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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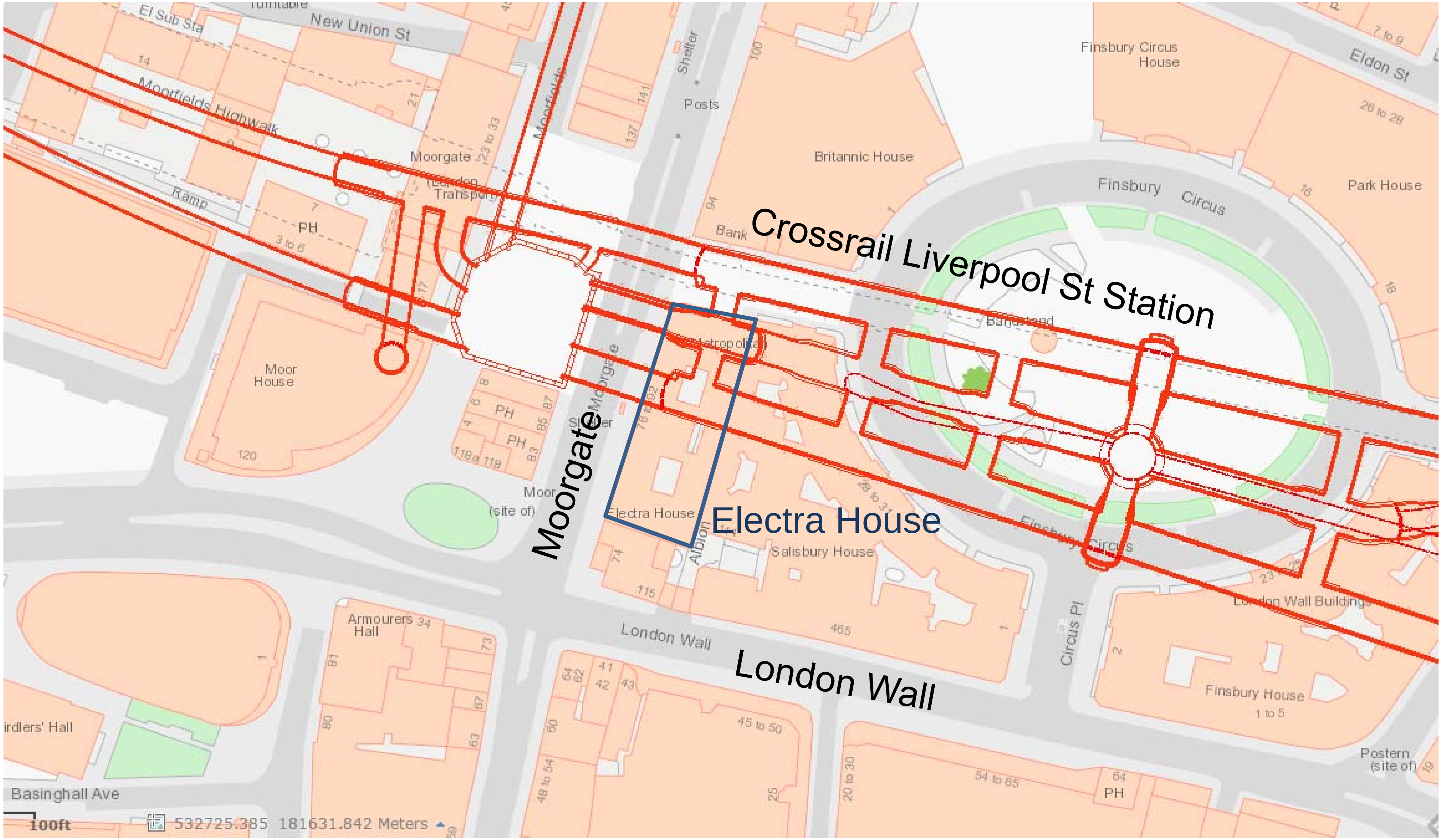
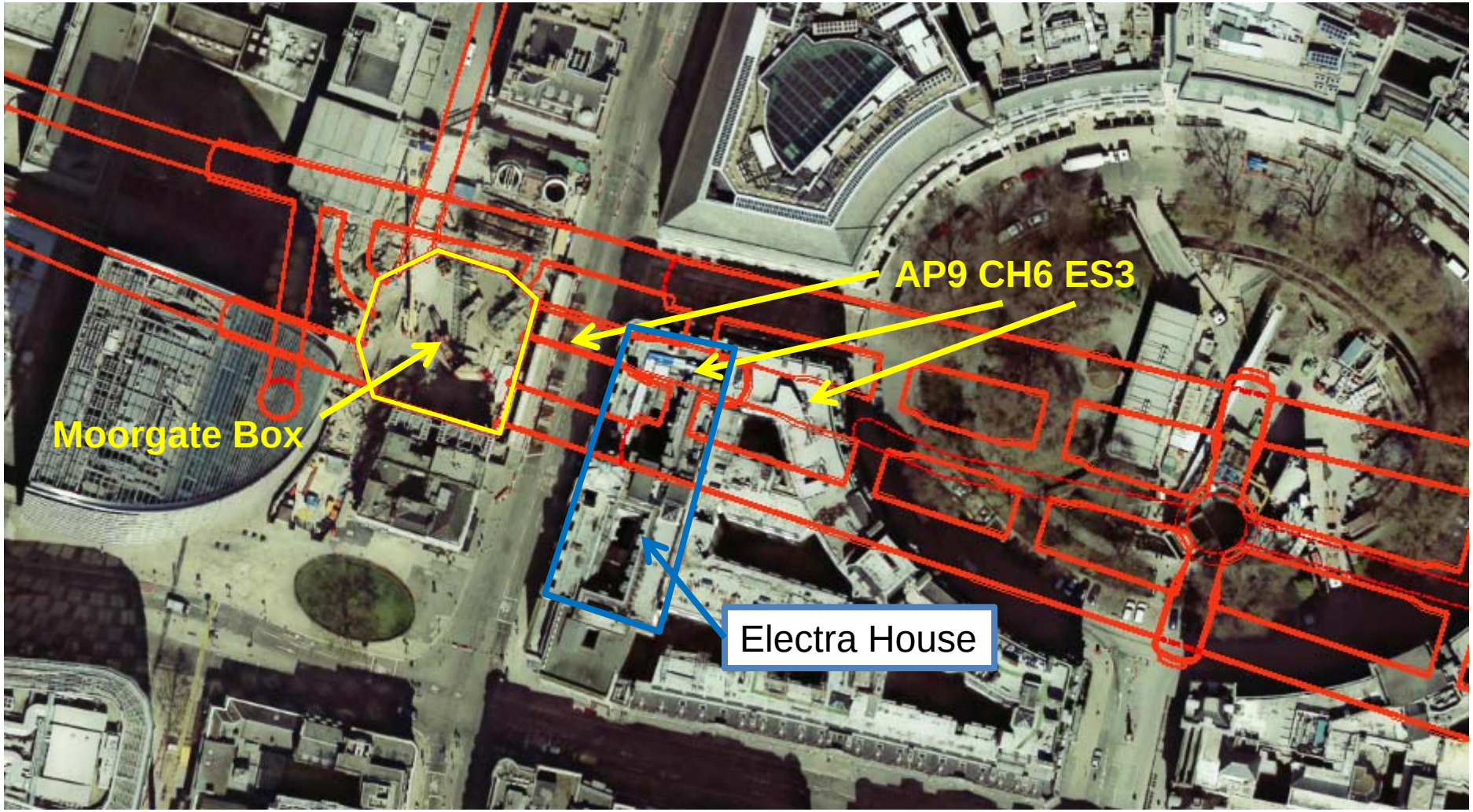
- Roser Soler Pujol BBMV

Location

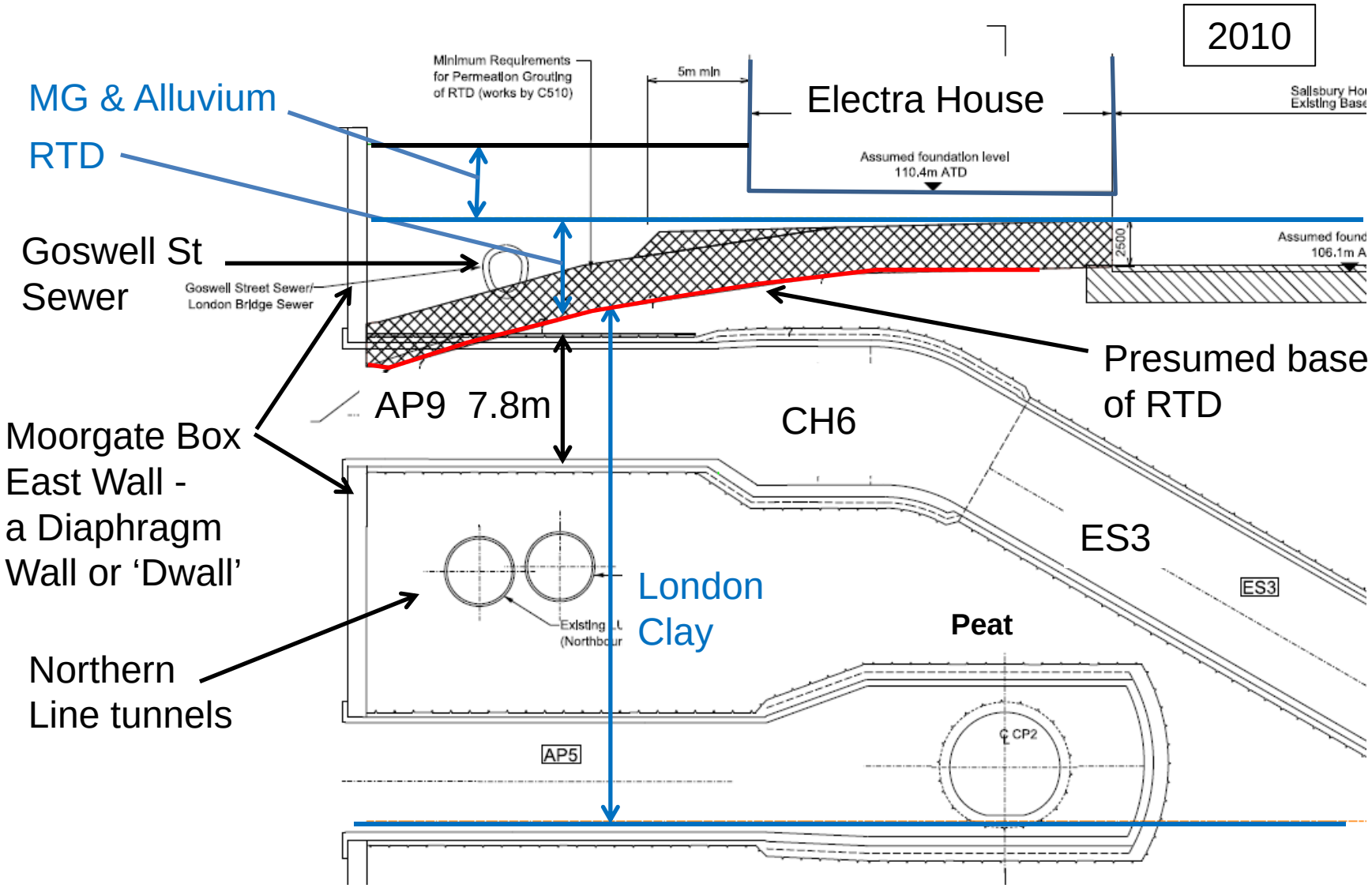


Crossrail Liverpool St Station
Electra House
Moorgate
London Wall
New Union St
Moorfields Highwalk
Moorgate
Moor House
Finsbury Circus House
Britannic House
Finsbury Circus
Park House
Eldon St
Salisbury House
London Wall Buildings
Armourers Hall
Finsbury House
Circus Pl
Basinghall Ave
100ft
532725.385 181631.842 Meters

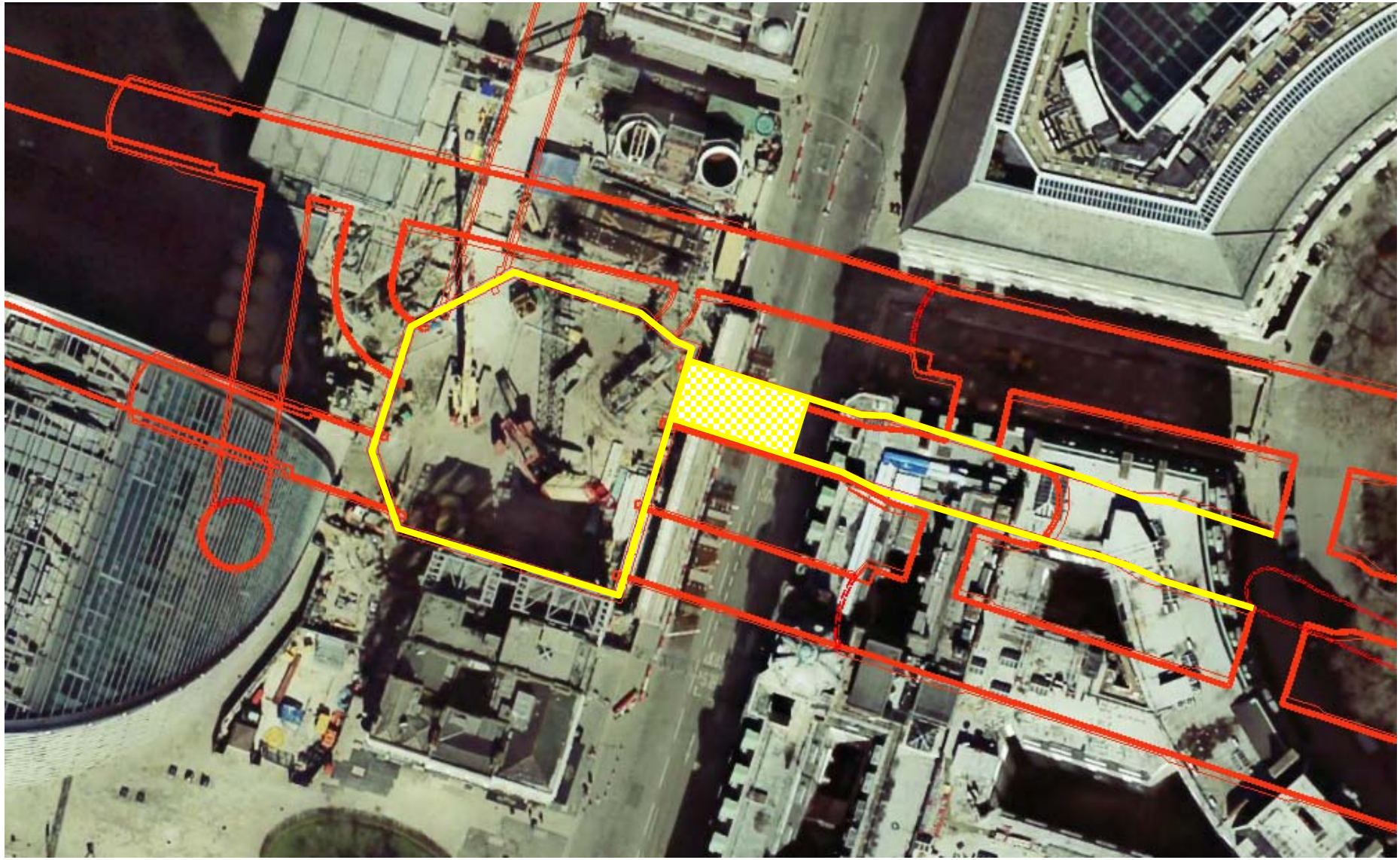
Location: AP9 CH6 & ES3



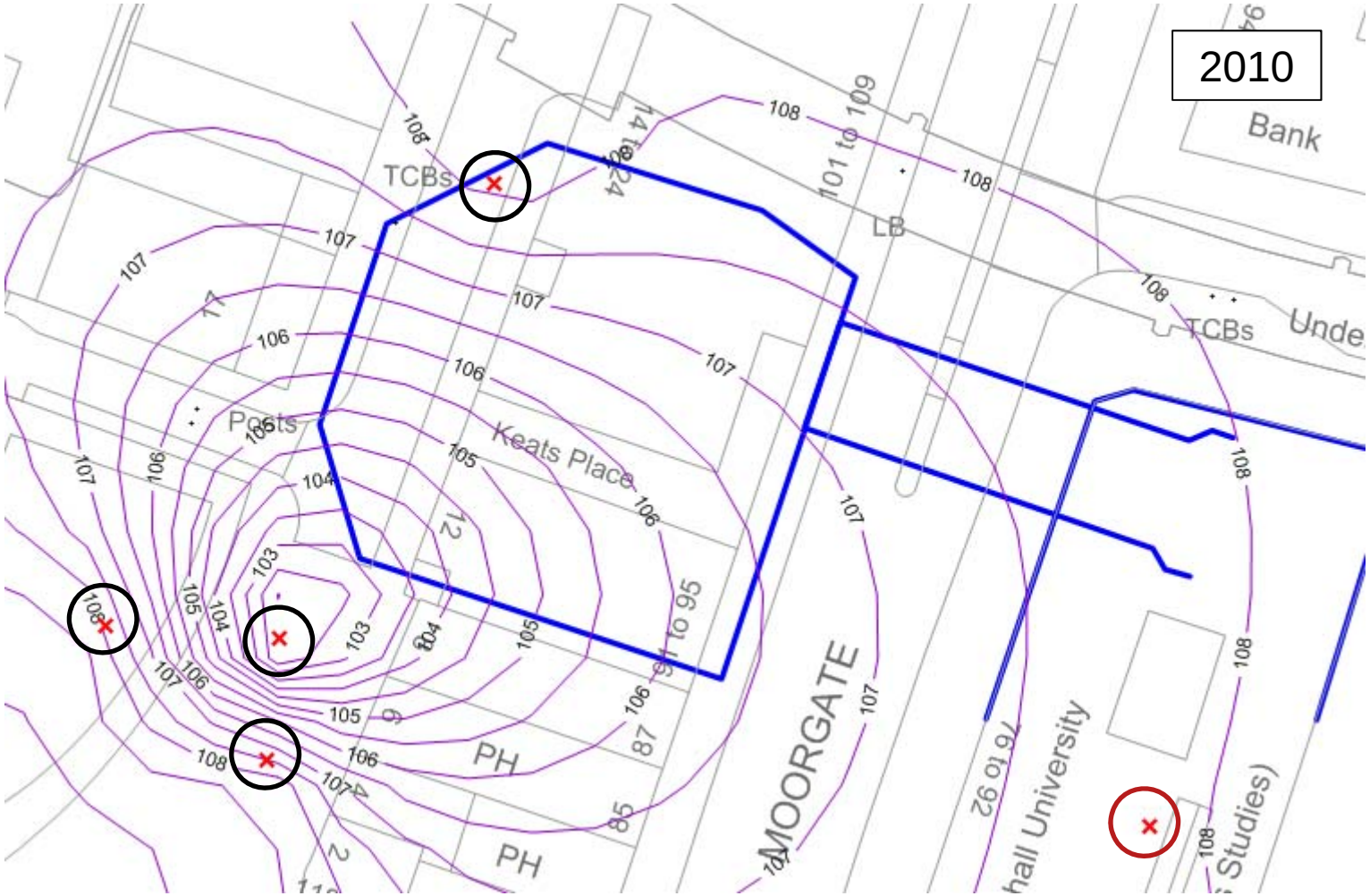
AP9 / CH6 / ES3


2010
MG & Alluvium
RTD
Goswell St Sewer
Moorgate Box East Wall - a Diaphragm Wall or 'Dwall'
Northern Line tunnels
Minimum Requirements for Permeation Grouting of RTD (works by C510)
5m min
Electra House
Assumed foundation level 110.4m ATD
Goswell Street Sewer/ London Bridge Sewer
2500
Presumed base of RTD
AP9 7.8m
CH6
ES3
ES3
London Clay
Peat
AP5
CP2

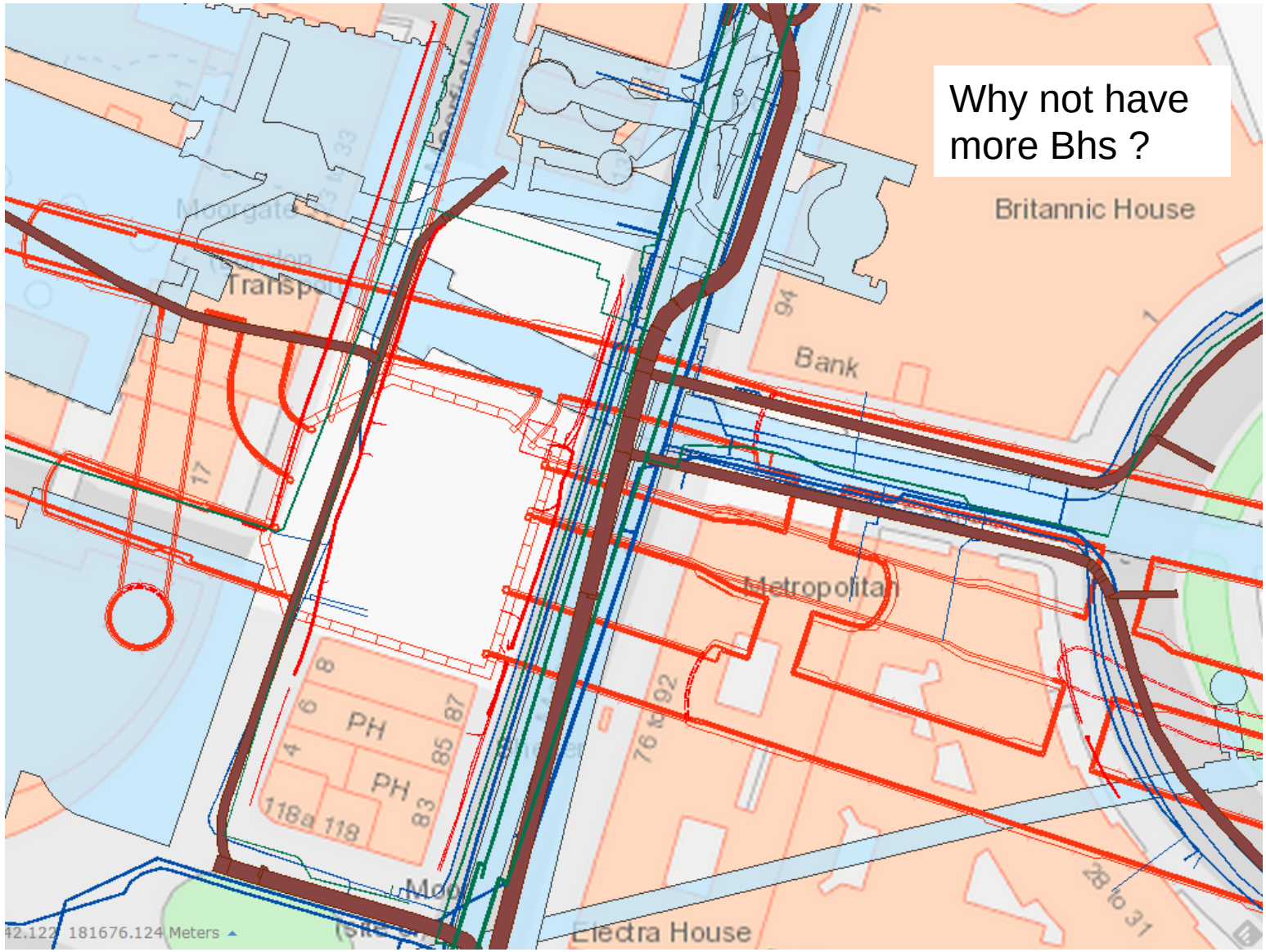
Location



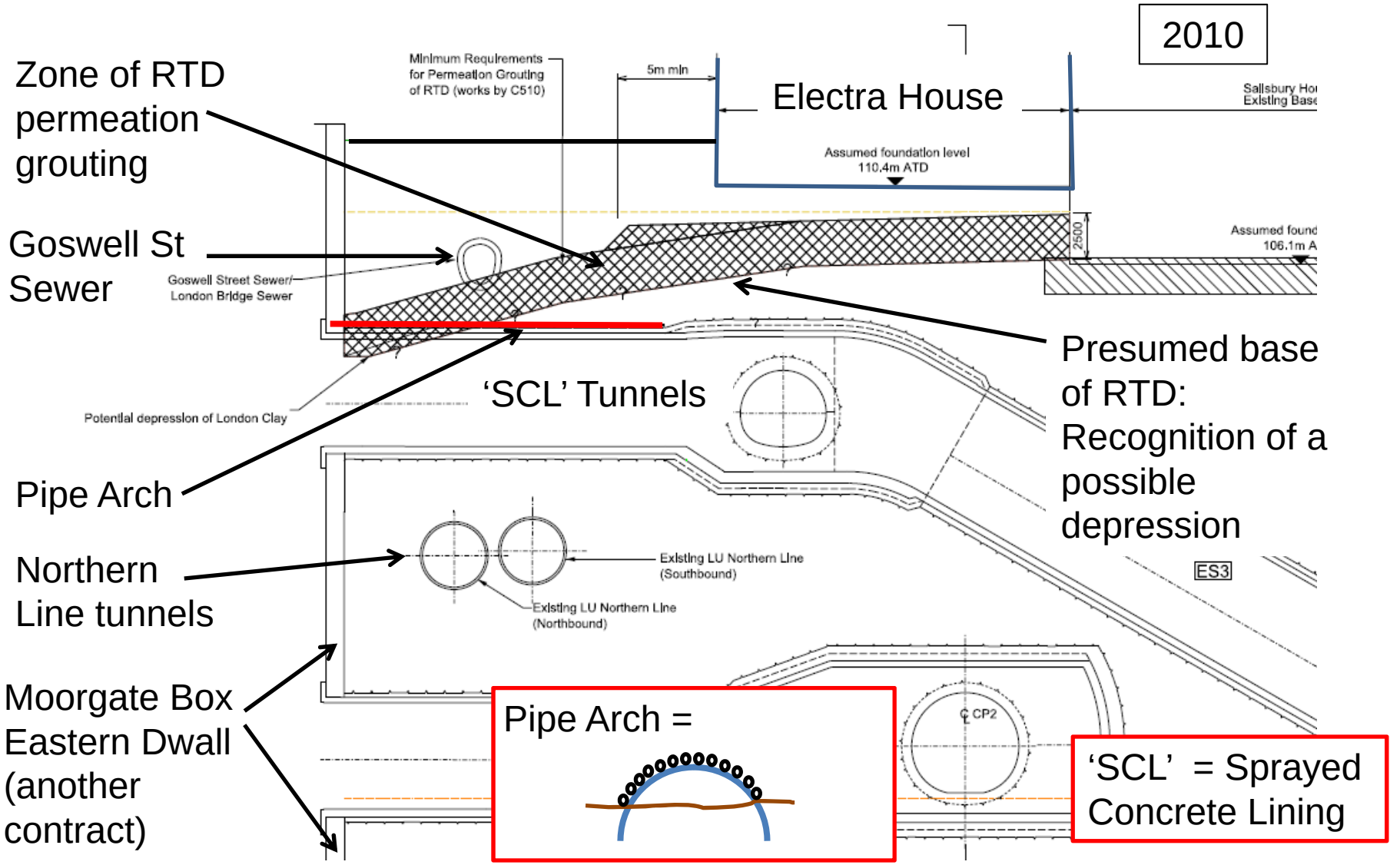
Base of RTD as known at design/pre-tender stage



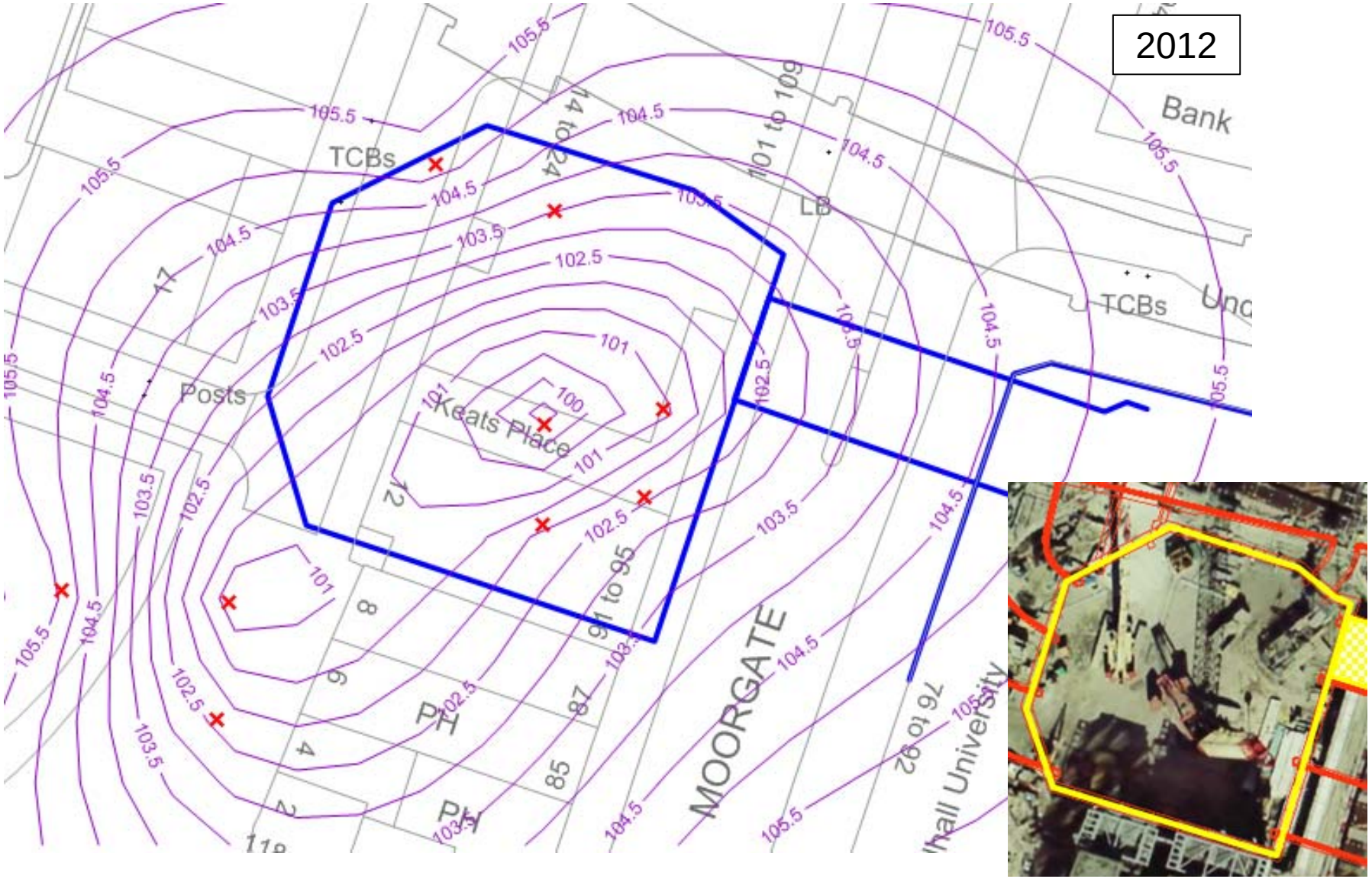
Underground constraints



Approach to AP9 / CH6 in the tender



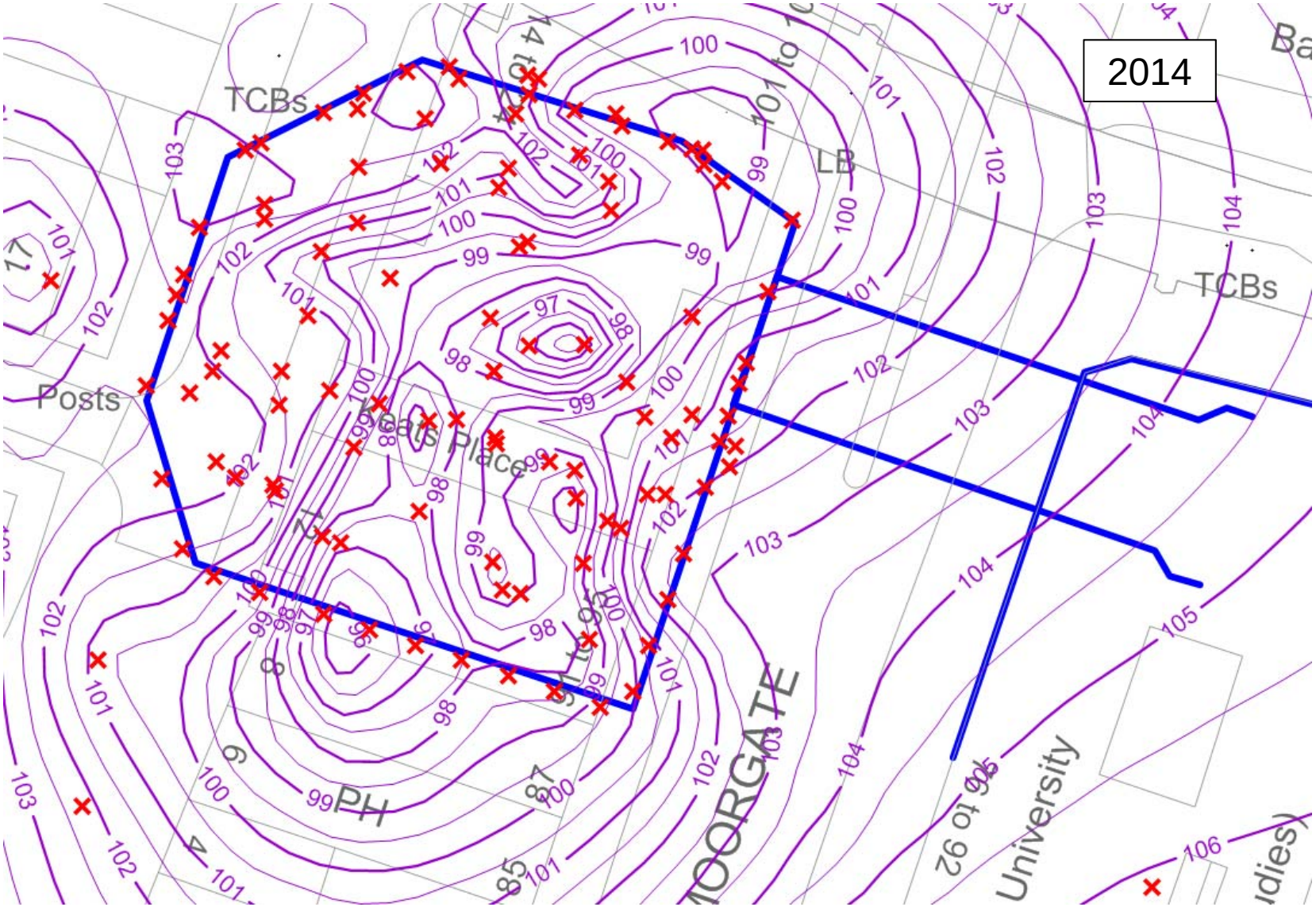
Base of RTD as known at post demolition / pre-box construction stage



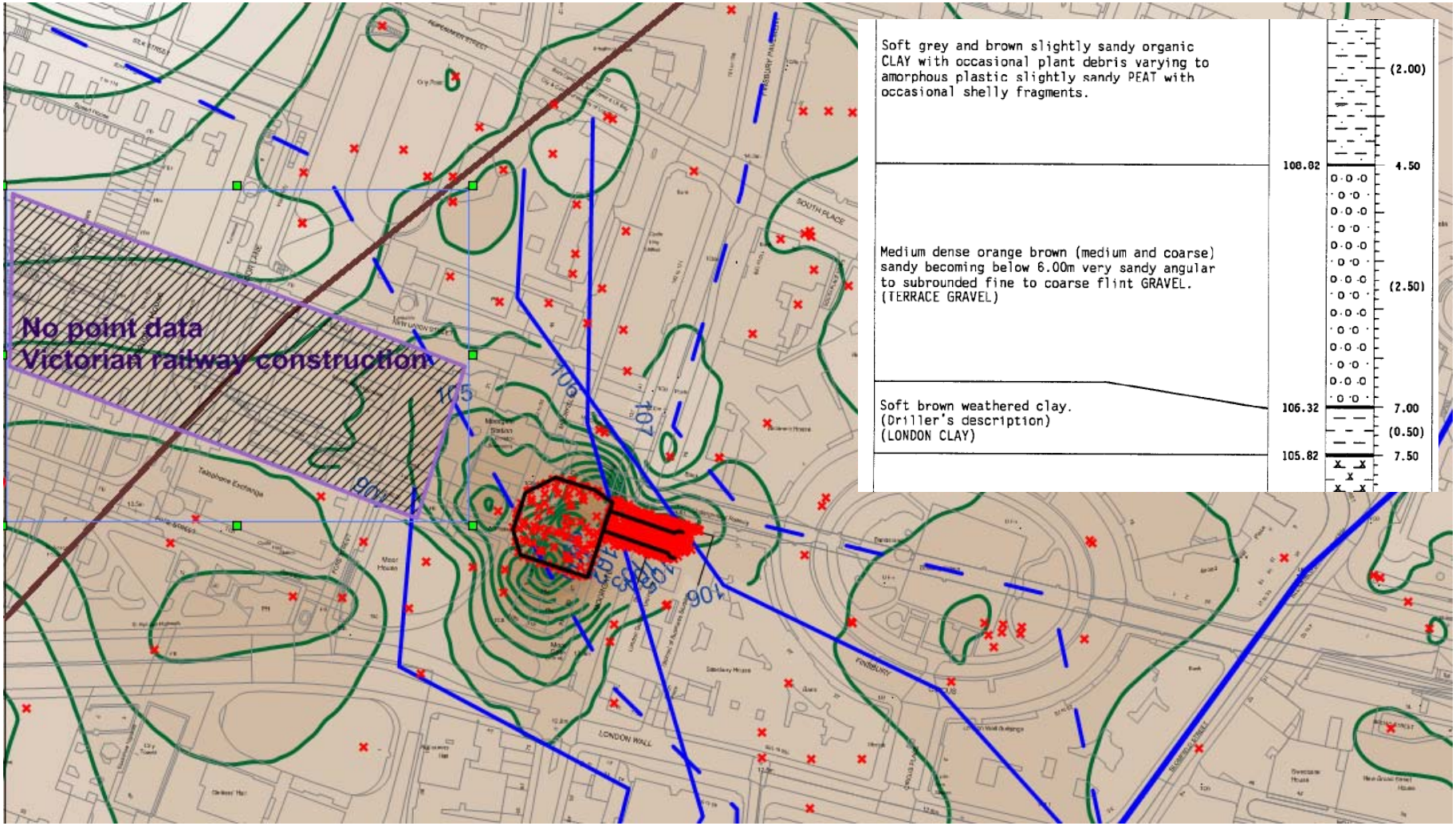
Pile removal clues

- 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.

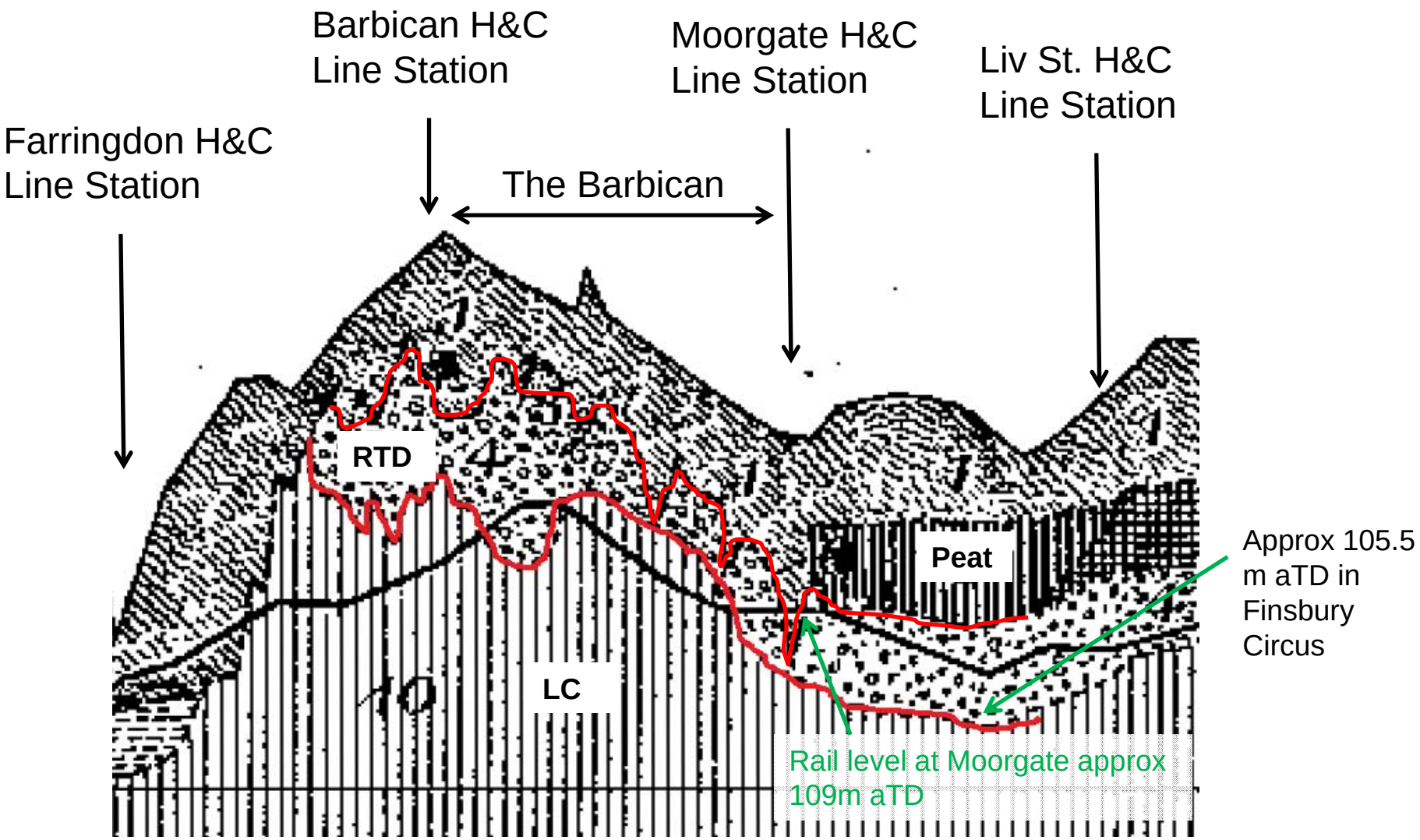
Base of RTD as known early in the excavation of the Box



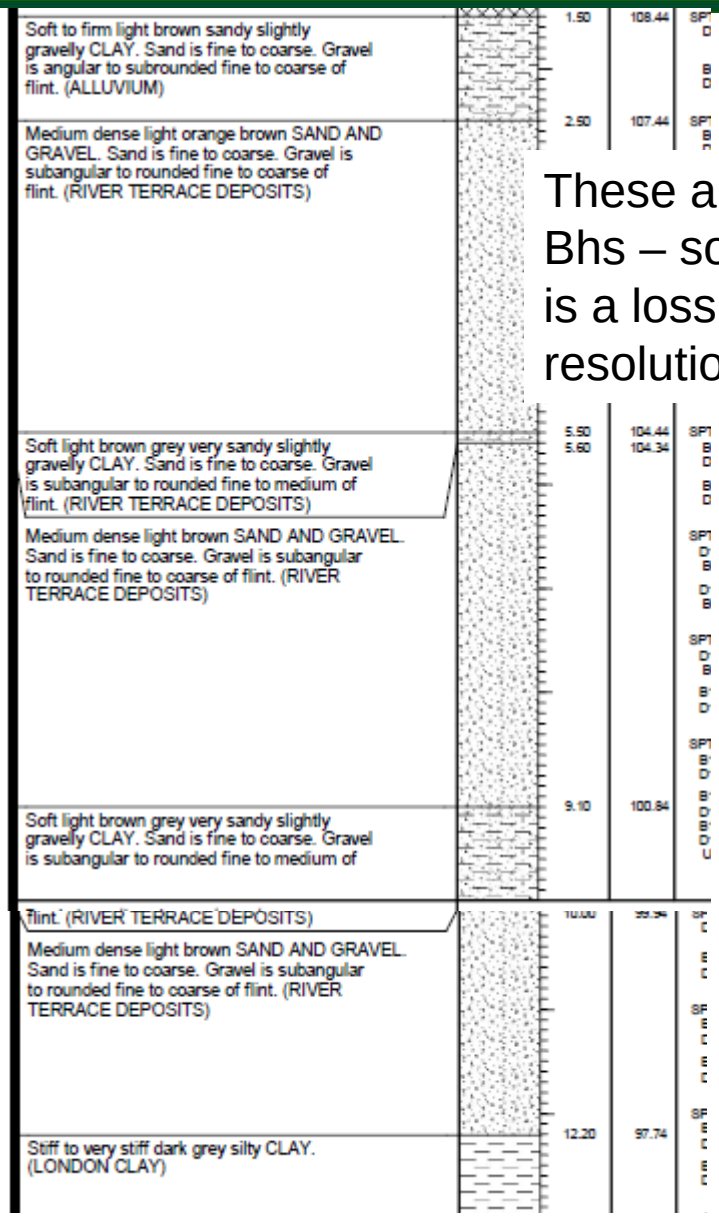
Wider Base of RTD context



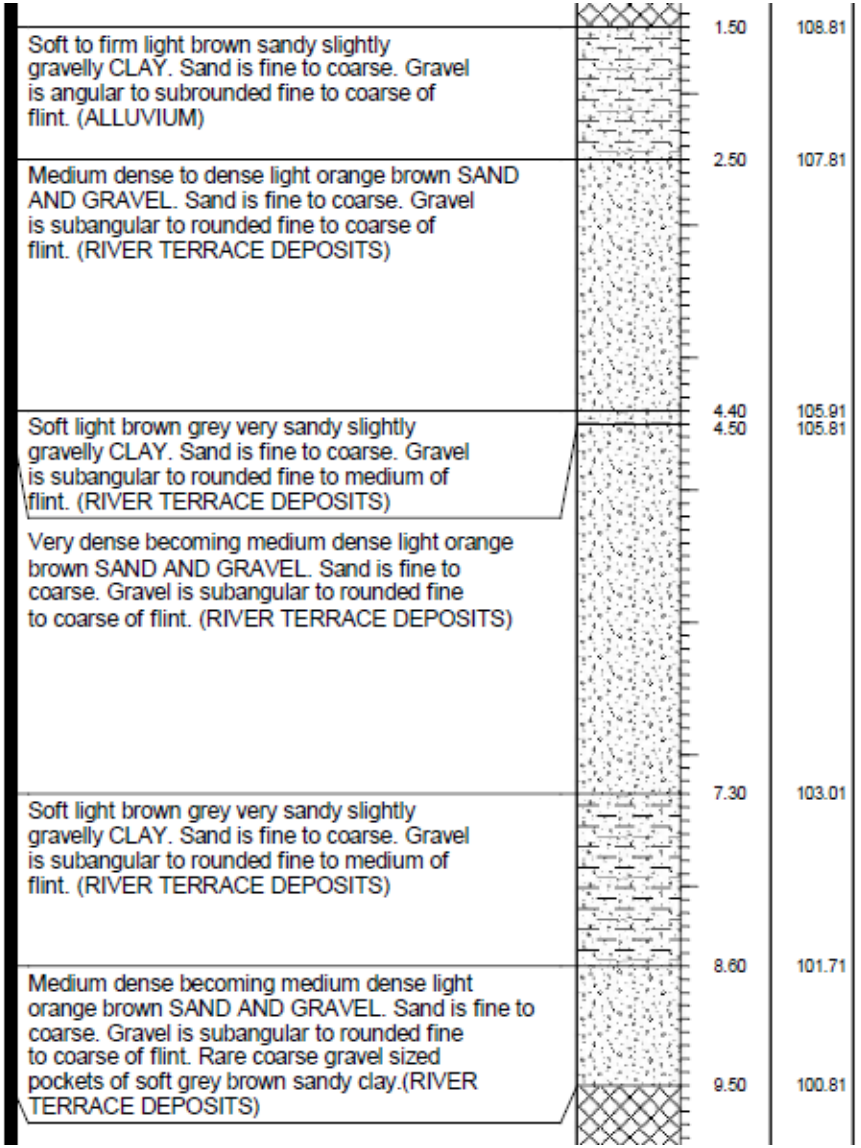
ICE Metropolitan Line Paper 1885



‘In hollow’ borehole log extracts



These are CP Bhs – so there is a loss of layer resolution



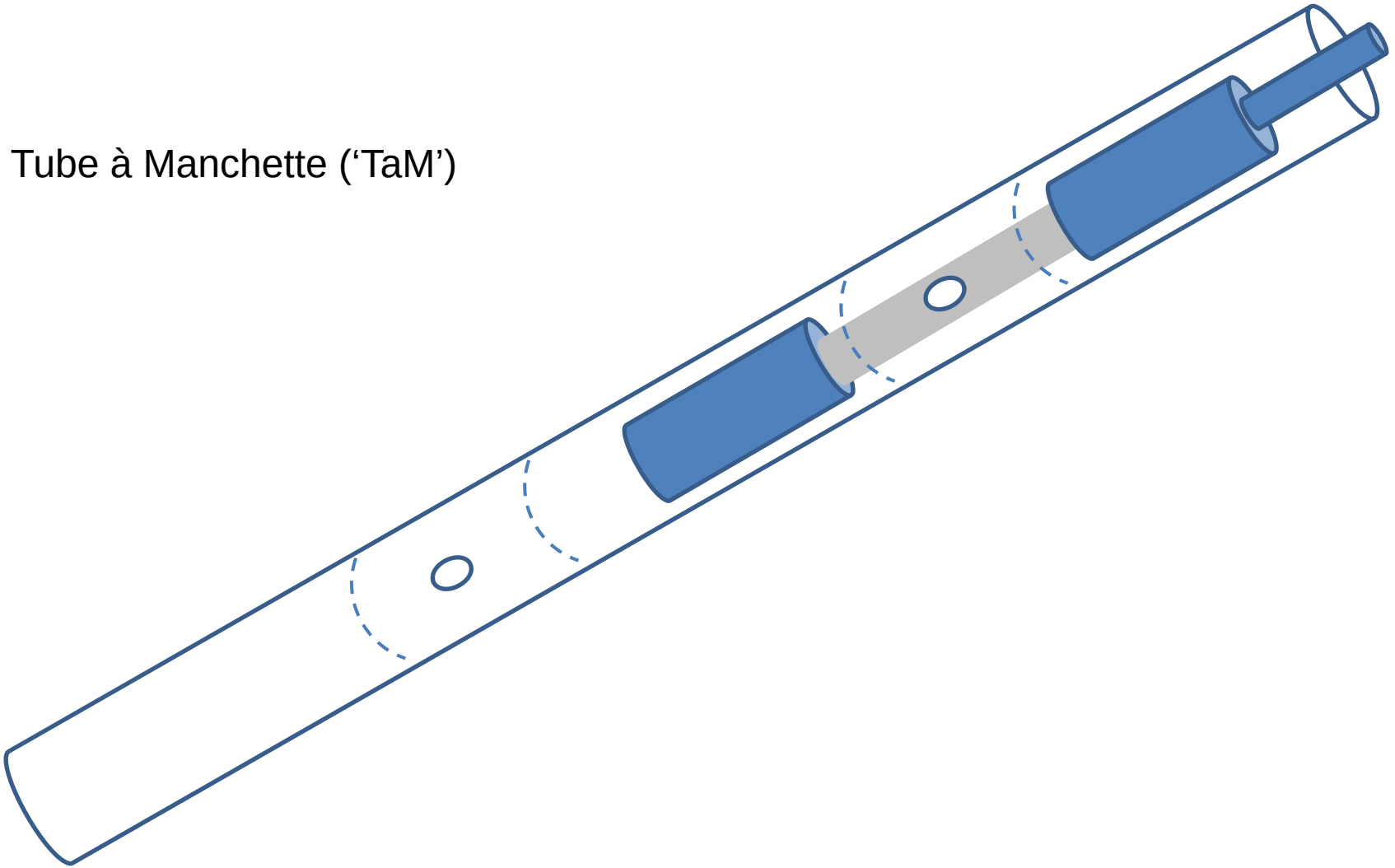
What to do with AP9 ?

- 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

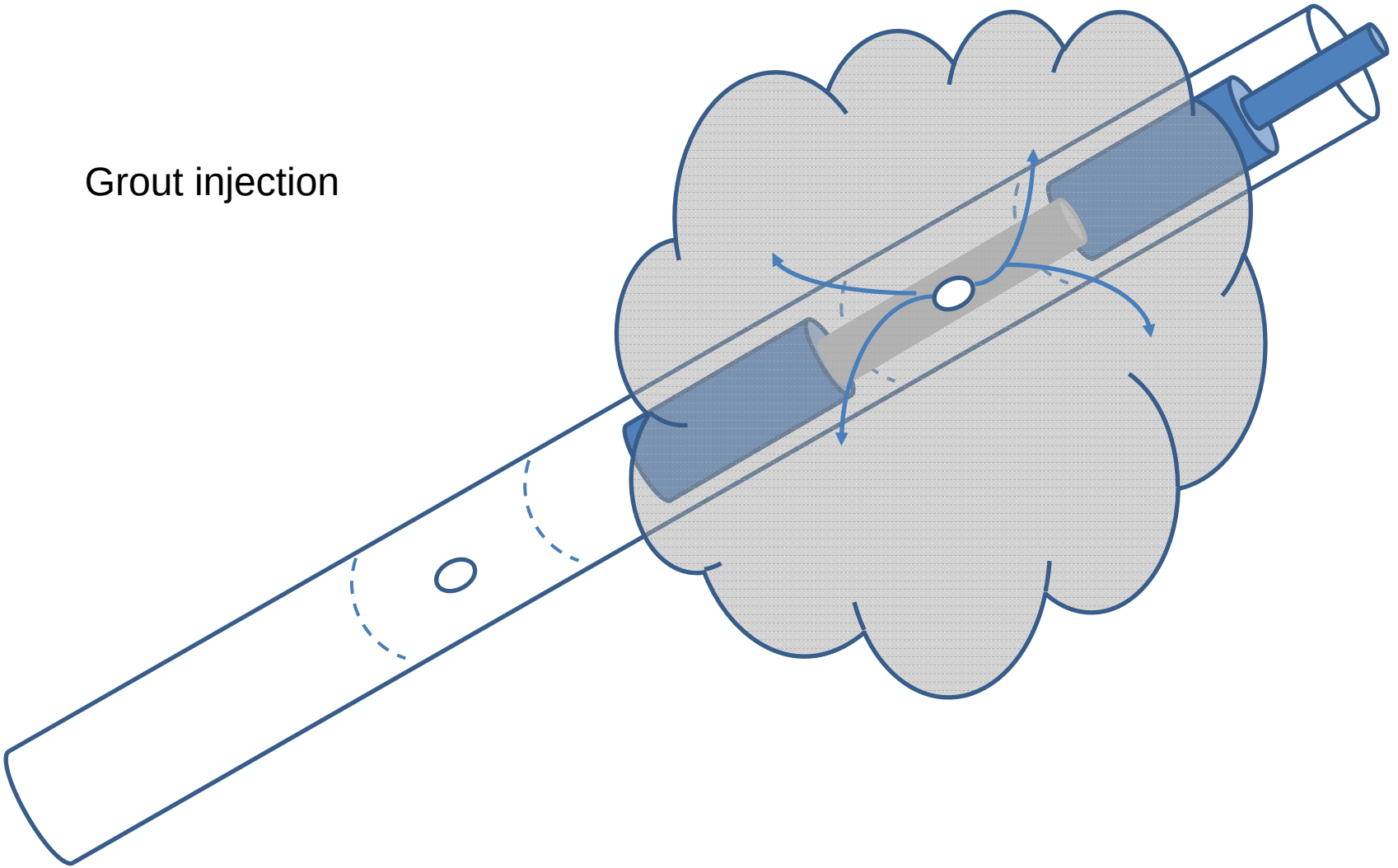
Permeation Grouting – how ?

Tube à Manchette (‘TaM’)

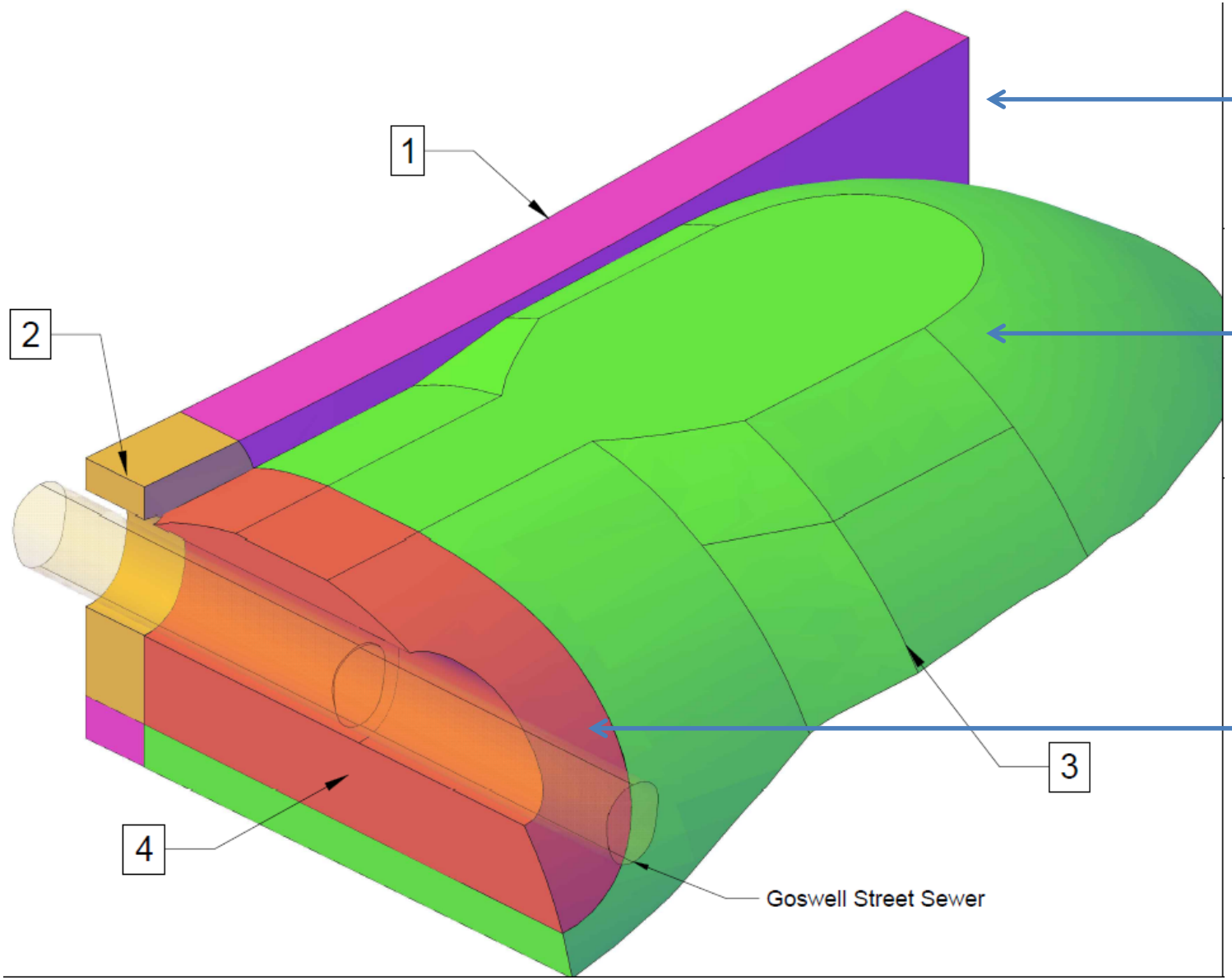


Permeation Grouting – how ?

Grout injection



Permeation Grouting – where ?



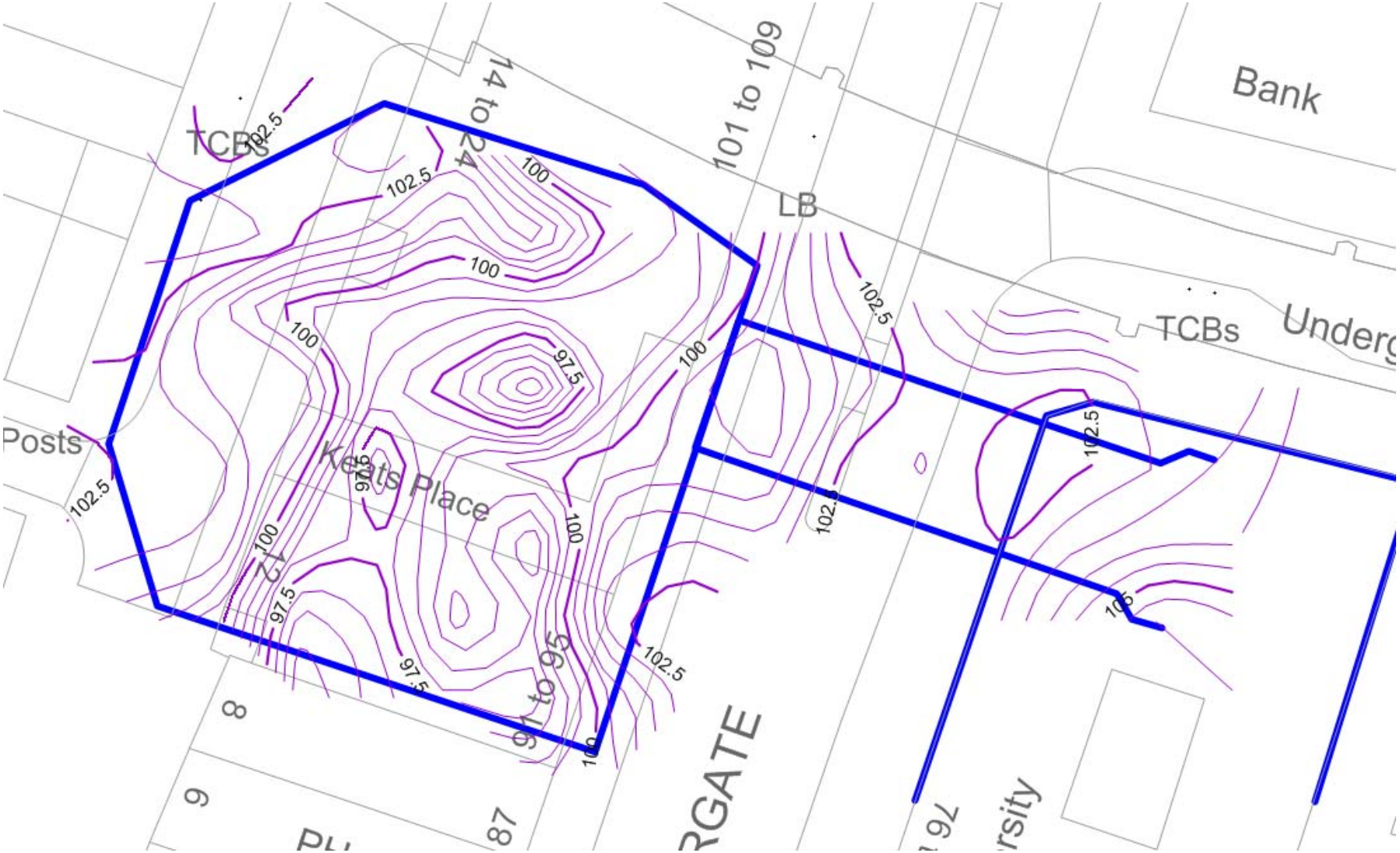
Low K cut off wall adjacent to H&C Line

Grout target zone = 6m radius from the extrados of the tunnel in the RTD

Reduced grouting pressure zone around the sewer

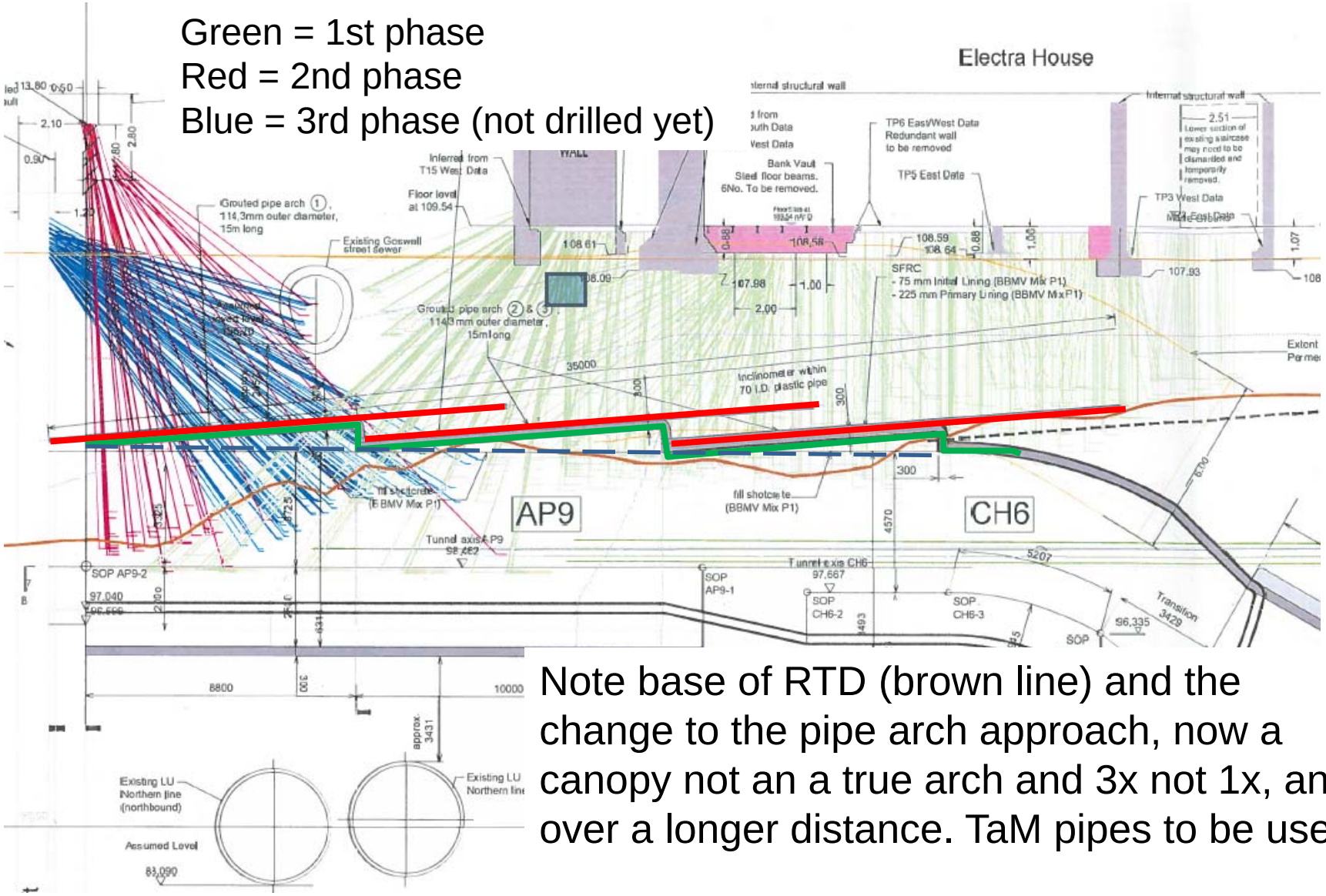
Base of RTD as known near the end of initial permeation grouting TaM drilling

Base of RTD as known near the end of permeation grouting TaM drilling



TaM arrangement & base RTD

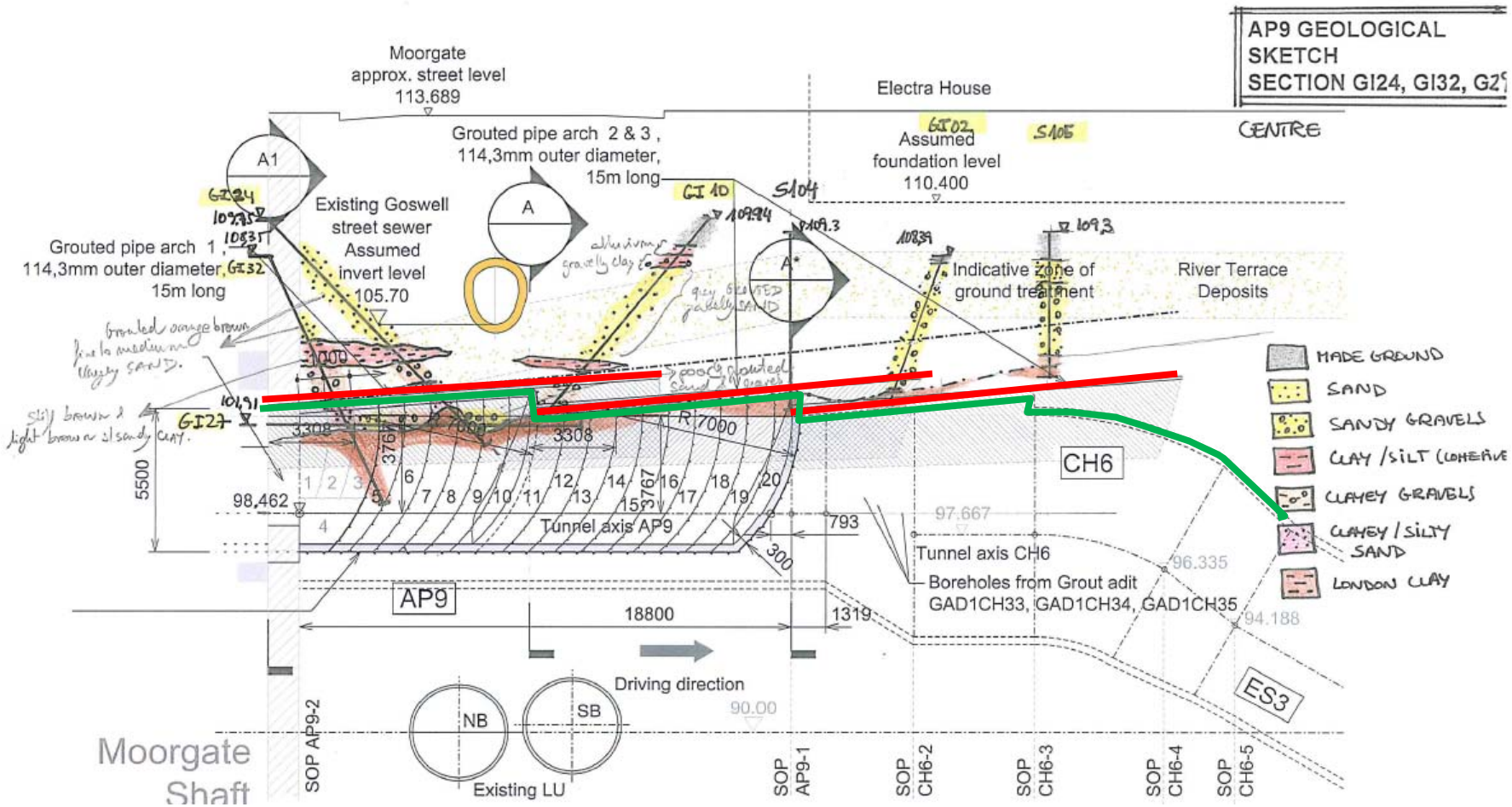
Green = 1st phase
Red = 2nd phase
Blue = 3rd phase (not drilled yet)



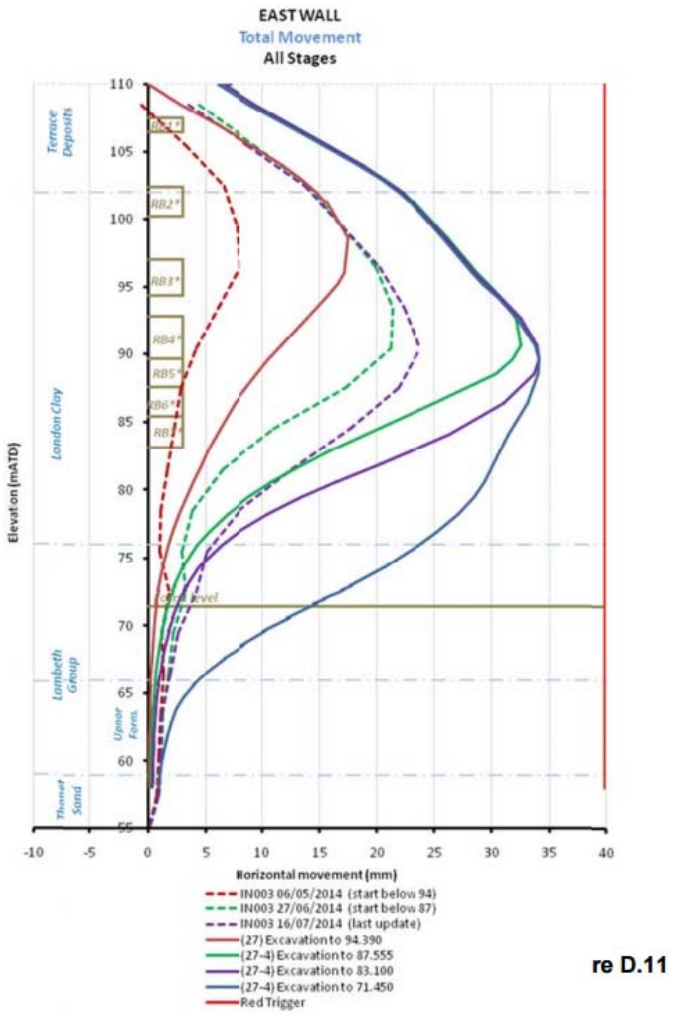
Note base of RTD (brown line) and the change to the pipe arch approach, now a canopy not an a true arch and 3x not 1x, and over a longer distance. TaM pipes to be used.

Electra House Grouting validation investigation

Updated long section



Grouting & Moorgate Box East wall oddities



re D.11

- 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.

Grouting & Moorgate Box East wall oddities

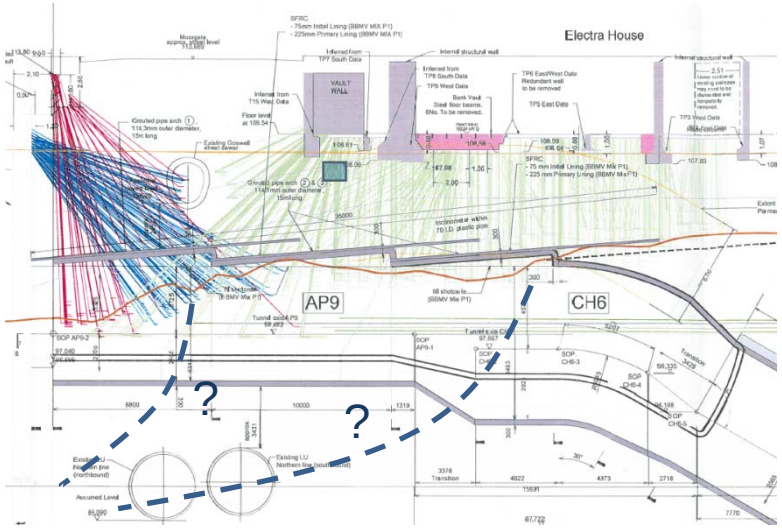
Impact on Tunnelling ?

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.

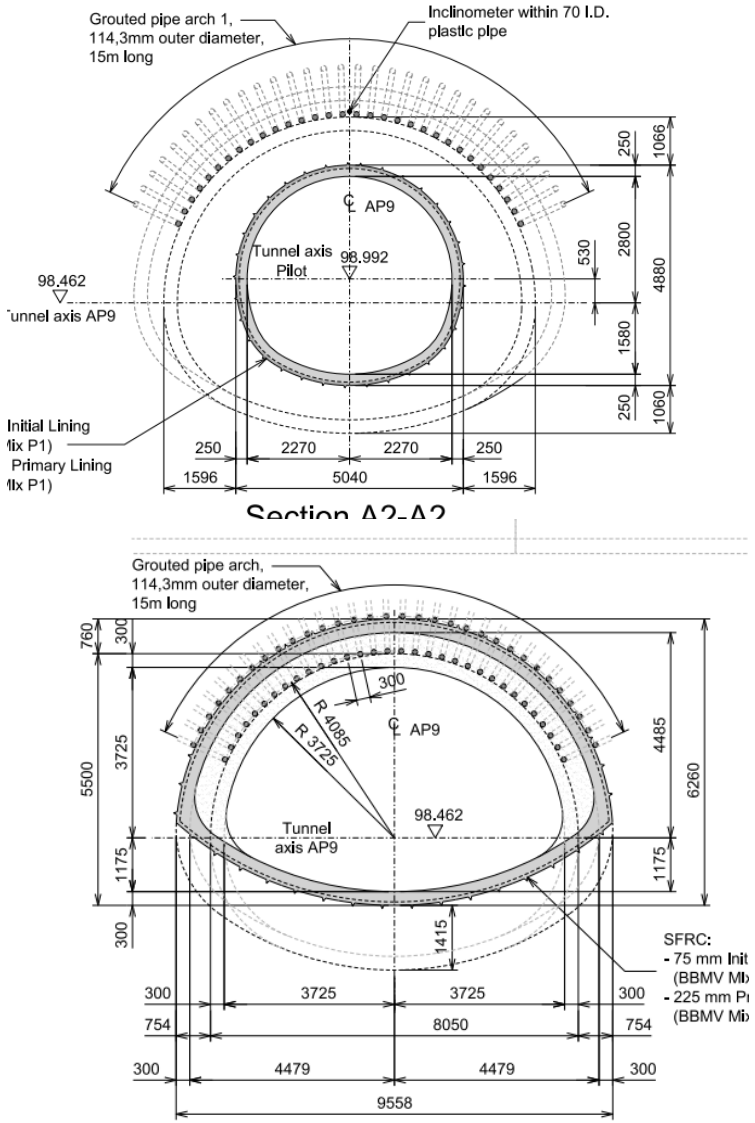


How to arrange the SCL tunnelling ?

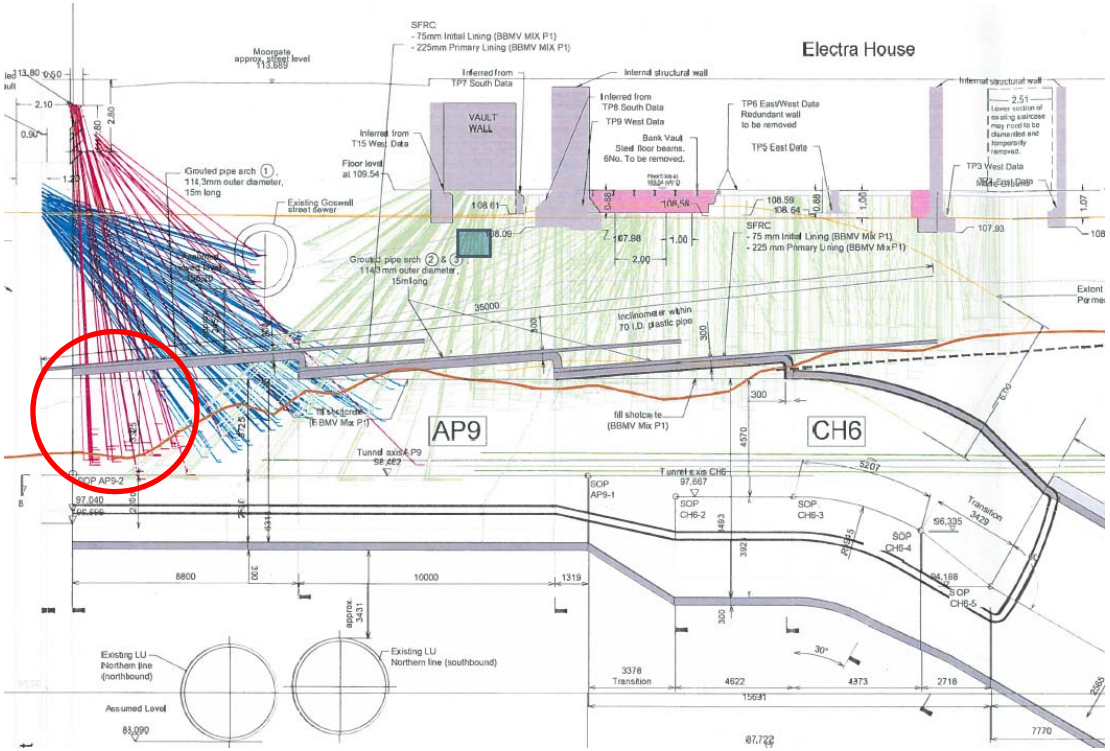
- Two main options
- Pilot & enlargement
- ‘Codsmouth’ & invert enlargement

- 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)

Response to ingress

- 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

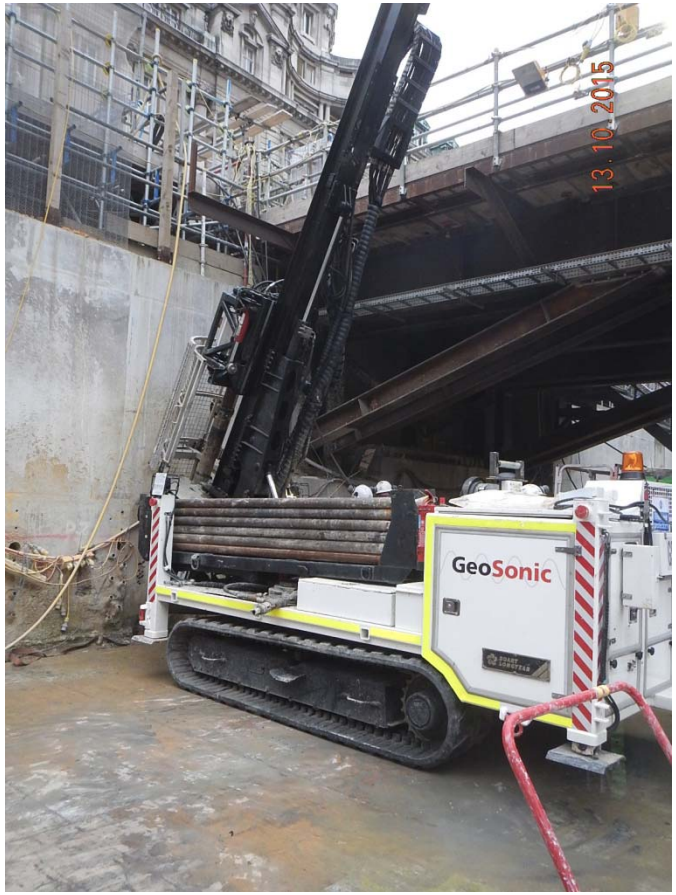
- But this creates some heave in Electra House.
- Grouting suspended whilst additional ceiling protection mitigation is installed
- Then carry out further validation GI prior to decision to open up.

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

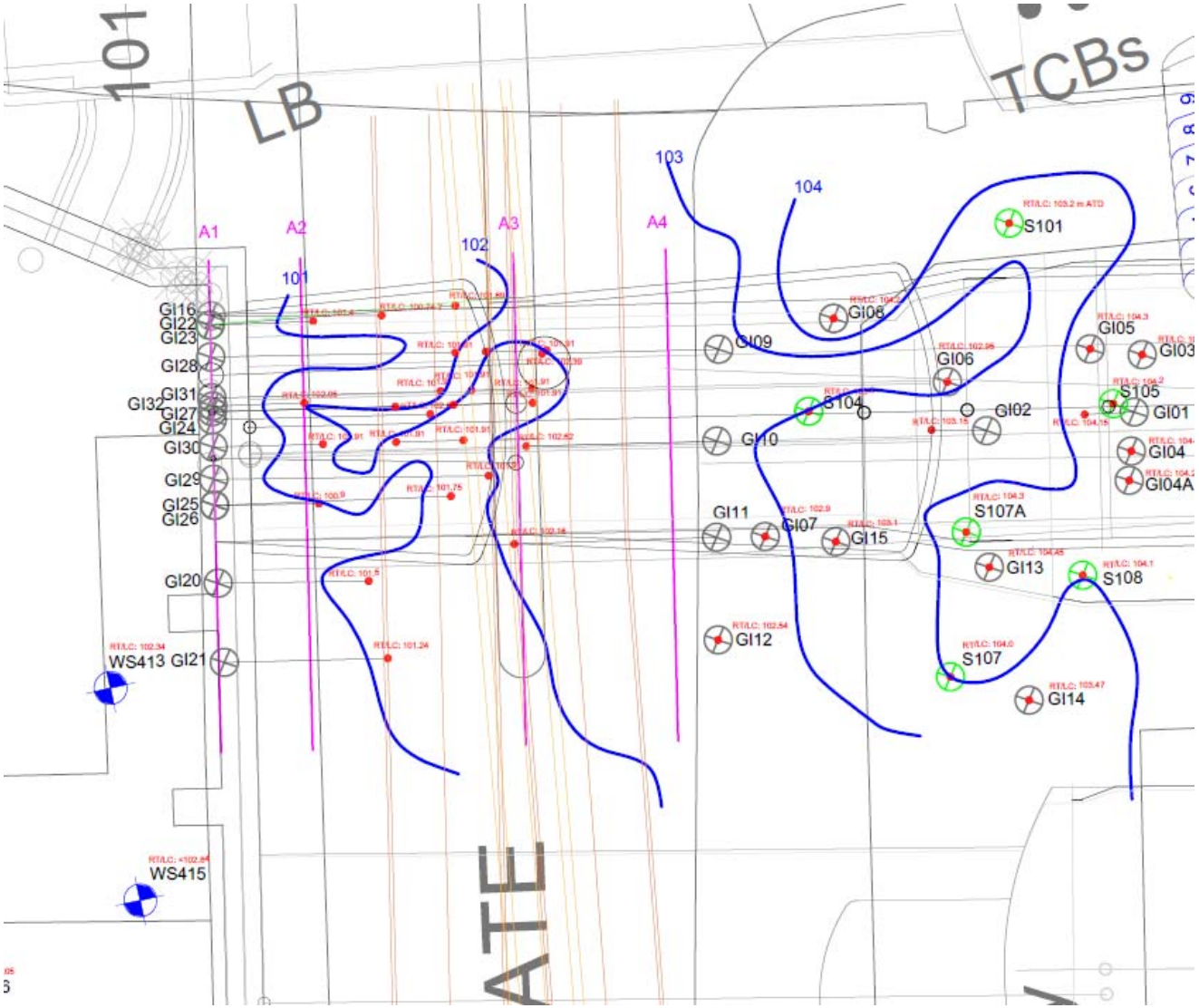
Moorgate GI


GI20
7.20-7.35m
AZCL
GI20
7.65-7.94m
AZCL
22 07 2015

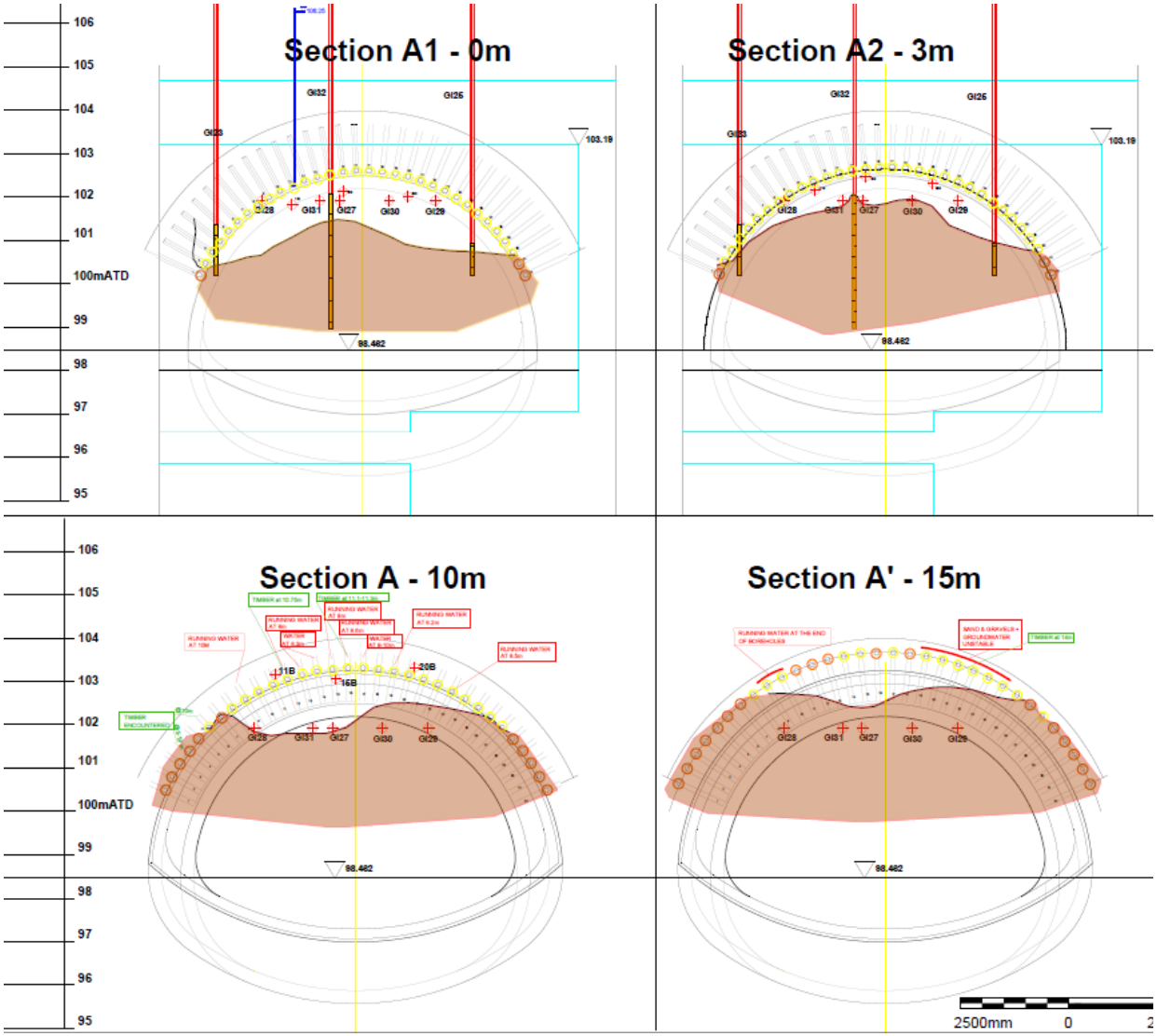

13.10.2015
GeoSonic

Updated contours on the base of RTD

1m interval



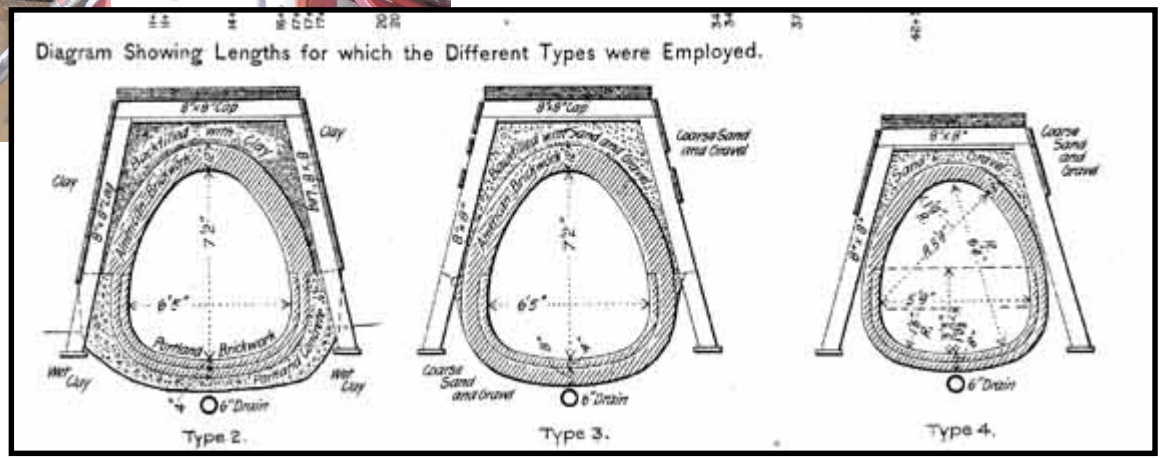
Transverse sections



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.

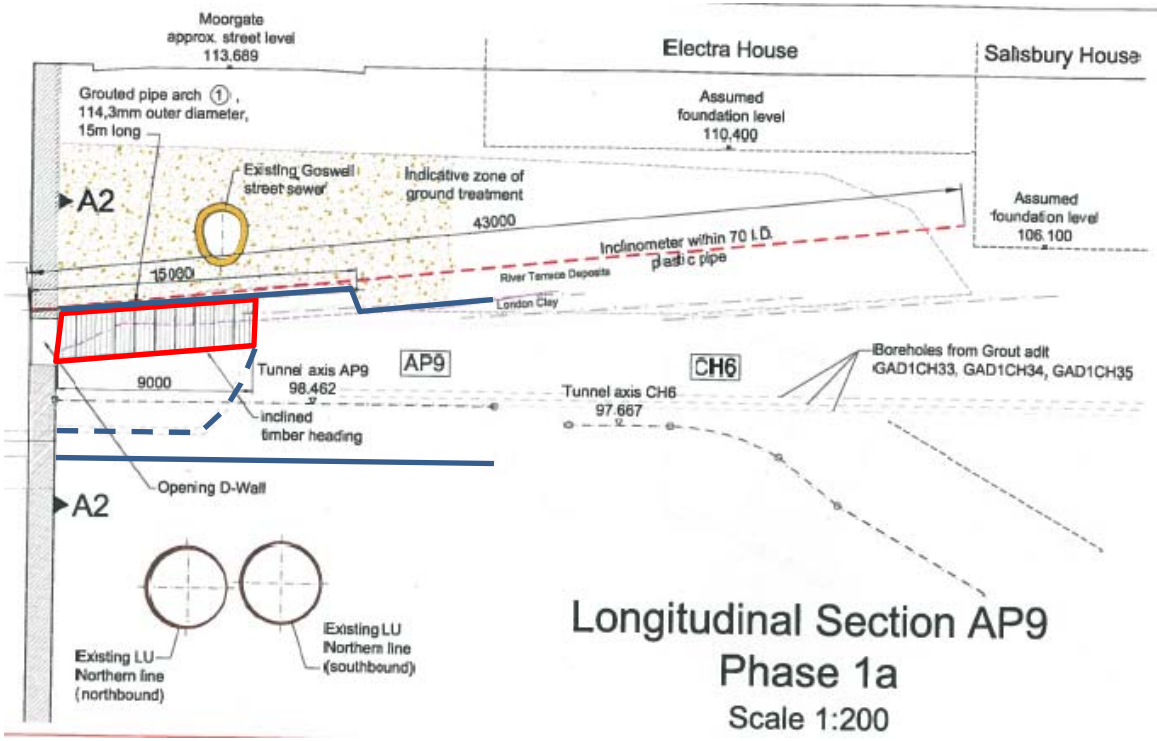
Pipe canopy installation



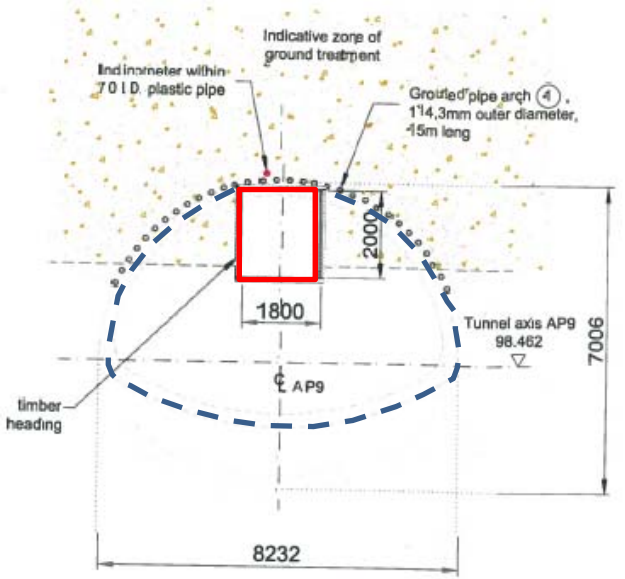
Adopted Solution

- Water flows are now much reduced. Abandon grounding freezing.
- Begin tunnelling with a 2m x1.8m 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

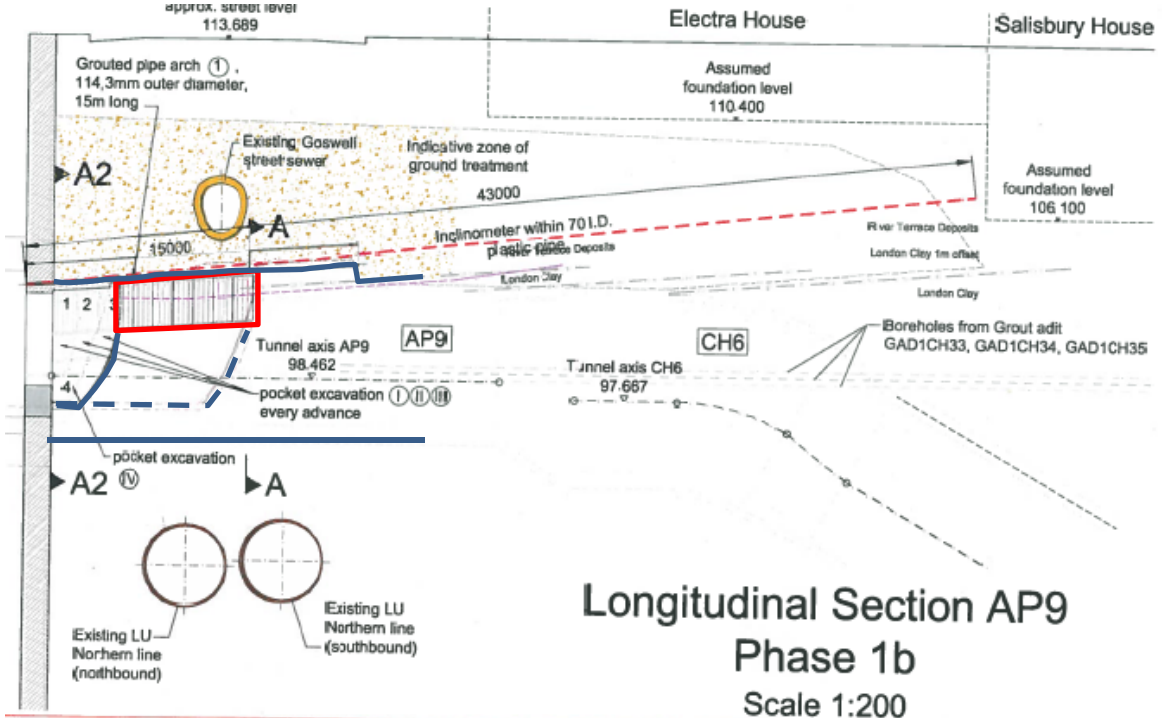


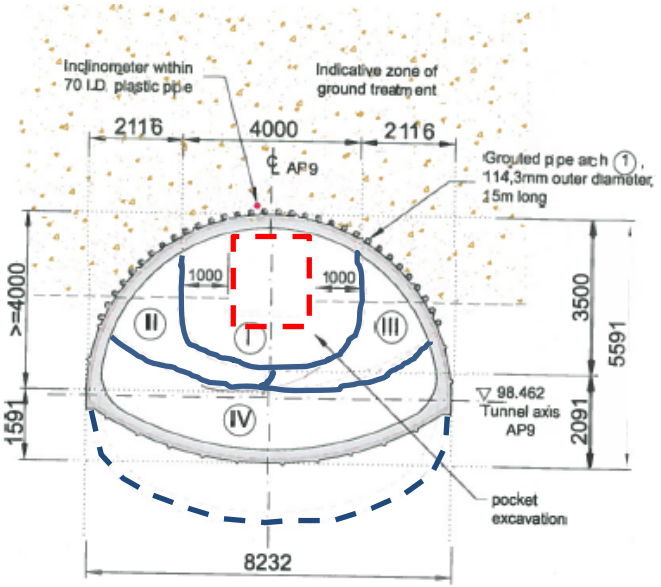
Longitudinal Section AP9
Phase 1a
Scale 1:200



Section A2-A2 - Phase 1a
Scale 1:100

Timber heading and SCL pockets

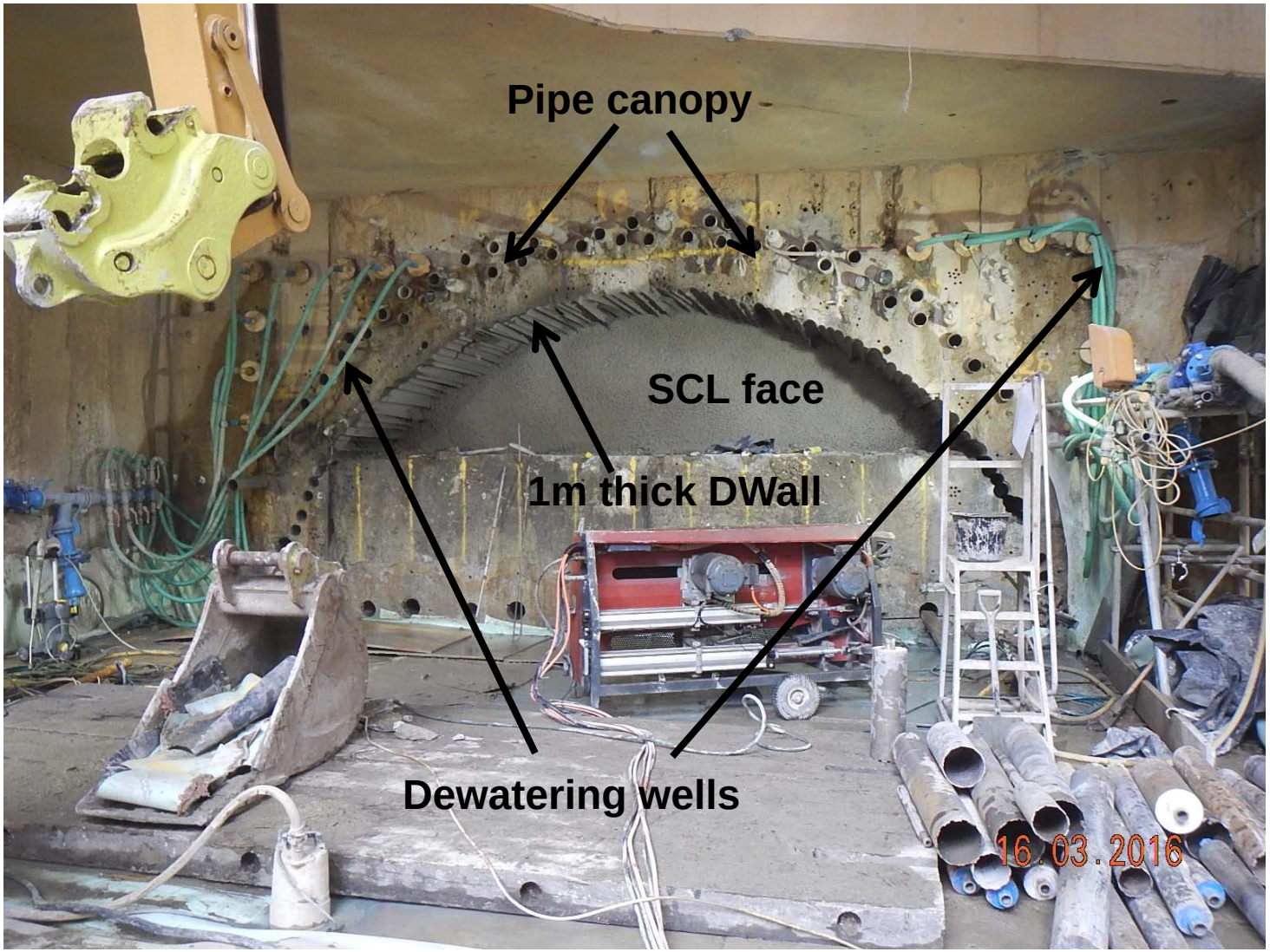




What happened ?

- 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

Opening Arrangement

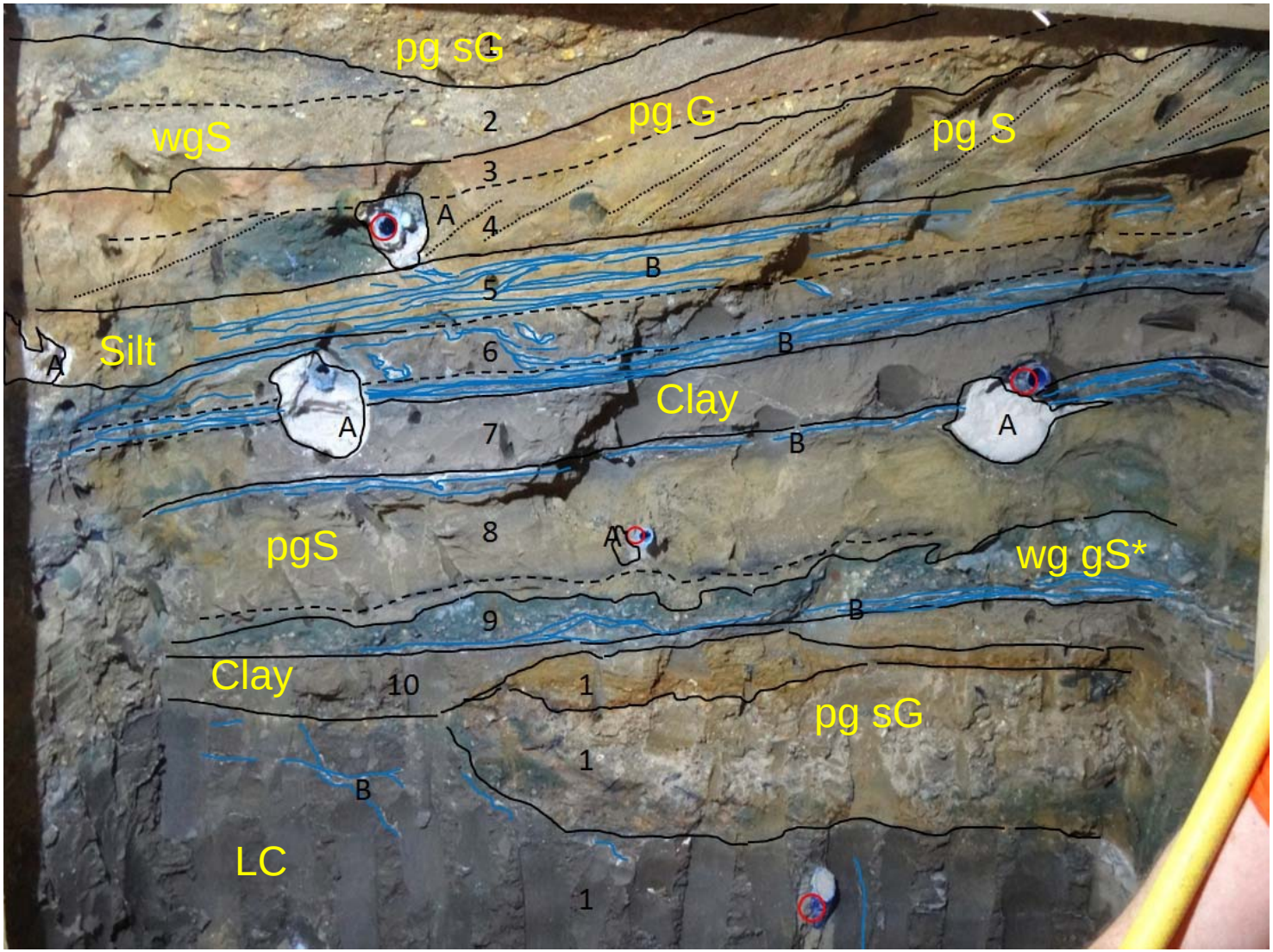


What did we see ? Opening the Dwall

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

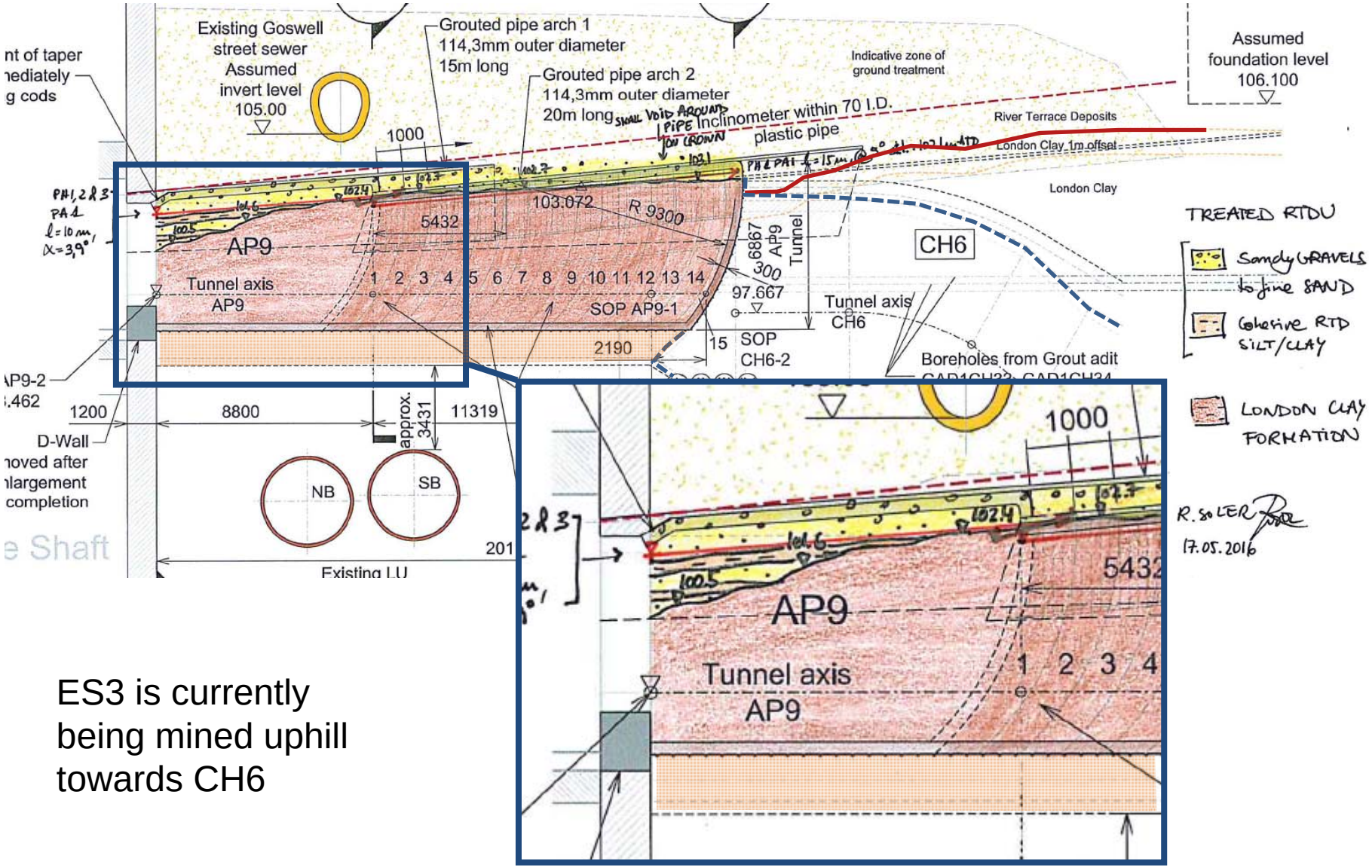
blue lines = grout fractures

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

AP9 invert enlargement

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.