Evolution of ground risk management and engineering mitigation measures for tunnelling through the wall of a drift filled hollow in the City Of London

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Location: AP9 CH6 & ES3

Moorgate Box

AP9 CH6 ES3

Electra House
Northern Line tunnels

Goswell St Sewer

Moorgate Box East Wall - a Diaphragm Wall or ‘Dwall’

MG & Alluvium

RTD

Electra House

Assumed foundation level 110.4m ATD

Presumed base of RTD

London Clay

Peat

Existing Clay (Northeastern)
Base of RTD as known at design/pre-tender stage
Why not have more Bhs?
Approach to AP9 / CH6 in the tender

- Zone of RTD permeation grouting
- Goswell St Sewer
- Pipe Arch
- Northern Line tunnels
- Moorgate Box Eastern Dwall (another contract)

Presumed base of RTD:
Recognition of a possible depression

2010

Electra House

Assumed foundation level 116.4m AOD
Assumed found 106.1m AOD

‘SCL’ Tunnels

Electra House

ES3

Moorgate Box Eastern Dwall (another contract)

‘SCL’ = Sprayed Concrete Lining
Base of RTD as known at post demolition / pre-box construction stage
Pile removal clues

• The top of London Clay in a temporary works CFA contiguous piled wall on the south side of the Box was much deeper in places than anticipated (circa 98 matd)

• Existing CFA piles that supported the demolished building were to be removed – they were irregularly oversized in the ‘deep’ RTD (circa 1000 to 1200mm compared to the 900mm design diameter)

• Minor casing base/piping failures occurred during pile removal – these are attributed to the presence of clay layers within the predominantly permeable sandy DFH infill.
Base of RTD as known early in the excavation of the Box
Wider Base of RTD context

Soft grey and brown slightly sandy organic CLAY with occasional plant debris varying to amorphous plastic slightly sandy PFAT with occasional shelly fragments.

Medium dense orange brown (medium and coarse) sandy becoming below 6.00m very sandy angular to subrounded fine to coarse flint GRAVEL. (TERRACE GRAVEL)

Soft brown weathered clay. (Driller’s description) (LONDON CLAY)

No point data
Victorian railway construction
ICE Metropolitan Line Paper 1885

Approx 105.5 m aTD in Finsbury Circus
Rail level at Moorgate approx 109m aTD
‘In hollow’ borehole log extracts

These are CP Bhs – so there is a loss of layer resolution
What to do with AP9?

- Base of RTD is lower than expected
- RTD below the water table is in the tunnel face at break out
- RTD is in the crown of AP9 and there is little LC cover above the crown in CH6
- RTD lithology is broadly as expected

- So permeation grouting is OK
Permeation Grouting – how?

Tube à Manchette (‘TaM’)
Permeation Grouting – how?

Grout injection
Permeation Grouting – where?

- Grout target zone = 6m radius from the extrados of the tunnel in the RTD
- Reduced grouting pressure zone around the sewer
- Low K cut off wall adjacent to H&C Line

Goswell Street Sewer
Base of RTD as known near the end of initial permeation grouting TaM drilling

1st phase drilled & grouted from Electra House basement

2nd phase partly drilled & grouted from high level in Moorgate Box prior to excavation
Base of RTD as known near the end of permeation grouting TaM drilling
TaM arrangement & base RTD

Green = 1st phase
Red = 2nd phase
Blue = 3rd phase (not drilled yet)

Note base of RTD (brown line) and the change to the pipe arch approach, now a canopy not an a true arch and 3x not 1x, and over a longer distance. TaM pipes to be used.
Electra House Grouting validation investigation
Updated long section
• Possible grouting related movements of the East wall of Moorgate Box?

• Much greater movements of the Eastern wall of the Box during Box excavation compared to the other walls.

• Ingress of displaced ‘grouty’ water into the Northern Line Tunnels in the London Clay.
Impact on Tunnelling?

Steep internal slopes in DFH, ‘lumpy’ DFH base = historic DFH slope failure?

Might explain larger E wall movements (higher than anticipated LC earth pressures)

Any resulting fissures might provide grout/water pathways to the NL

Increased risk of ‘greasy backs’ in the LC – risk especially increased if tunnelling from east to west where release surfaces might overhang the face.
How to arrange the SCL tunnelling?

- Two main options
- Pilot & enlargement
- ‘Codsmouth’ & invert enlargement

This choice prompted much debate on the pros & cons (debate mostly related to possible impacts on Electra House – not at this stage about breakout from the Box)

- Pilot approach initially preferred
- High level Moorgate Box grouting *for the breakout* now considered complete
- So proceed with concrete coring for lower level Phase 3 TaM installation and pipe canopy installation
Ingress
(this was a video)
More contact grouting between the DWall and the ground
Complete phase 3 grouting
Drill & grout additional low level phase 3 TaMs within the Box
Re-inject some earlier TaMs with even finer and less viscous materials

- But this creates some heave in Electra House.
- Grouting suspended whilst additional ceiling protection mitigation is installed
- Then carry out further validation GI prior to decision to open up.
Validation of Moorgate Box Grouting

- Shallow inclined boreholes drilled out from Moorgate Box.
- These experience unexpected core loss & water ingress in places.
- Switched to sonic coring. This found complex layered and channelled clay/silt/sand just the above the LC / RTD interface.
- Grout unevenly distributed – even in groutable materials.
  - This flags up the risk of pathways within the treated area that link to permeable water bearing in untreated ground.
  - Encounters with flowing water and permeable ground are very difficult to manage safely in an SCL tunnel and risk significant surface settlement and face instability.
  - Breakout through the DWall prior to tunnelling becomes a high risk activity.
Updated contours on the base of RTD

1m interval
Transverse sections
Pipe canopy installation (used as a form of further GI)

- The installation of the groutable canopy TaM pipes finds areas of untreated ground and some limited (clear) flowing water, particularly in the crown just below the sewer.
- Painted timber fragments were seen in some pipe drill returns below the Goswell Sewer.
- This timber raises possibility of unexpected Victorian Goswell Sewer temporary works and associated drains and/or dewatering sumps just above the AP9 crown. These could act as high permeability conduits across the top of AP9.
- Ground freezing was now seriously being considered – parallel design for this was begun.
- Additional infill pipes were added to the canopy scope above the opening.
Pipe canopy installation
Water flows are now much reduced. Abandon grounding freezing.

Begin tunnelling with a 2m x 1.8m timber heading to 5m from the end of the first pipe canopy. This is effectively a large ‘borehole’ which allows rapid control of the face if flowing water and/or untreated sand/gravel is found. It also allows easy forward or lateral probing and/or ground treatment from within the heading.

Install a vacuum dewatering system outside the pipe canopy to intersect any ungrouted pathways or sewer temp works drains.

Then enlarge in SCL pockets out from the heading to the earlier ‘codsmouth’ top heading.

Repeat for the second pipe canopy (with an option to delete the timber heading).

Enlarge down to the final invert. This would complete AP9.

Install 3rd pipe canopy & construct CH6 from below
Timber heading and SCL pockets

Longitudinal Section AP9
Phase 1a
Scale 1:200

Section A2-A2 - Phase 1a
Scale 1:100
Timber heading and SCL pockets

Longitudinal Section AP9
Phase 1b
Scale 1:200

Section A2-A2 - Phase 1b
Scale 1:100
What happened?

- AP9 completed without incident and with minimal settlement
- No water
- No loose ground
- No Victorian timber
- Dewatering flows very small
- No significant wall or ground movements
- No significant tunnel distortions
- No ‘greasy backs’
- Only very fine vertical grout filled fissures
What did we see? Opening the Dwall
What did we see? – upper Dwall opening
AP9 opening with the timber heading
What did we see?

pg = partially grouted
wg = well grouted
sG = sandy gravel
S = sand
gS = gravelly sand

*gravel inc claystone fragments

blue lines = grout fractures

A= sleeve grout around TaMs

Dotted lines = cross beds

The photo is approx 1.8m across
Current status

ES3 is currently being mined uphill towards CH6
Thanks are due to:

- Crossrail
- BBMV, especially Roser Soler Pujol and Alfred Staerk
- Bachy Soletanche
- Lily Dickson at GCG

London Clay
Moorgate DFH Geological context

- ‘Normal’ strata sequence = Alluvium / Taplow Fm / LC
- DFH strata sequence = Alluvium / Taplow Fm / LC
- Shape – irregular conical, diameter = approx 70m
- Local natural thickness of Taplow Fm away from the DFH = approx 4m
- Thickness of LC away from the DFH = approx 35m
- Natural thickness of Taplow Fm in the DFH = approx 15m
- Thickness of LC remaining below the DFH = approx 20m
- The DFH infill is variable, but dominated by Sands and Gravels
- The maximum internal DFH slope angle is approximately 1V:2.5H
Moorgate DFH Geological context

• Broadly coincident with the upper reaches of a minor Walbrook tributary.
• Located away from the main Walbrook channel.
• Located at the back edge of the Taplow Terrace.
• Surrounding Taplow Fm is thin & flat.
• Slightly thicker Alluvium/Peat above than elsewhere locally – but this may be a Roman/City Wall effect.
• No obvious vertical component of faulting at depth.
• Very small Lambeth Group Sand Channels are present beneath.
• Not in an area of reduced LC thickness. ‘Normal’ LC in the base of the DFH.