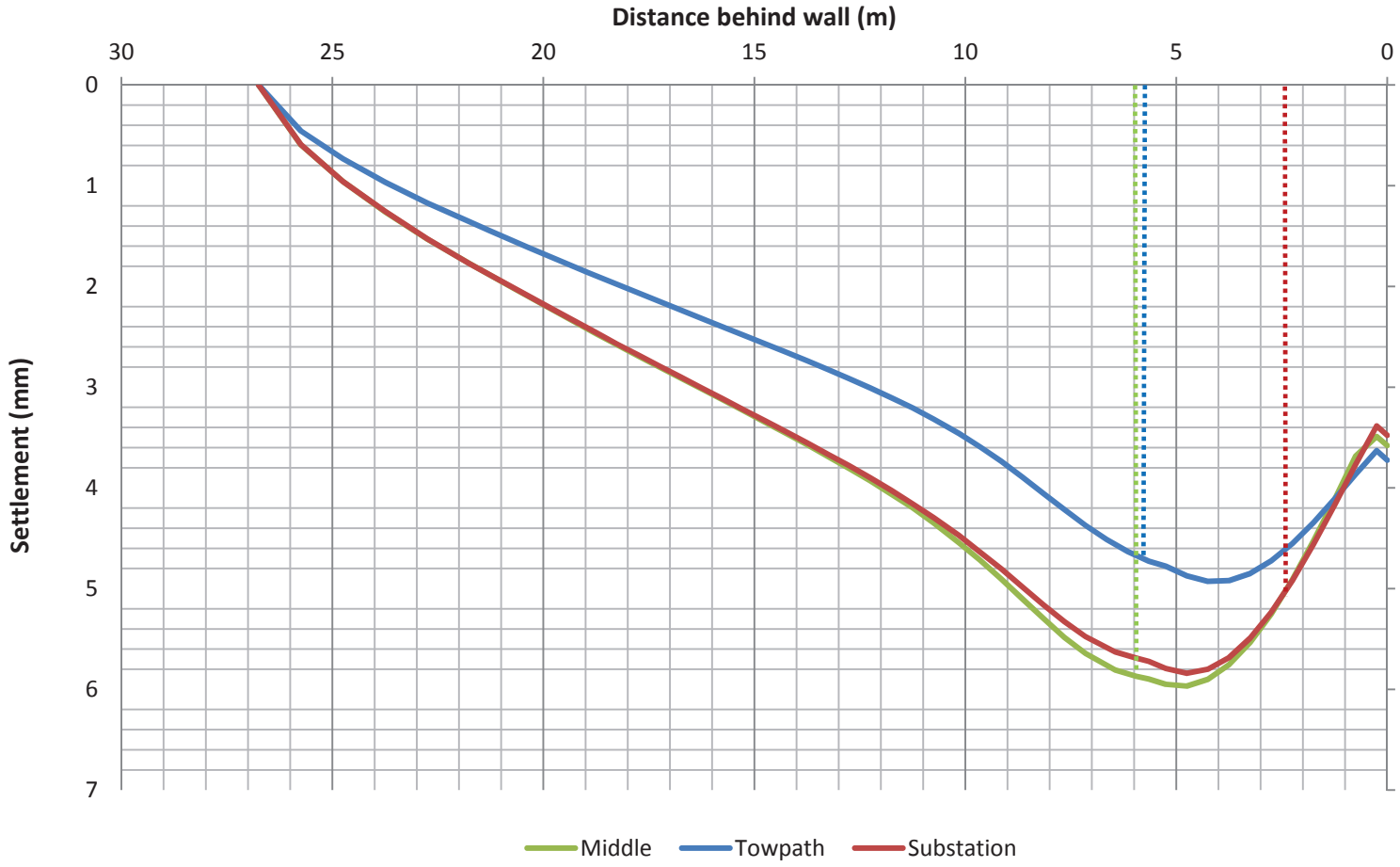


Middle section

	Towpath	Middle	Substation
Final Formation Level (mOD)	+23.25	+22.05	+22.05
Natural Ground Level (mOD)	+28.25	+28.25	+28.25
Surcharges	Train (50kPa) at 4.5m offset	Train (50kPa) at 7m offset	Train (50kPa) at 14.5m offset Substation (30kPa) Live Load (5kPa)
Toe level (mOD)	+5	+5	+2

Section of wall analysed	Predicted maximum wall movement (mm)
Adjacent to towpath	10
Middle section	12
Adjacent to substation	12

Predicted vertical ground movements behind wall due to excavation



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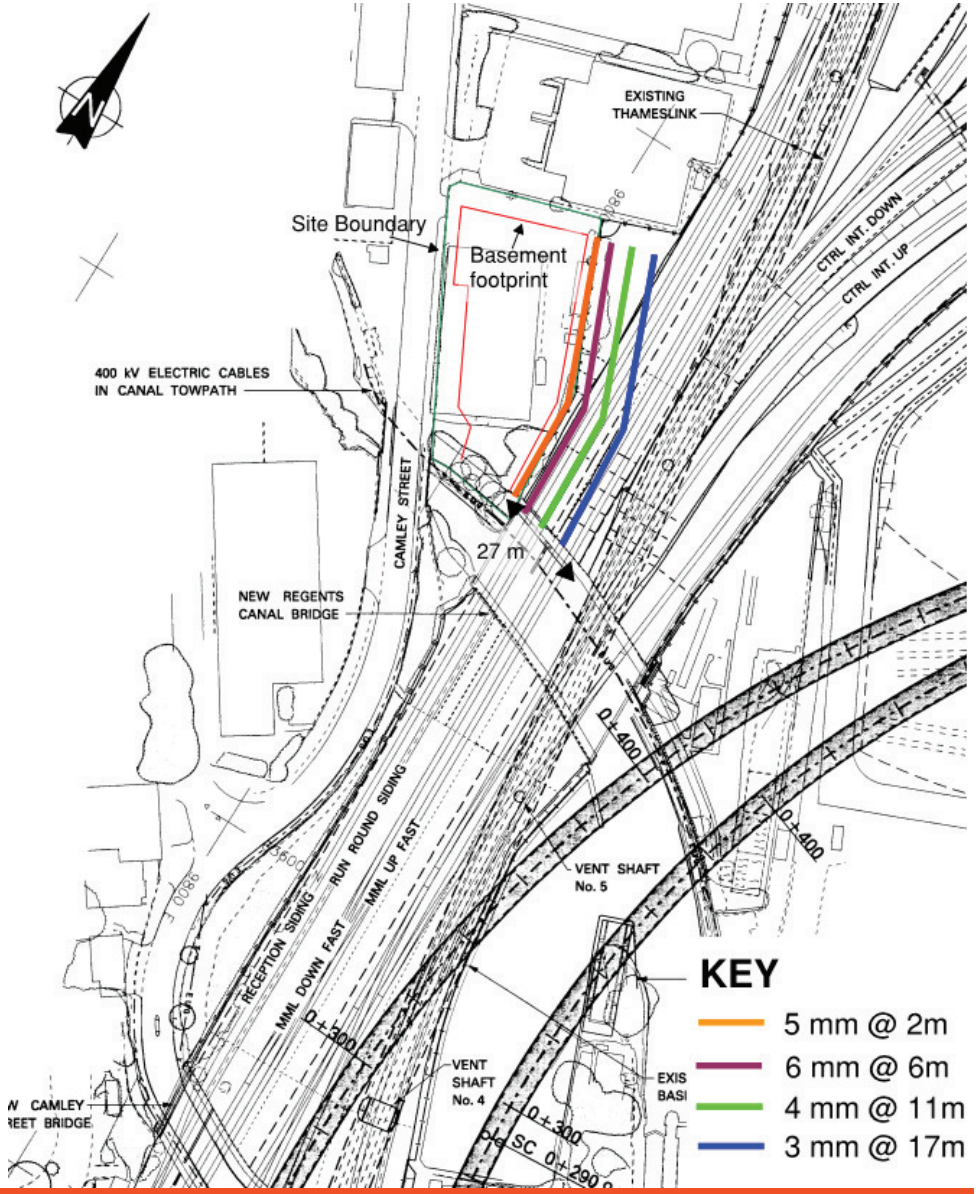
Ground movement analysis results

Results from excavation analysis

- vertical movements



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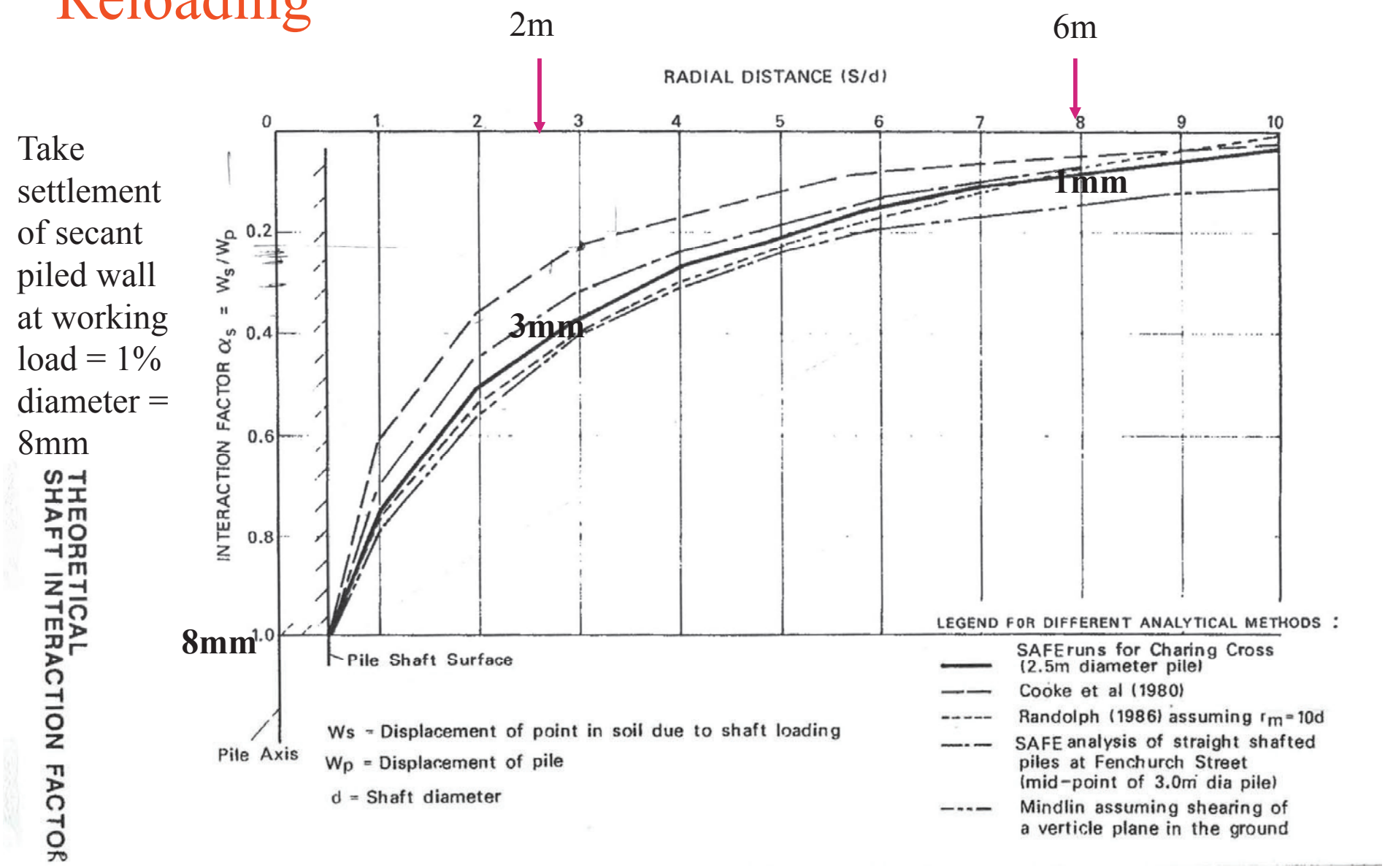
Predicted horizontal ground movements behind wall due to excavation

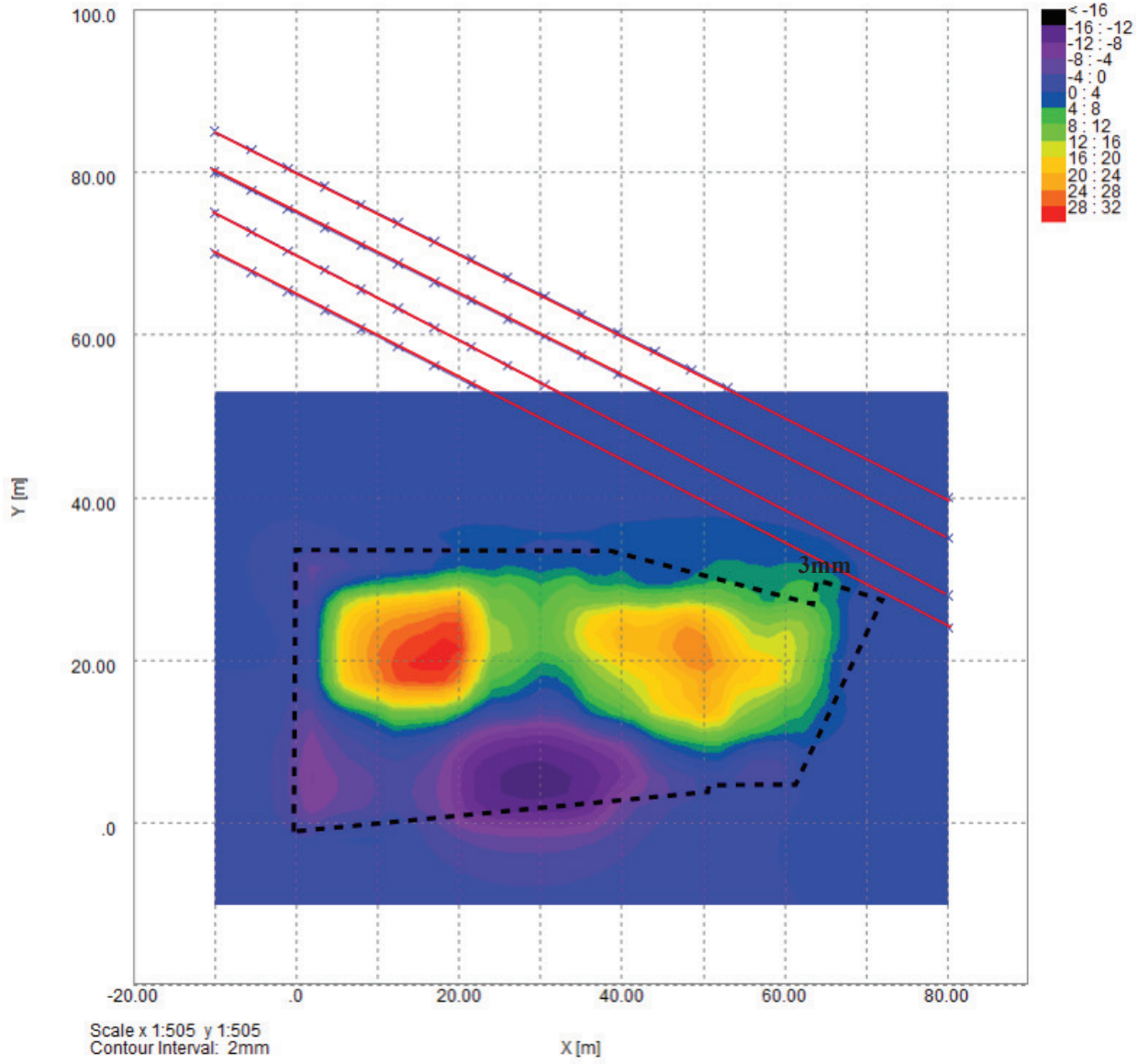
- Horizontal ground movement behind wall = horizontal displacement at top of wall
- Maximum movement at top of wall predicted from FREW = 7.5mm
- Based on CIRIA C580 ground movements reduce linearly to zero over 4x excavation depth = 24.8m maximum.

Reloading

Take settlement of secant piled wall at working load = 1% diameter = 8mm



Long term vertical ground movement due to net increase



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Ground movement analysis results - vertical

Distance from new basement (m)/ Stage	Displacement (mm)				
	@ 2 m	@ 6 m	@ 11 m	@ 17 m	@ 27 m
Demolition	-1	0	0	0	0
Wall installation	4	3.5	3	2.5	1.5
Excavation - max	5	6	4	3	0
Reloading	3	1	0	0	0
Long term increment	3	0	0	0	0
Total	**14**	**11**	**7**	**6**	**2**

Predicted build up of vertical movements with time behind secant piled walls

Ground movement analysis results - vertical

Track summary

Asset	Distance of nearest rail from basement (m)	Max. Total settlement (mm)	Cant (mm)	Twist
Reception Siding	5.8	11	1.2	1/5000
Run Round Siding	9.3	8	1.1	1/4286
MML Down Fast	15.9	6	0.3	1/10,000
MML Up Fast	19.1	5	0.3	1/10,000

Limits from NR/BS/LI/045 (Issue 3)

Fault	Trigger Level
Level 1	Twist >1/300
Level 2	Twist >1/200
Level 3	Twist >1/125
Level 4	Twist >1/90
Cant variation	Changes in cant +/- 20mm or +/- 15mm*
Displace-ment fault	25mm^{+} difference from the original

Ground movement analysis results - horizontal

Track summary

Asset	Distance of nearest rail from basement (m)	Lateral movement due to installation (mm)	Lateral movement due to exacavation (mm)	Total lateral movement (mm)
Reception Siding	5.8	3.4	5.8	9.2
Run Round Siding	9.3	3.0	4.7	7.7
MML Down Fast	15.9	2.4	2.7	5.1
MML Up Fast	19.1	2	1.8	3.8

Damage Assessment Substation

Follows guidance of CIRIA C580 and approach of Burland (1977)

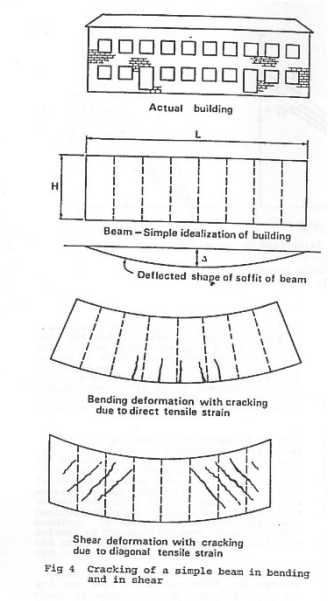
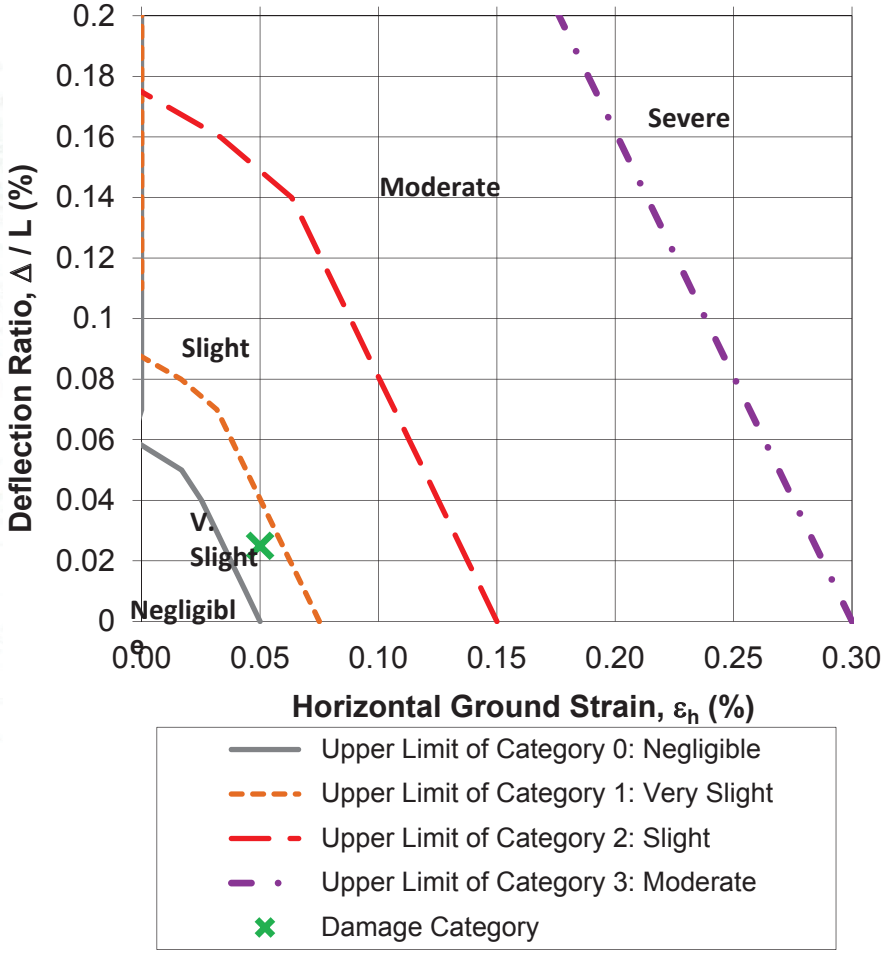


Fig 4 Cracking of a simple beam in bending and in shear

TABLE 1
Classification of visible damage to walls with particular reference to ease of repair of plaster and brickwork or masonry

Category of damage	Normal degree of severity	Description of typical damage (Ease of repair is underlined) Note: Crack width is only one factor in assessing category of damage and should not be used on its own as a direct measure of it.
0	Negligible	Hairline cracks less than about 0.1mm
1	Very Slight	Fine cracks which are easily treated during normal decoration. Damage generally restricted to internal wall finishes. Close inspection may reveal some cracks in external brickwork or masonry. Typical crack widths up to 1mm.
2	Slight	Cracks easily filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings. Cracks may be visible externally and some repointing may be required to ensure weathertightness. Doors and windows may stick slightly. Typical crack widths up to 5mm.
3	Moderate	The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired. Typical crack widths are 5 to 15mm or several up to 3mm.
4	Severe	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably[1]. Walls leaning[1] or bulging noticeably, some loss of bearing in beams. Service pipes disrupted. Typical crack widths are 15 to 25mm but also depends on the number of cracks.
5	Very severe	This requires a major repair job involving partial or complete rebuilding. Beams lose bearing, walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25mm but depends on the number of cracks.

[1] Note: Local deviation of slope, from the horizontal or vertical, of more than 1/100 will normally be clearly visible. Overall deviations in excess of 1/150 are undesirable.

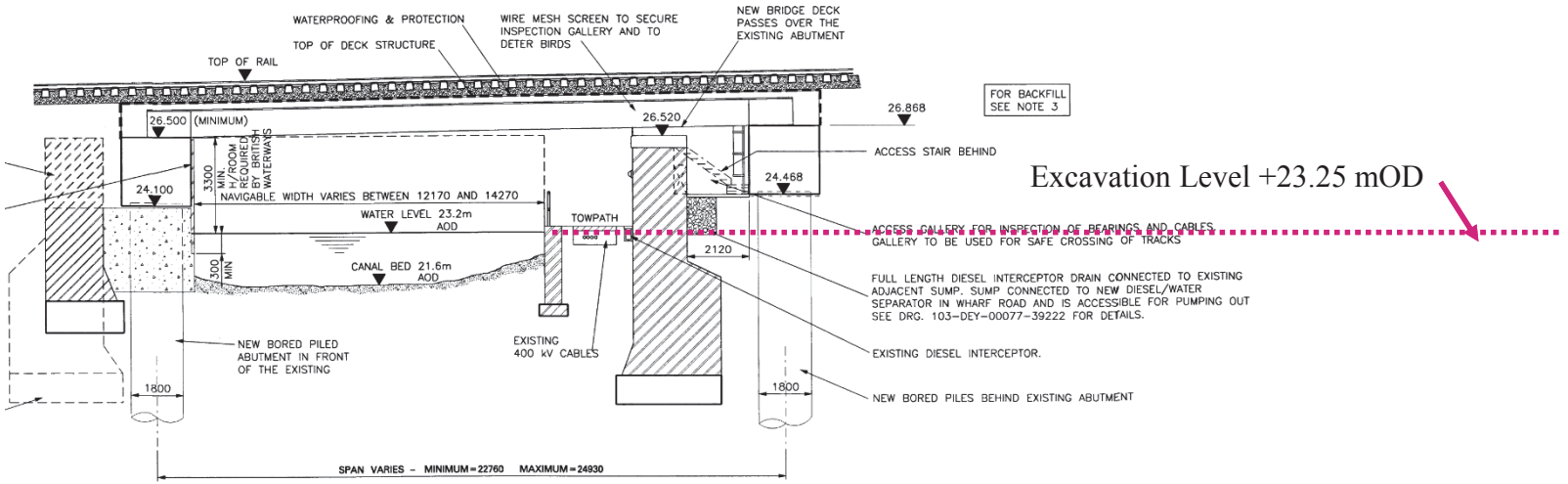


Ground movements Regents Canal Bridge

- **Bridge sits on piled cap. Bridge abutment approx. 3m from edge of full basement dig. Max long term ground movement 14mm at ground level**

- **At pile cut-off , ground movements less than at ground level. Also, bridge abutment close to corner of basement excavation where ground movements due to excavation are < 75% of those behind middle sections of the walls.**

- **Bridge piles 1200mm diameter founded between +5.5mOD and -0.5mOD, transferring load deep within the ground. Therefore settlement of the piles (and hence bridge) significantly less than at the pile cut-off. Max. movement of the bridge in the long term is expected to be less than 6mm. Detailed calcs to follow at later stages.**



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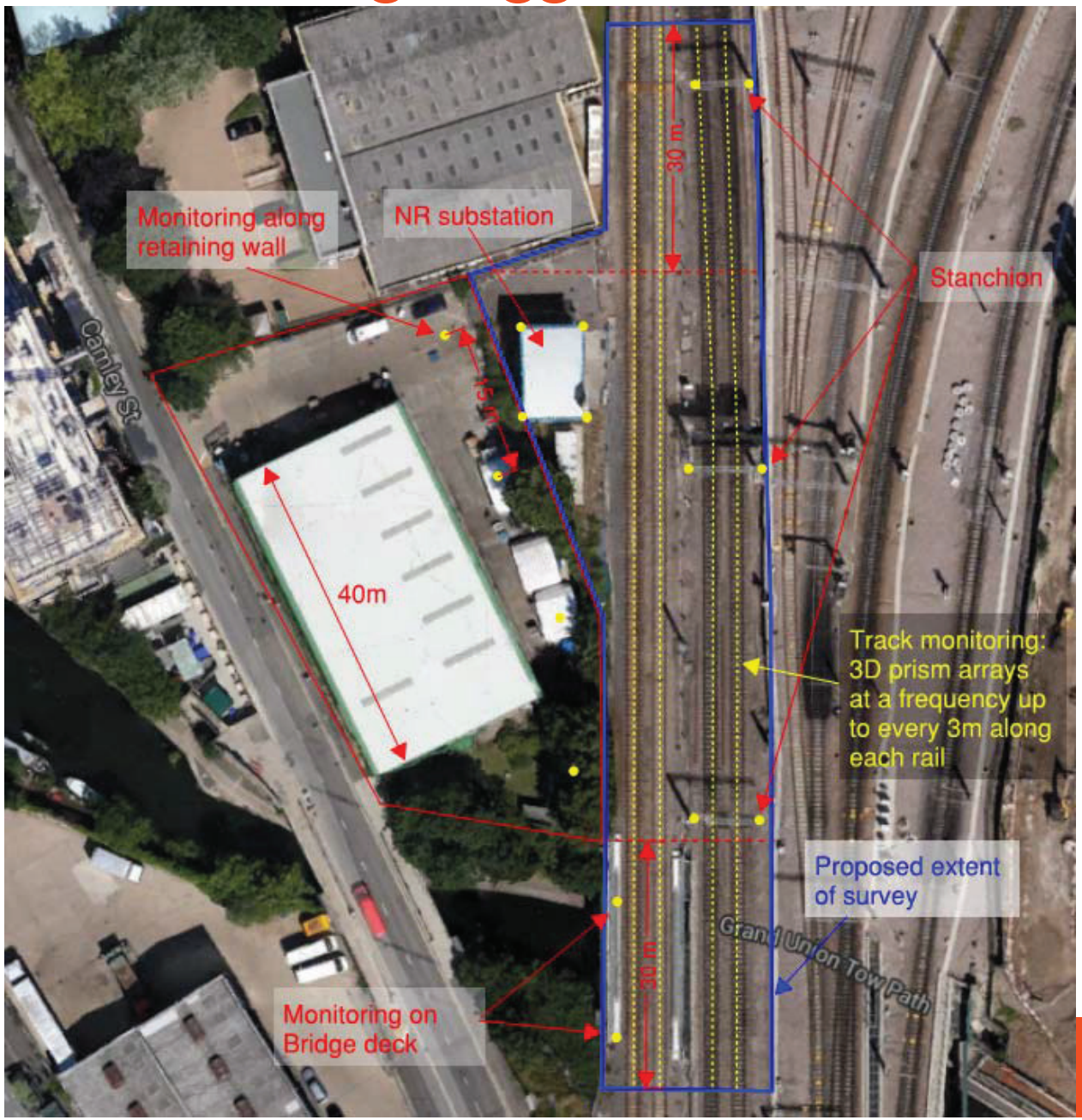
Monitoring Suggestions



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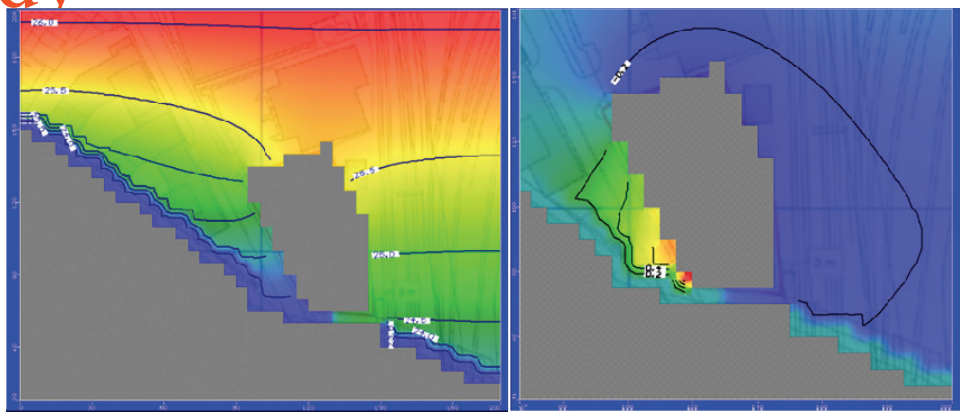
Monitoring Strategy

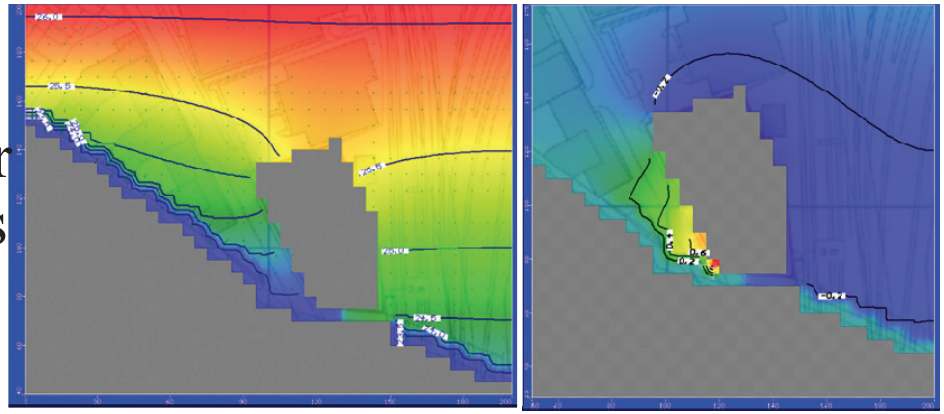
Alert Level	Action
Green	Early review of monitoring procedures and accuracy to confirm data reliability
Amber	Minuted site review to establish: - Which operations responsible for movements - Whether these operations will lead to further excessive movements - Contingency action(s) should red level be reached Frequency of monitoring to be increased Contractor to prepare to implement agreed contingency measures
Red	All site work that may be causing movements to cease Contingency measures implemented Review of construction activities Future construction methods and tolerances to be agreed
Black	Emergency measures due to safety issue for rail authority related structures

Hydrogeological Study

- Draw down shown as positive
- Draw up shown as negative.
- Water table level rise on the up-gradient side (to the north & east) is approximately 0.2 m over a radius of 20 m - 40 m.
- On the down-gradient side (to the west and south) water table levels fall over a radius of ~20m by between 0.2 & 0.6 m



MODFLOW groundwater model: post excavation, k=1x10^{-5}. (a) Water table levels and (b) residual drawdowns



MODFLOW groundwater model: post excavation, k=1x10-7. (a) Water table levels and (b) residual drawdowns

ARUP

102 Camley Street

Safeguarding the Railway during Demolition & Construction

SISK

Construction techniques

Safeguarding the Railway during Demolition & Construction

Techniques

- Basement Construction
- Superstructure
- Cranes
- Concrete frame
- Access to MML Substation during Construction Works

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Construction techniques

Safeguarding the Railway during Demolition & Construction

Basement Construction

- Piling Rigs

- It is proposed that the 'Piling contractor' will be familiar with the logistics of working adjacent to 'Network rail Infrastructure' (ie Van Elle / Keltbray) and will have the expertise, plant, equipment and labour force that are qualified and knowledgeable in the requirements for safe working practices in close proximity to the railway.

Construction techniques

Safeguarding the Railway during Demolition & Construction

Basement Construction

Vibration Monitoring:-

- Carried out by Vibration Monitoring Services Ltd to measure/establish existing vibration through the ground – generated by train movements, state of the track or any other existing vibration sources i.e. road traffic or other construction works. This specialist work is to be carried out over a period of several days (24hr periods) prior to commencement to establish existing levels of moving and standing rail transport etc.

Construction techniques

Safeguarding the Railway during Demolition & Construction

Basement Construction

- Monitor vibration of demolition tasks
- Monitor vibration of Piling works
- Monitor vibration of Superstructure
- The Monitoring equipment can differentiate between Rail Transport and site equipment and from this an acceptable level of vibration can be established that is acceptable to all parties.

Construction techniques

Safeguarding the Railway during Demolition & Construction

Superstructure

- Protection of the Railway from falling objects:- As the concrete frame is erected a proprietary edge protection system will be installed (Combi Safe or similar) in addition to this there are a number of additional safety options which can be fixed to the concrete frame as it is erected :-
- A Safety Net Fan specifically designed for High rise buildings that can withstand winds of 100mph can be installed

Construction techniques

Safeguarding the Railway during Demolition & Construction

Superstructure

- A scaffold frame built from floor to soffit at each level that is covered in a ‘Shrink Wrap Sheeting’ product especially designed for scaffold frames

Construction techniques

Safeguarding the Railway during Demolition & Construction

Superstructure

Construction techniques

Safeguarding the Railway during Demolition & Construction

Superstructure

- Installation of Pre formed wall panelling as quickly as possible on completion of the concrete frame. Similar to those shown below

Construction techniques

Safeguarding the Railway during Demolition & Construction

Superstructure

- Installation of Pre-fabricated Balconies that can be fitted from within the building avoiding the need for scaffolding or other mechanical access equipment.

Construction techniques

Safeguarding the Railway during Demolition & Construction

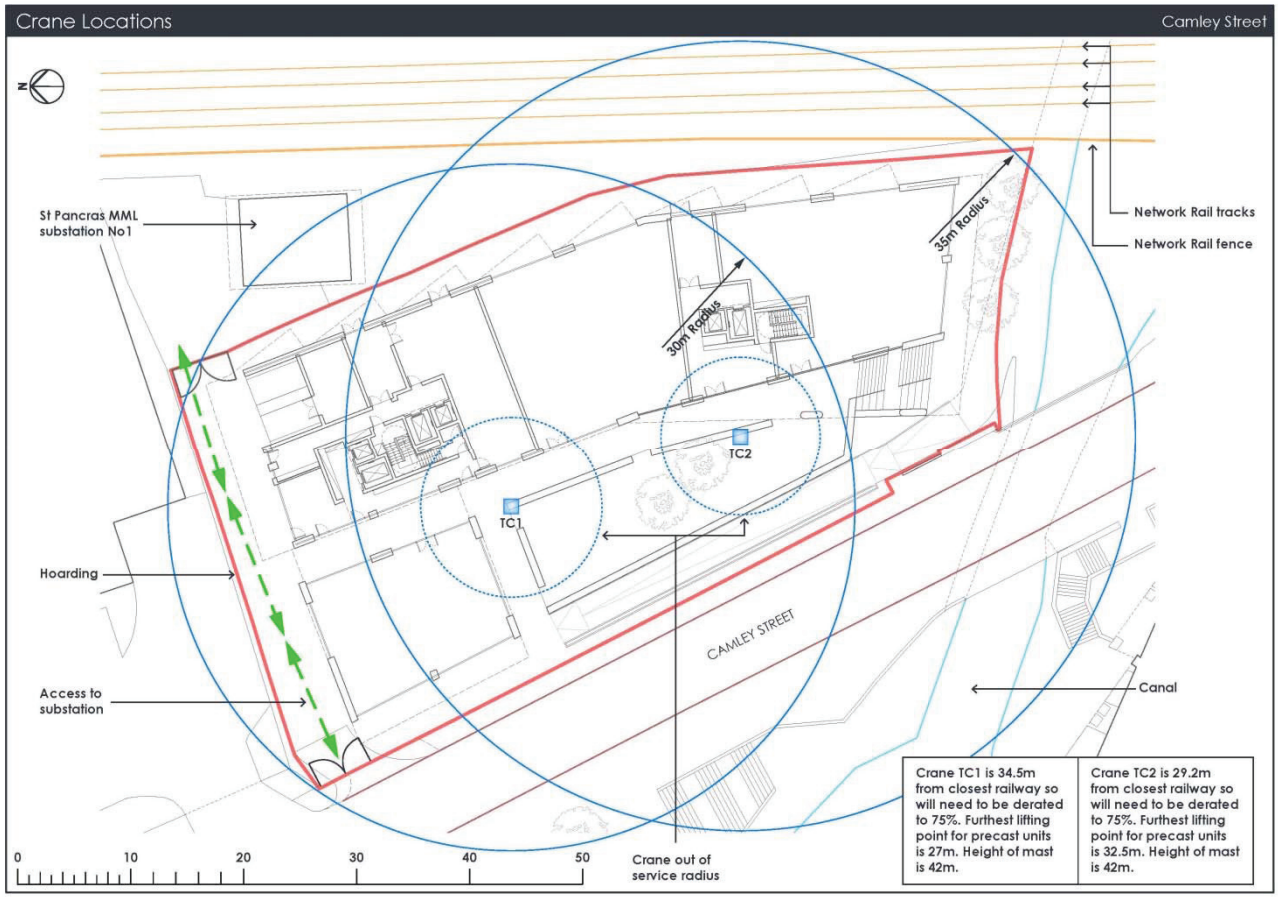
Cranes

- 1. The Cranes will be erected and operated in accordance with the 'Requirements for Tower Cranes alongside Railways Controlled by Network Rail' documentation and site specific method statements, risk assessments and lifting plans.
- 2. It is proposed that the tower cranes selected for the project will be 'Luffing Cranes' that are fitted with 'Anti-Collision Path Protection' they can also be fitted with a 'zone protection' system to prevent over sailing into a restricted area if necessary.
- 3. As the concrete frame progresses both crane masts are increasingly shielded from the rail infrastructure.
- 4. All crane operators and banks men are trained and qualified.

Construction techniques

Safeguarding the Railway during Demolition & Construction

Cranes



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Construction techniques

Safeguarding the Railway during Demolition & Construction

Concrete frame

- It is proposed that the 102 Camley St is constructed as a concrete frame and where possible pre-fabricated units will be incorporated into the project – Stairs, Balconies Wall panels - to advance the works and reduce the need for external scaffolding.
- Proprietary aluminium formwork (Peri Skydeck or Similar) will be used to construct the columns and floor slabs, this will be repositioned up the building as the frame progresses.
- The tower cranes will be utilised to move the formwork, place concrete, pre-fabricated items and waste skips to the ground. Waste material will be placed in secure areas that are located as far away from the Network Rail boundary as possible.

Construction techniques

Safeguarding the Railway during Demolition & Construction

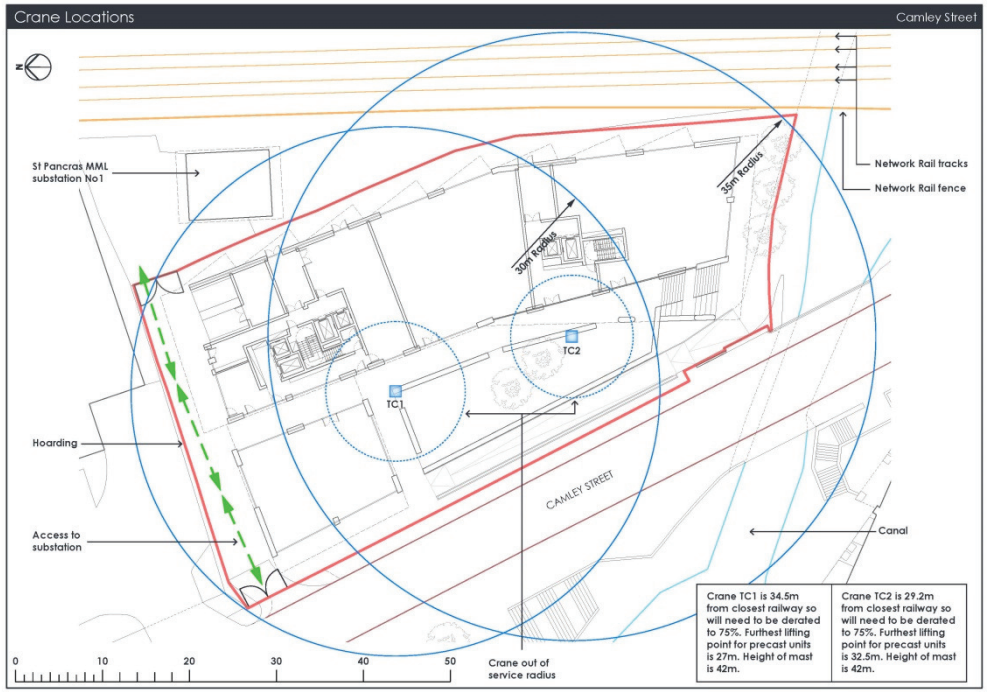
Concrete frame

Construction techniques

Safeguarding the Railway during Demolition & Construction

Access to MML Substation during Construction Works

- From Camley Street at the Northern Boundary gate a clear unobstructed route will be maintained for access to the Sub Station at all times during construction.



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Construction techniques

Safeguarding the Railway during Demolition & Construction

Access to MML Substation during Construction Works

- From Camley Street at the Northern Boundary gate a clear unobstructed route will be maintained for access to the Sub Station at all times during construction.

- The gate will be either, staffed by Sisk operatives during working hours, Monitored by CCTV & or Security guards at other times and also be fitted with a security Combination padlock or a specialist lock agreeable to all parties that need access to the gate.