



C300/410
Western Tunnels & Caverns Project

Report

Grouting Summary & I & M Final Report - BOS GS5

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APPENDICES

1. PURPOSE OF THIS REPORT

A number of summary reports (or written submissions) are required by the Works Information within the Compensation Grouting (KC21) and Instrumentation and Monitoring (KX10) Materials and Workmanship Specifications. The relevant Clauses are reproduced in Figure 1.1.

The requirements that are addressed in this report are:

- Summary of pre-treatment, concurrent grouting and grout jacking records
- Summary of construction activities
- Comparison of measured movements with predicted movements
- Comparison of measured movements with Specification limits
- Proposal to de-commission Grout Shaft 5 at Bond Street Station

As required by the Compensation Grouting Specification KC21 Clause KC21.3220(c), a written submission is required to justify the de-commissioning of compensation grouting facilities a minimum of 3 months after the completion of construction. Comparisons are made to the Compensation Grouting Performance Requirements defined in the C410 Specification for the Control of Ground Movement Clause 3.2.5.1 and 3.2.5.2 which apply for 3 months following the completion of construction (Clause 3.2.5.3).

All BFK excavation (tunnelling) works within the plan extent of the compensation grouting arrays from Bond Street Station Grout Shaft 5 were completed by the end of August 2014, over 8 months ago. Grout jacking episodes were implemented up to one month after tunnelling was completed. It is understood that excavation of the Eastern Ticket Hall (ETH) is ongoing and is not expected to be completed until August 2015.

This report aims to summarise the relevant construction, compensation grouting and monitoring information for Grout Shaft 5 at Bond Street Station and provide justification for the decommissioning of the shaft.

The requirements of KC21.3228(e) & (f) not fulfilled by this report are:

- H&S file – submitted separately for construction and a further file will be submitted after de-commissioning.
- Grout shaft & array construction – submitted separately.

The requirements of KX10.2013 and KX10.2014 not fulfilled by this report are:

- Updated as-built record and status for all instrumentation
- Justification for de-commissioning instrumentation other than the hydrostatic levelling cells (HLCs).

The HLCs have been used for construction control during compensation grouting works and a separate “close out” report is not required, since the 2mm/year criterion does not apply. Examples of data from the HLCs in the GS5 area are included in Appendix C.

The “as-built record and status” will be supplied as co-ordinates and digital data for incorporation in UCIMS.

Table 1.1 Extracts from Works Information

KC21.3220 Compensation Grouting - General Requirements

- c) The grouting facilities shall be maintained in place for a minimum of three months after the end of excavations or other construction activities which could produce settlement within the zone of compensation grouting. The grouting facilities shall be maintained for a further period until such time that the *Contractor* can demonstrate, by written submission, to the satisfaction of the *Project Manager*, that the specified criteria on movement specified in Volume 2C, *Specification* for the Control of Ground Movements will not be exceeded as a result of post-construction long term settlement. Automatic monitoring can be decommissioned at the same time as the grouting facilities whereas precise levelling points will be maintained in place and monitored until the *Contractor* can demonstrate compliance with the specified criteria for the cessation of monitoring to the satisfaction of the *Project Manager*.

KC21.3228 Reporting

- e) Within one month of the completion of concurrent grouting the *Contractor* will supply a summary report of the grout shaft and array construction, pre-treatment and concurrent grouting, site H&S file, ground movement monitoring, construction activities and a comparison of observed behaviour with both predicted movements and the *Specification* limits on movement. This report is to be updated one month after the completion of any episodes of grout jacking.
- f) A final version of the report will be prepared to incorporate the justification for de-commissioning, as required by Compensation Grouting - general requirements, and as-built records of the reinstatement of grout shafts and arrays including H&S closeout reporting.

KX10.2113 Final Report

Within three months after completion of the Works the *Contractor* shall issue a final report providing an updated as-built record and status for all instrumentation. The report shall include a summary of the observed movements for each monitoring area (relative to the construction works) and appropriate *Drawings*. The report shall be submitted to the *Project Manager* in an approved format.

KX10.2114 Close-Out Reports

Prior to the de-commissioning of any instrumentation, the *Contractor* shall produce a "close-out" report which summarises the data from the instrumentation the *Contractor* wishes to remove and relates it to the construction activities which produced any observed changes. The report shall demonstrate that the rate of change in the data has reached an acceptably small rate either in accordance with specified rates or, where no rate is specified, in relation to trigger values and an evaluation of any potential residual risks.

3.2.5 Compensation grouting at Bond Street and Tottenham Court Road Stations

- 3.2.5.1 The Works Information expressly requires the *Contractor* to provide a zone of compensation grouting in the vicinity of the two stations extending over the platform tunnels and associated station structures. The *Contractor* shall provide this compensation grouting to limit ground settlements as far as is practicable and in any event shall ensure the induced settlement complies with the following Compensation Grouting Performance Requirements. The settlement shall not produce: (i) a slope between any adjacent monitoring points in excess of 1/1000 and (ii) a deflection ratio (Δ/L) determined from any three points along a building boundary wall (including party walls), or on surface points above a utility, in excess of 1/2000. These values are subject to modification where the grouting extent is complex and for buildings adjacent to either piled buildings or those where additional mitigation measures are required.
- 3.2.5.2 Green, amber and red trigger values shall be set at values equal to 80%, 100% and 125% of the specified Compensation Grouting Performance Requirements respectively. A trigger will be deemed to have occurred if the relevant value is exceeded at more than 2 locations or by more than 25% at a single location.
- 3.2.5.3 The Compensation Grouting Performance Requirements given in Clause 3.2.5.1 shall apply from the commencement of installation of grouting facilities to a period of three months after completion of construction in the specified compensation grouting zone.

2. CONSTRUCTION WORKS PROGRESS

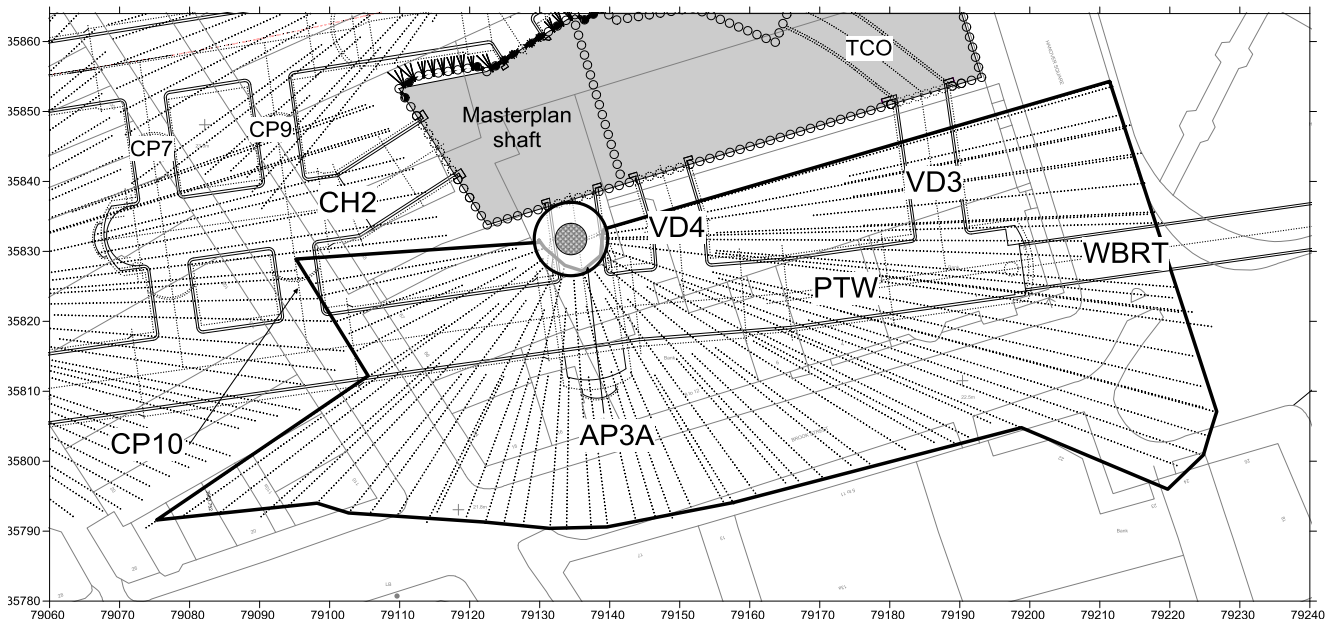
2.1. Tunnels

Table 2.1 and Figure 2.1 show the tunnel construction works undertaken within the footprint of the compensation grouting arrays installed from Grout Shaft 5 at Bond Street Station. Tunnel excavation commenced with the soft eye for TCO at the end of October 2012 and was completed with the excavation of VD3 at the end of August 2014. To facilitate comparison of monitoring data with construction activities 7 periods (A to G) have been assigned. Tunnelling was completed in 4 of these periods (B, C, E & F) as shown in Table 2.1. The main construction activities in each period are summarised in Table 2.2.

Table 2.1. Progress of C300/C410 works at BOS GS5 area.

| | TUNNEL | ABB. | START DATE | NOTES | END DATE |
|----------|---|----------|------------|--|------------|
| Period B | Temporary Crossover | TCO | 31/10/2012 | Abandoned at chainage 18m (4m short of south wall of ETH) | 25/01/2013 |
| | Access Passage 3A | AP3A | 07/12/2012 | Final chainage 24.51m | 23/03/2013 |
| | Westbound Running Tunnel | WBRT | 05/04/2013 | Stop for maintenance 06/04/13 – 22/04/13 | 01/05/2013 |
| Period C | Lower Concourse 3 | CH3 | 13/05/2013 | Final chainage 51.42m | 15/07/2013 |
| | Cross Passage 10 | CP10 | 31/07/2013 | Phase 2 concluded. Final chainage 11.63m | 04/02/2014 |
| Period E | Platform Tunnel Westbound (Enlargement) | PTW | 10/12/2013 | Excavated up to ch. 269.12 (Permanent headwall reached for westernmost end). | 19/04/2014 |
| Period F | | PTW East | 25/06/2014 | Back excavation from AP3A. From chainage 50.12 up to final chainage 81.29m | 15/08/2014 |
| | Ventilation Duct 3 | VD3 | 19/08/2014 | Final chainage 24.75m | 28/08/2014 |
| | Ventilation Duct 4 | VD4 | 28/07/2014 | Final chainage 18.24m | 04/08/2014 |

Figure 2.1. Tunnels within extent of grout array from Grout Shaft 5



2.2. Other construction works

Works by BFK prior to the commencement of tunnelling included:

- Drilling for installation of TaMs
- Pre-treatment grouting

Works by Others prior to the start of tunnelling included:

- Sinking of Grout Shaft 5
- Demolition for ETH
- Piling for ETH
- Excavation of the North west and Masterplan shafts

Works by Others during tunnelling comprised:

- Excavation of ETH to Level -1 (17/01/14 – 30/03/14)
- Excavation of ETH to Level -2 (27/05/14 – 18/07/14)

Works by Others after completion of tunnelling include:

- Excavation of ETH to Level -3 (27/08/14 – 10/12/14)
- Excavation of ETH to Level -4 (programmed to complete mid-May 2015)
- Excavation of ETH to Level -5 (programmed to complete August 2015)

2.3. Compensation Grouting

The volume of grout injected from GS5 is plotted against time on Figure 2.2 together with a plot of when each of the tunnels was constructed. Figure 2.2 shows that pre-treatment comprised approximately 80m³ injected prior to tunnelling, concurrent grouting over 300m³ and grout jacking just over 90m³. Concurrent grouting was undertaken with all tunnels except TCO (within the ETH piles) the WBRT and VD4. A VE proposal was implemented to avoid any delays to the running tunnel drive which allowed grouting to be undertaken pre- and post- tunnelling – the volume of grout associated with this is included under grout jacking. VD4 is a short length of tunnel and the extent of the exclusion zones over the tunnel face and adjacent to the ETH piled wall, as defined in the SCoGM, rendered concurrent grouting impractical.

Figures 2.3 to 2.5 show contours of the total grout intensity for each of the three types of grouting (pretreatment, concurrent and jacking respectively) and a cumulative total of all grout injected from GS5 is shown in Figure 2.6. The grout intensity is the equivalent thickness of grout injected into the ground in millimetres. The methodology used to generate these contours is described in Appendix A. Comparison of the contour plots of grout intensity with observed settlements is discussed in Section 3. The exclusion zone adjacent to the ETH and a similar 3m exclusion zone around the grout shaft are clearly evident in the contours.

Table 2.1. Construction Periods for works in BOS GS5 area.

| Period | Start Date | End Date | Main Works |
|--------|------------|----------|---|
| A | 30/09/11 | 16/11/12 | ETH piling; Excavation of Masterplan & NW shafts. Sinking of GS5. GS5 drilling & pretreatment |
| B | 17/11/12 | 01/05/13 | TCO, AP3A, WBRT. Concurrent & grout jacking. |
| C | 02/05/13 | 05/08/13 | CH3. Concurrent & grout jacking. |
| D | 06/08/13 | 10/11/13 | Grout jacking |
| E | 11/11/13 | 05/02/14 | PTW (west). Concurrent grouting. ETH excavation starts. |
| F | 06/02/14 | 27/08/14 | PTW (east), VD3, VD4. Concurrent & grout jacking. ETH excavation to -2 level completed |
| G | 28/08/14 | 10/05/15 | ETH excavation to -3 level, grout jacking |

Figure 2.2 Volume of grout injected from GS5 by grouting type.

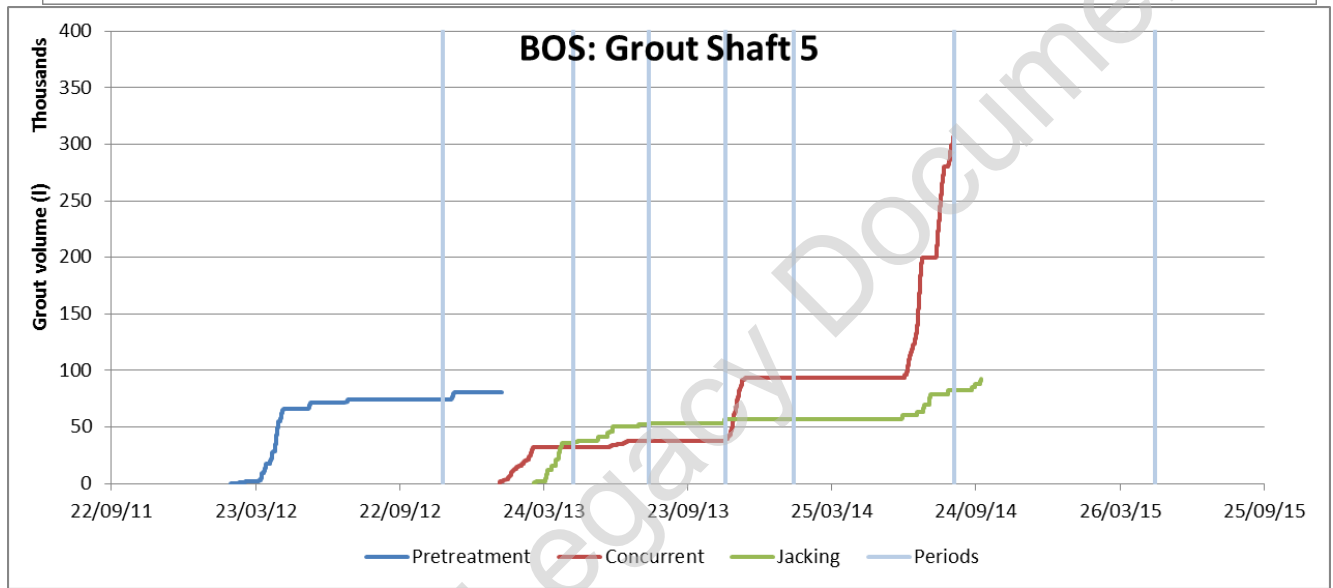
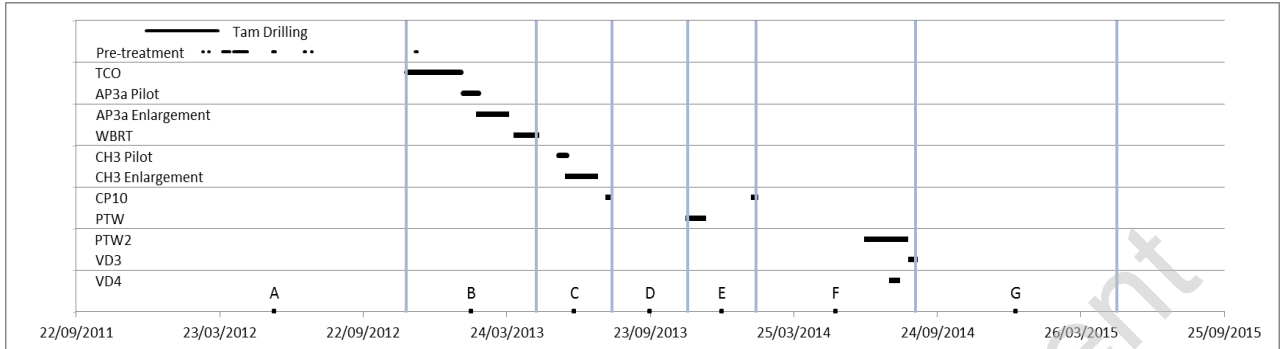


Figure 2.3 Distribution of grout injected from GS5: Pretreatment grouting. Grout Intensity (mm).

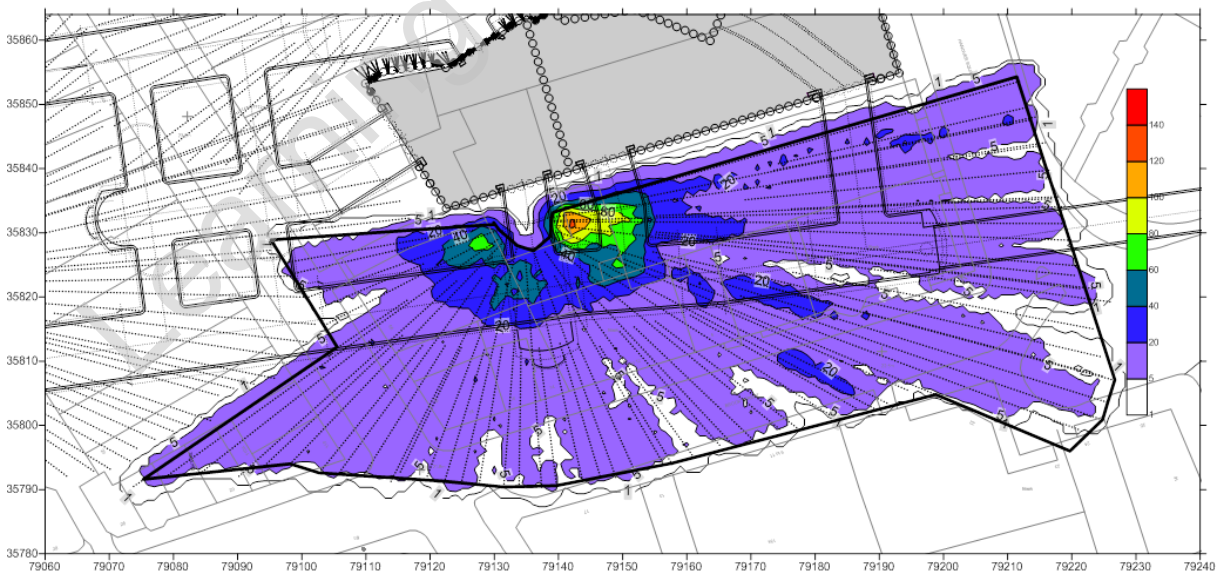


Figure 2.4 Distribution of grout injected from GS5: Concurrent grouting. Grout Intensity (mm).

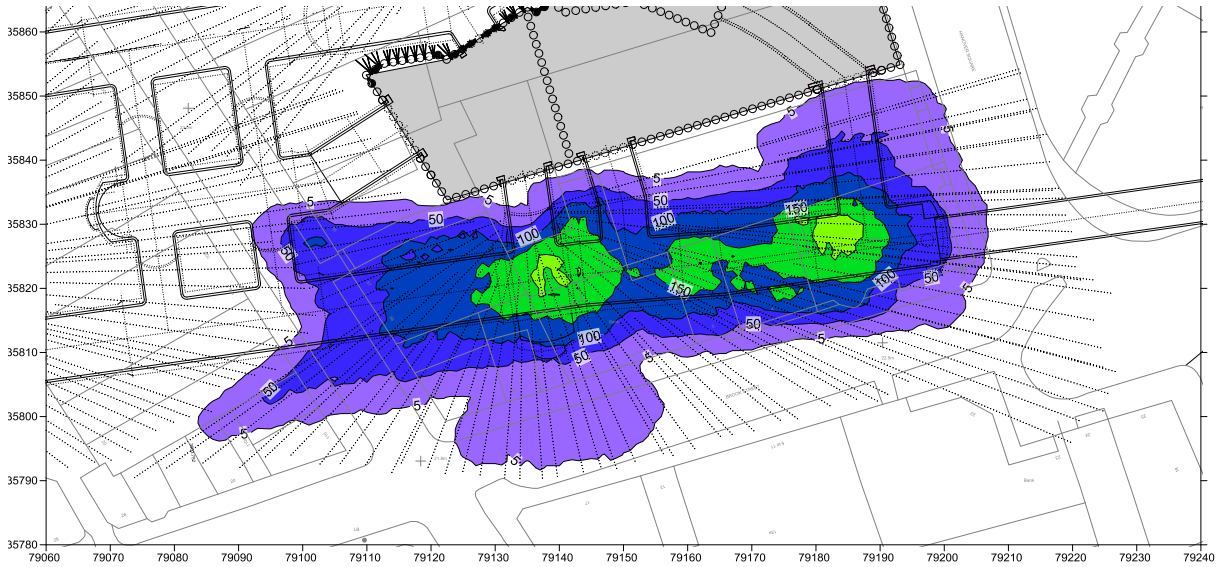


Figure 2.5 Distribution of grout injected from GS5: Jack grouting. Grout Intensity (mm).

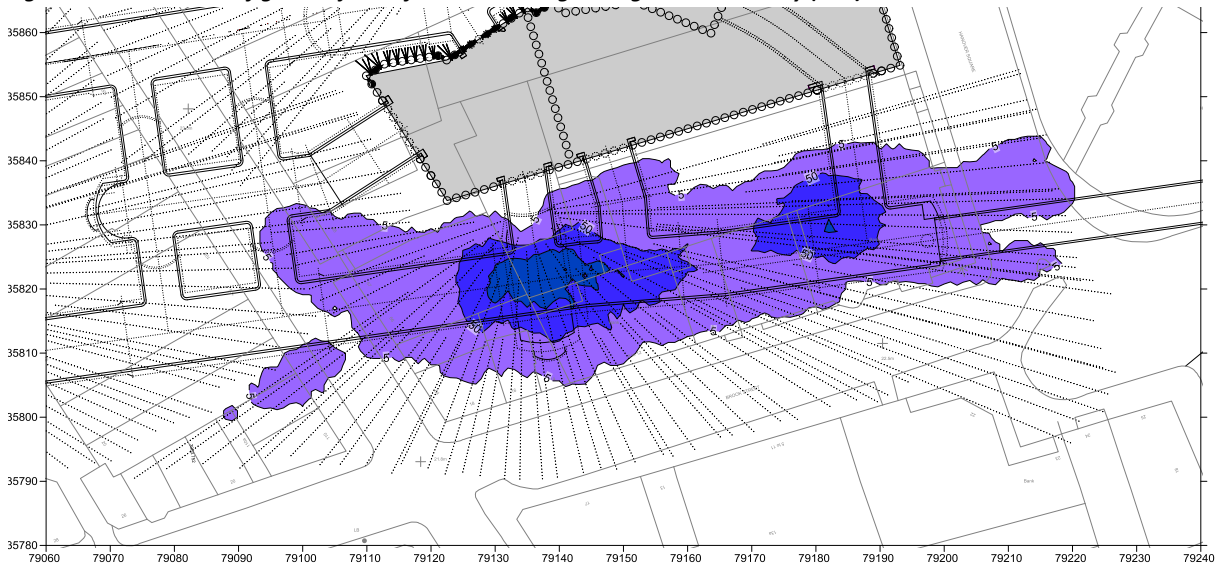
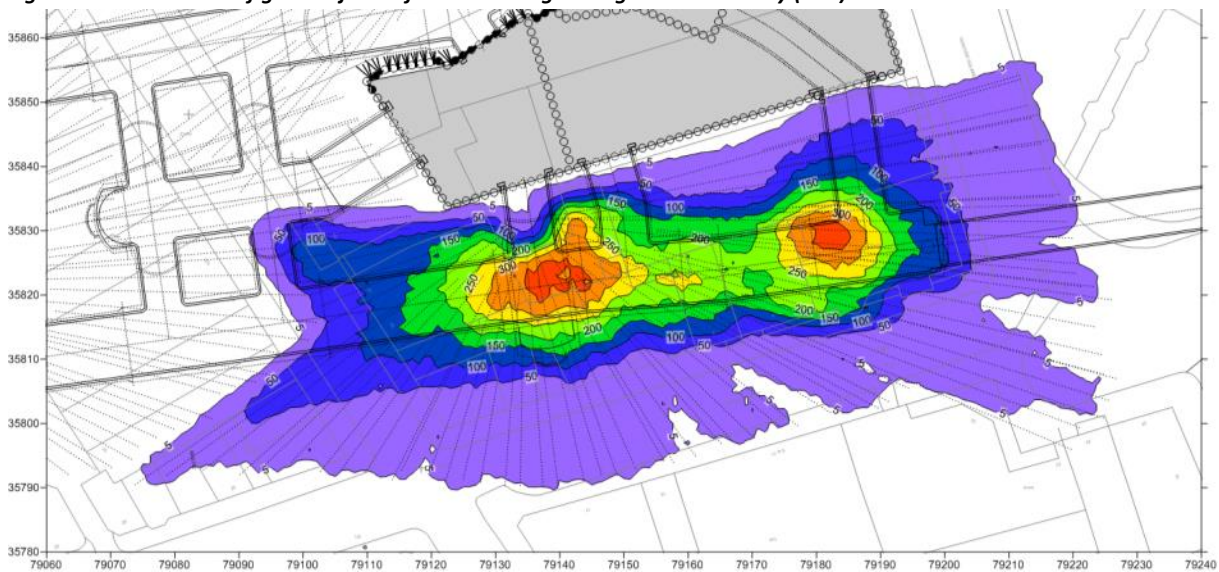


Figure 2.6 Distribution of grout injected from GS5: All grouting. Grout Intensity (mm).



3. COMPARISON OF OBSERVED AND PREDICTED SETTLEMENT

3.1. SETTLEMENT OVERVIEW

Contours of total predicted short term settlement (supplied on C122 is shown in Figure 3.1.1. The measured settlement to April 2015, including consolidation settlement during the period of construction is shown in Figure 3.1.2.

The following points are noted:

- Settlements are generally less than 50% of the predicted values, notwithstanding that the observed movements include a significant proportion of consolidation settlement over the 3 ½ year construction period.
- The most obvious differences between the predictions and the observations are:
 - the substantially reduced settlement along the party wall with the ETH (90 to 115mm predicted, 15 to 40mm observed);
 - on the west side of New Bond Street just outside the extent of GS5 arrays where a maximum settlement of over 70mm has occurred (this is described in more detail in the report for GS2)
 - the extent of the zone of settlement is much less than predicted with only minor settlement recorded at the 10mm predicted contour.

Figure 3.1.1 Predicted settlement contour (supplied by C122)

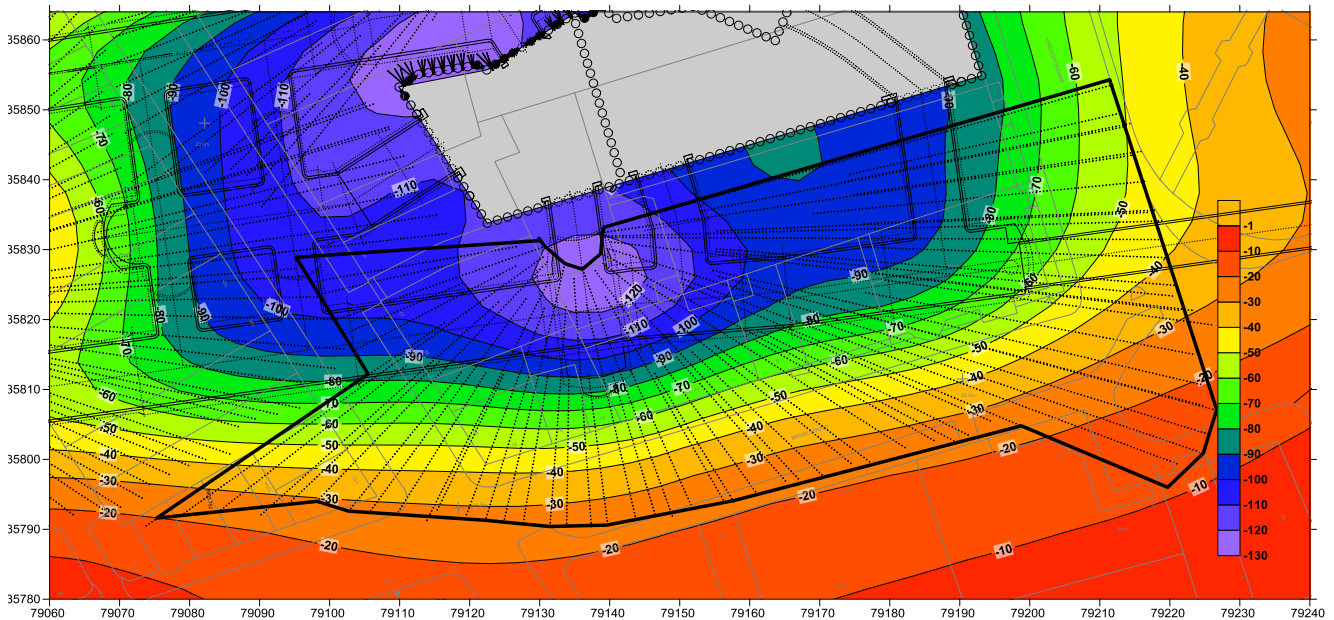
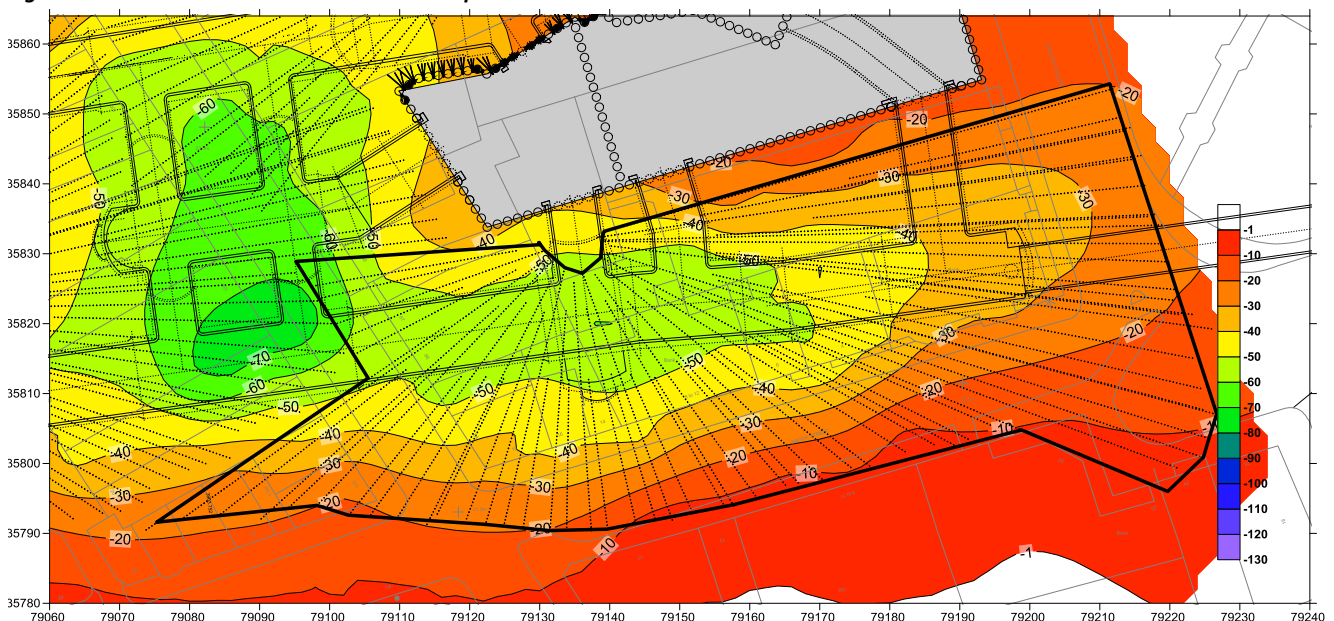


Figure 3.1.2 Observed settlement contour in April 2015



In order to compare the predicted and actual movements at various stages of construction the overall monitoring period from September 2011 to May 2015 has been divided into a number of periods, based largely on tunnel excavation. The dates of and construction activities in each period are summarised in Table 2.1, repeated here as Table 3.1.

The following plots are presented, as appropriate, for each period:

1. Volume loss settlement for tunnels constructed in the Period at the specified volume loss values;
2. Observed change in settlement within the Period;
3. Total settlement at the end of the Period;
4. Contour of grout intensity for concurrent grouting within the Period;
5. Contour of grout intensity for grout jacking within the Period

Table 3.1. Construction Periods for works in BOS GS5 area.

| Period | Start Date | End Date | Main Works |
|--------|------------|----------|---|
| A | 30/09/11 | 16/11/12 | ETH piling; Excavation of Masterplan & NW shafts. Sinking of GS5. GS5 drilling & pretreatment |
| B | 17/11/12 | 01/05/13 | TCO, AP3A, WBRT. Concurrent & grout jacking. |
| C | 02/05/13 | 05/08/13 | CH3. Concurrent & grout jacking. |
| D | 06/08/13 | 10/11/13 | Grout jacking |
| E | 11/11/13 | 05/02/14 | PTW (west). Concurrent grouting. ETH excavation starts. |
| F | 06/02/14 | 27/08/14 | PTW (east), VD3, VD4. Concurrent & grout jacking. ETH excavation to -2 level completed |
| G | 28/08/14 | 10/05/15 | ETH excavation to -3 level, grout jacking |

3.2. Period A – Prior to tunnelling

Period A includes all of the preparatory work prior to the commencement of tunnelling, including demolition, piling and excavation of the Masterplan and North-West Shafts of the Western Ticket Hall. BFK works comprised the drilling and pre-treatment of TaMs from GS5.

The calculated short term movements associated with piling and excavation of the Masterplan and North-west shafts are shown in Figure 3.2.1 (as supplied by C122). Greatest settlement is at the ETH piled wall adjacent to GS5 where ~50mm settlement is indicated.

The observed settlements (adjusted to allow for movements prior to the start of BFK monitoring) are shown on Figure 3.2.2. Pre-treatment was almost entirely completed in Period A and, consequently, the contours of grout intensity shown in Figure 3.2.3 are virtually identical to those in Figure 2.3.

A maximum settlement of over 20mm was produced by the preparatory works with more than 10mm over almost the entire footprint of the buildings north of Brook Street. It is notable that the greatest settlement is along the party wall between the ETH and 20 Hanover Square with the maximum value immediately to the east of GS5. The observed differential settlement between the pile wall and Brook Street façade was about 10mm much lower than the predicted value of ~40mm.

The contours of grout intensity show that significant efforts were made to reduce the movement in the area of maximum settlement: over the majority of the area less than 20l/m² was required to complete pre-treatment (uplift 3 – 5mm) whereas in the vicinity of the shaft about 40l/m² was injected and in the area of maximum settlement this rose to over 100l/m².

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Figure 3.2.1. Period A: Total predicted settlement (supplied by C122)

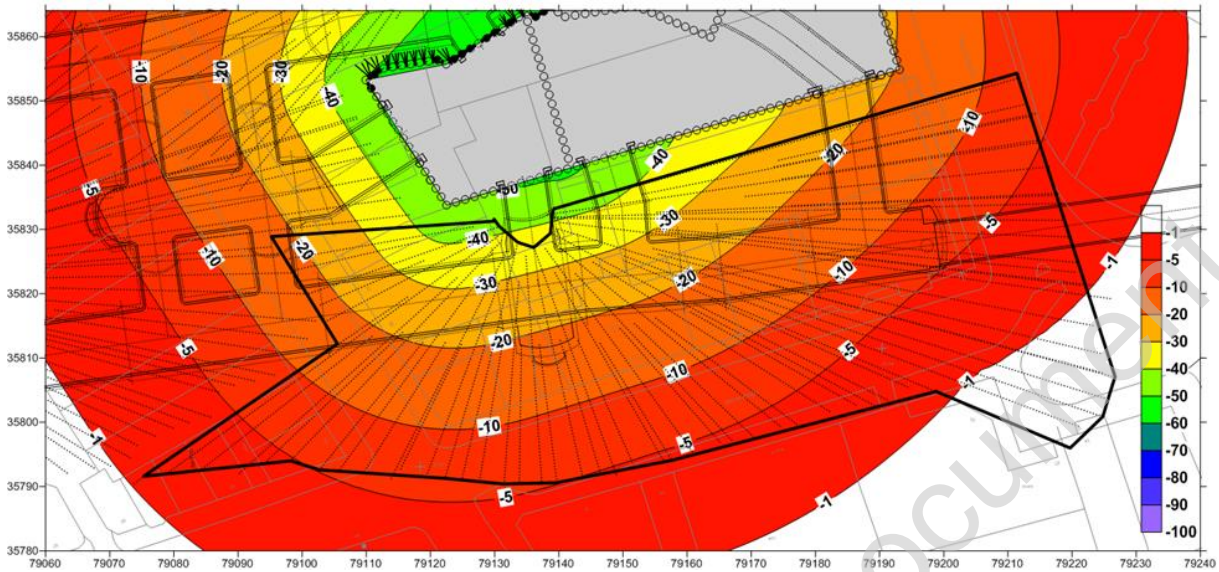


Figure 3.2.2. Period A: Total measured settlement

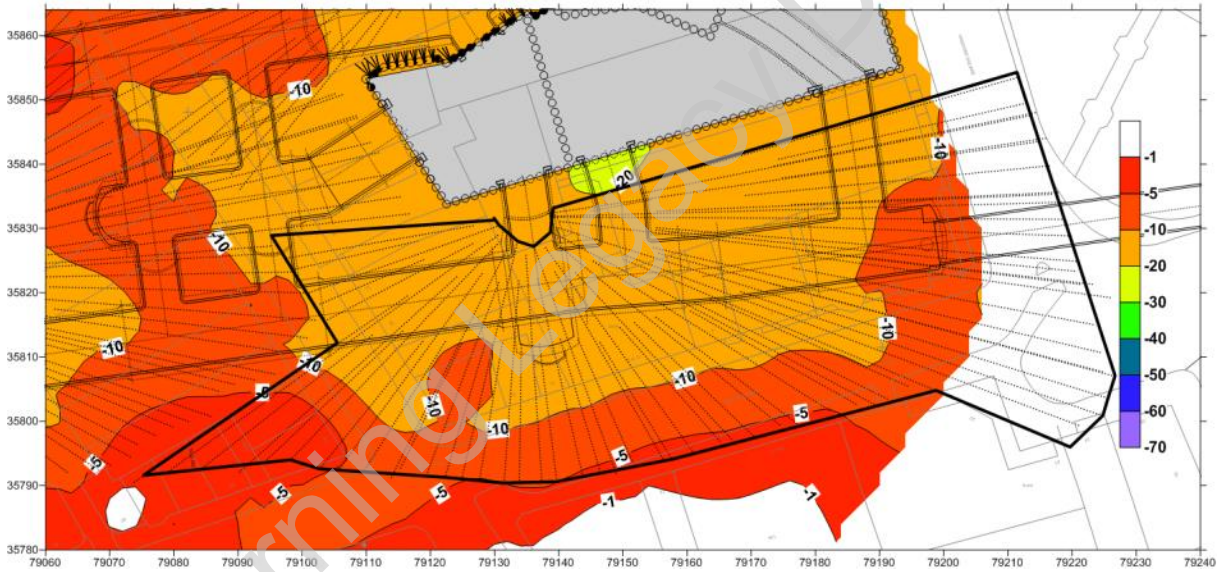
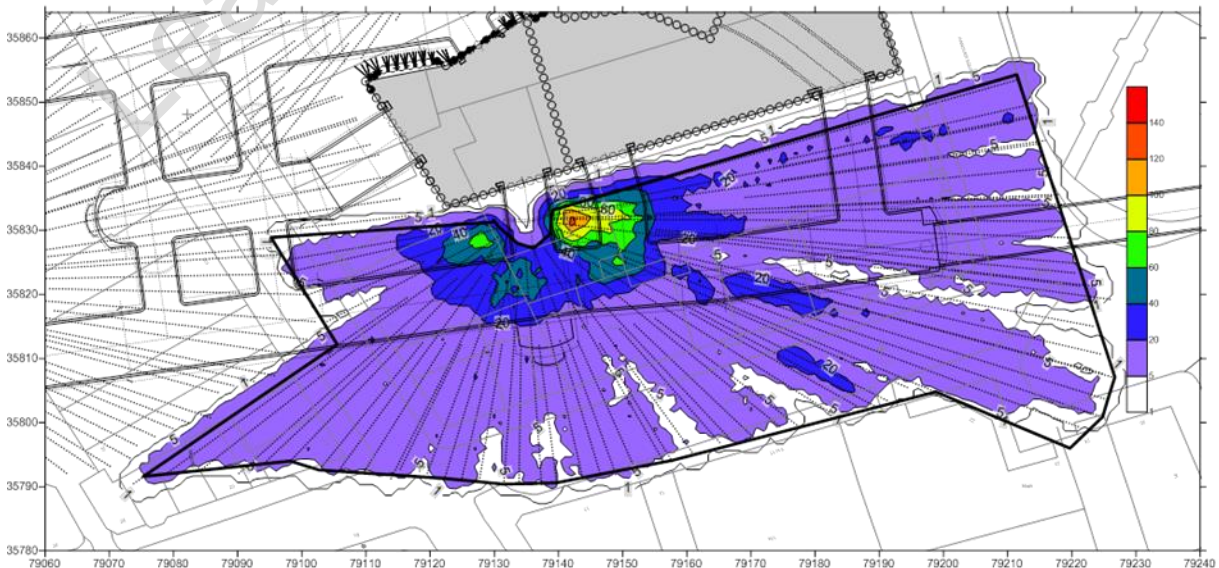


Figure 3.2.3 Distribution of grout injected from GS5: Pretreatment grouting. Grout Intensity (mm).



3.3. Period B: TCO, AP3A and WBRT

Figure 3.3.1 Period B: (a) Volume loss settlement. (b) Change in measured settlement. (c) Total measured settlement

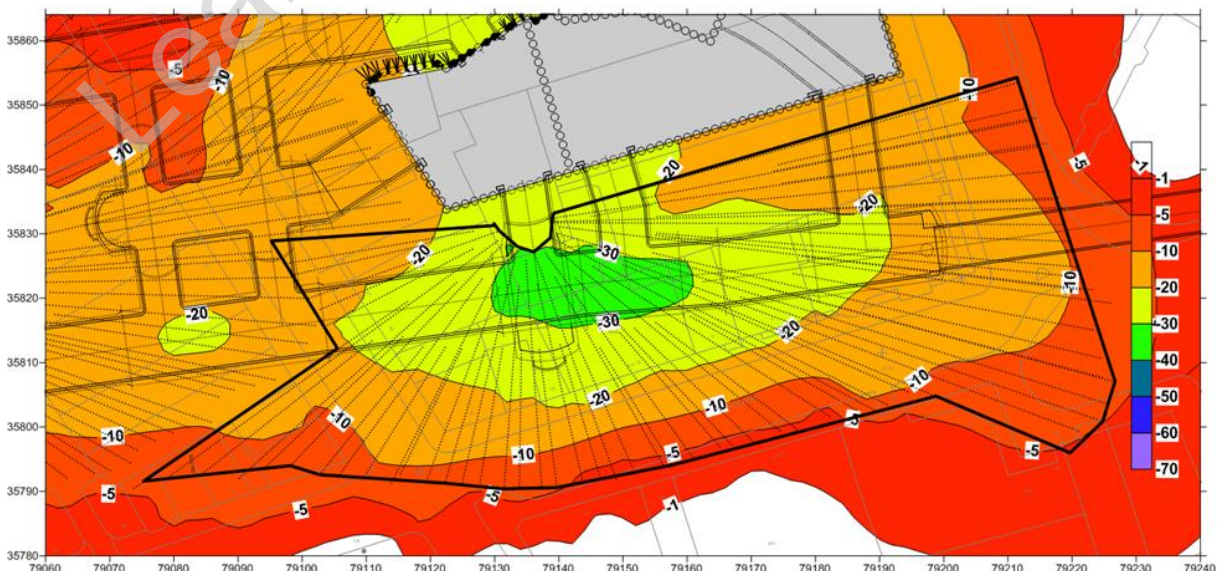
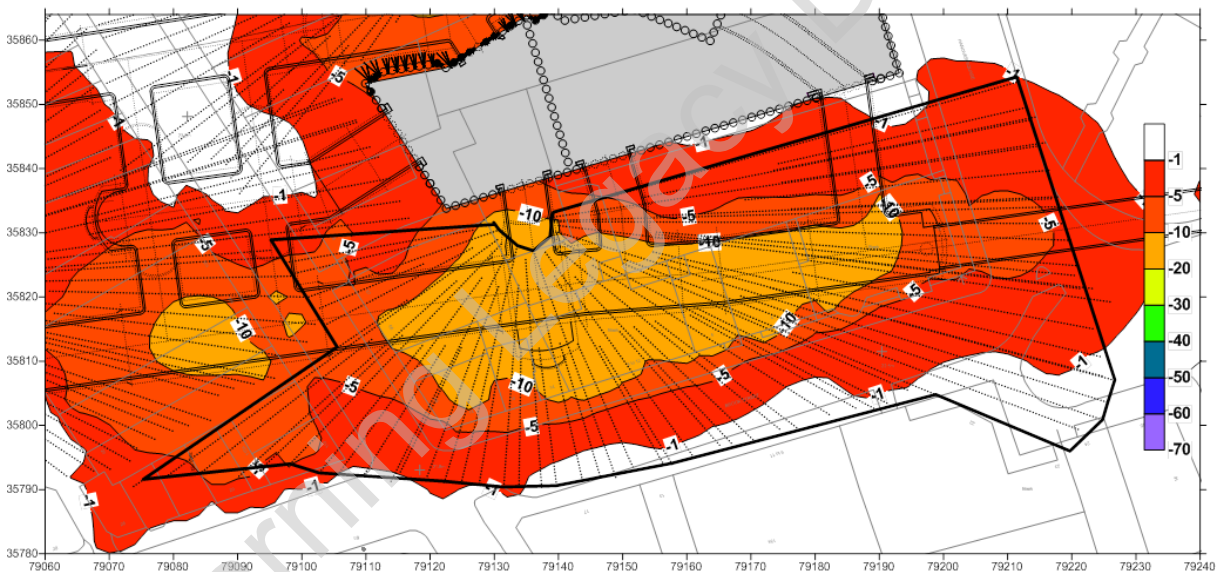
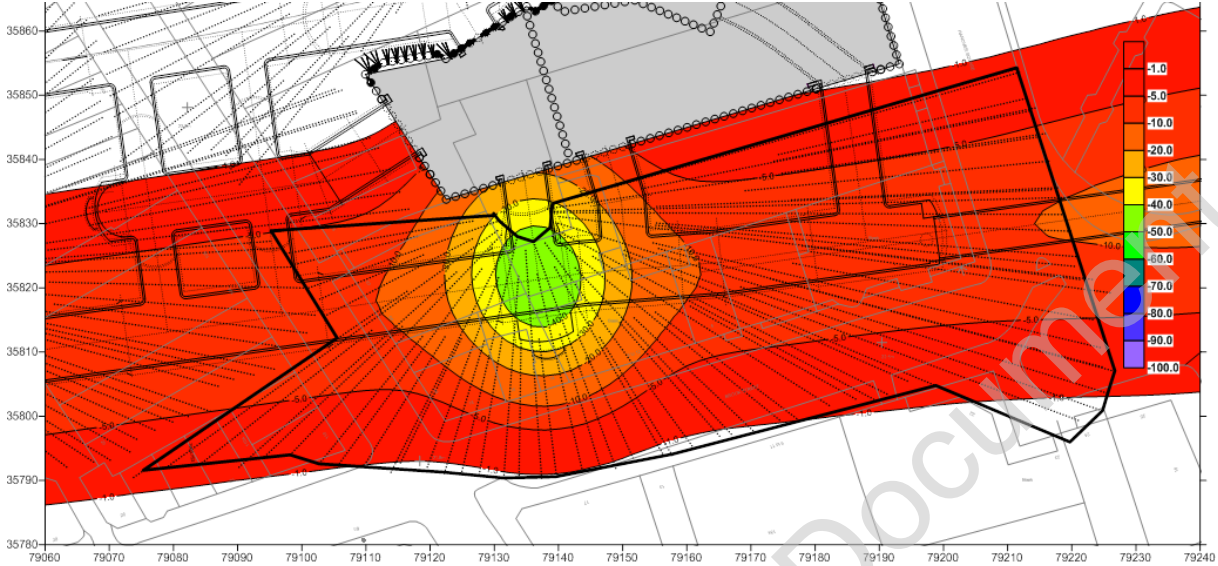


Figure 3.3.2 Period B: Distribution of grout injected from GS5: Concurrent grouting. Grout Intensity (mm).

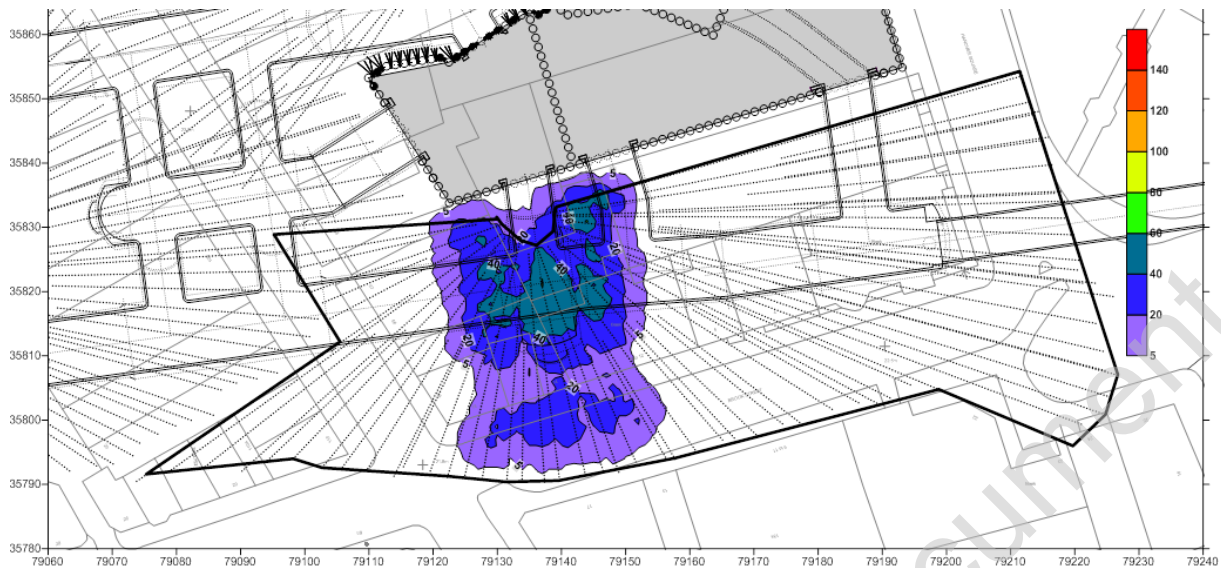


Figure 3.3.3 Period B: Distribution of grout injected from GS5: Grout jacking. Grout Intensity (mm).

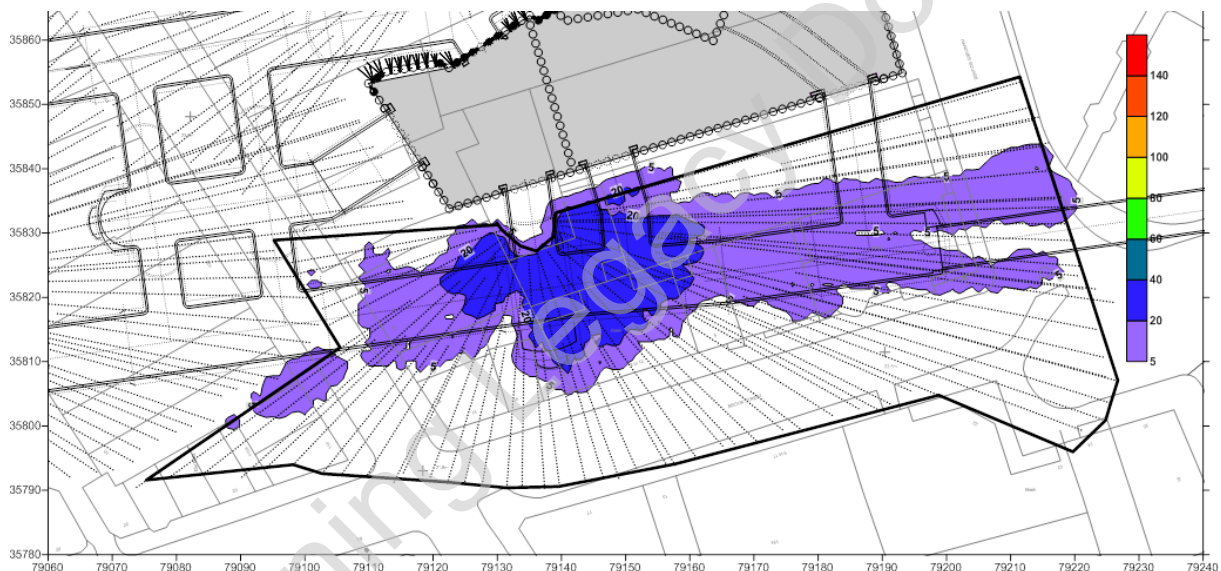


Figure 3.3.1(a) shows that over 40mm volume loss settlement was anticipated for AP3A wraparound tunnel, whereas just less than 10mm was expected for the WBRT. No volume loss has been added for the TCO since this is entirely within the piled wall of the ETH.

Figure 3.3.1(b) shows that maximum recorded settlement was 17mm over the junction of AP3A and WBRT. It is notable that the volume loss contours on Figure 3.3.1(a) extend within the plan extent of the ETH and in this area the maximum settlements associated with the WBRT are larger being greater than 10mm with negligible movement of the party wall. At the end of Period B the cumulative movements (Figure 3.3.1(c)) show a maximum of ~30mm over the AP3A / WBRT junction area rather than at the ETH piled wall.

Figure 3.3.2 shows the concurrent grouting undertaken with AP3A. The effect of the exclusion zones around the tunnel face and the grout shaft is evident due to the short length of the tunnel with reduced intensity at either end (~20l/m²) and a maximum of over 40l/m² over the centre of the tunnel. Pre-jacking for the WBRT had an intensity of about 10l/m². Comparison of Figures 3.3.1(c) and 3.3.3 confirms that additional grout jacking was undertaken in the area of maximum total settlement.

3.4. Period C: CH3 pilot & enlargement

Figure 3.4.1 Period C: (a) Volume loss settlement. (b) Change in measured settlement. (c) Total measured settlement

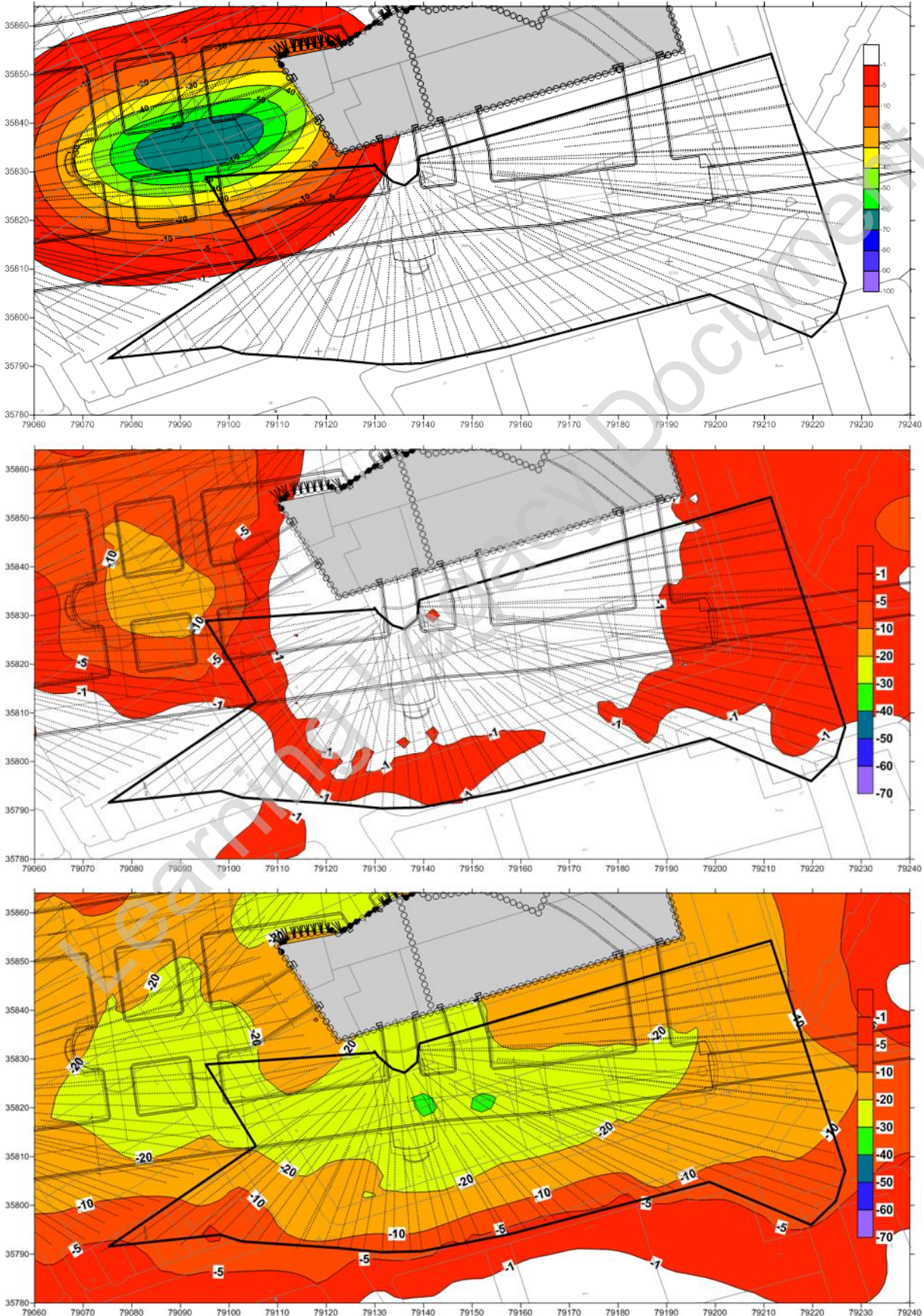


Figure 3.4.2 Period C: Distribution of grout injected from GS5: Concurrent grouting. Grout Intensity (mm).

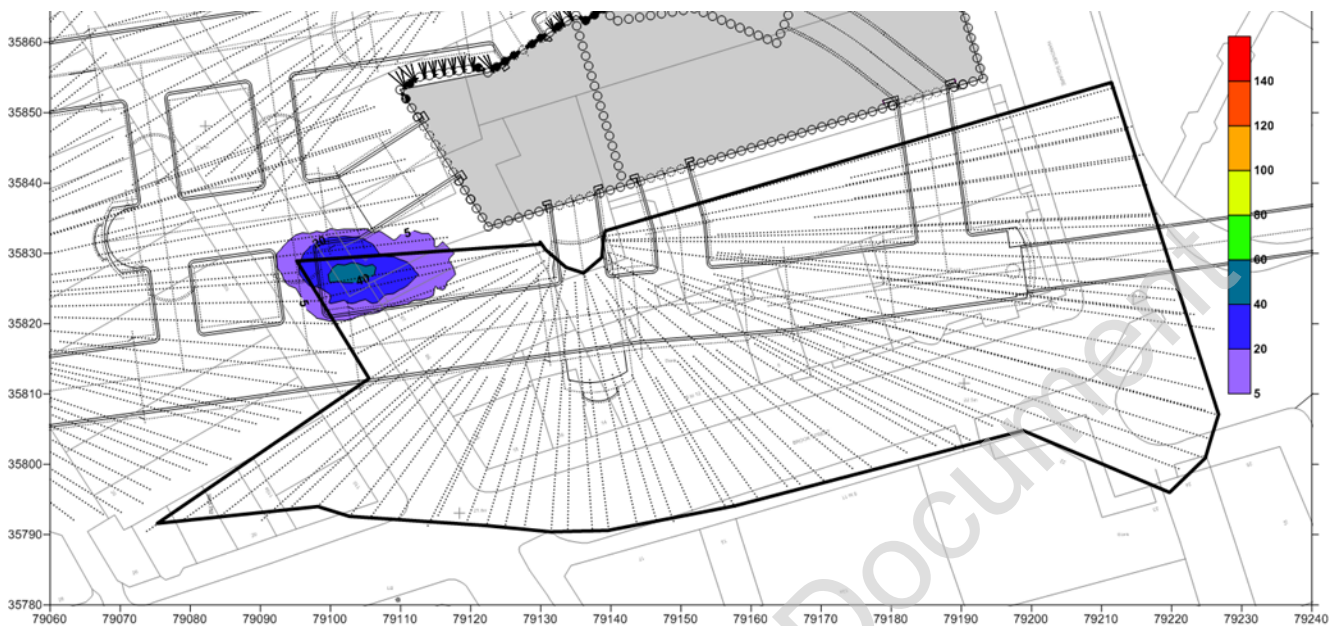


Figure 3.4.3 Period C: Distribution of grout injected from GS5: Grout jacking. Grout Intensity (mm).

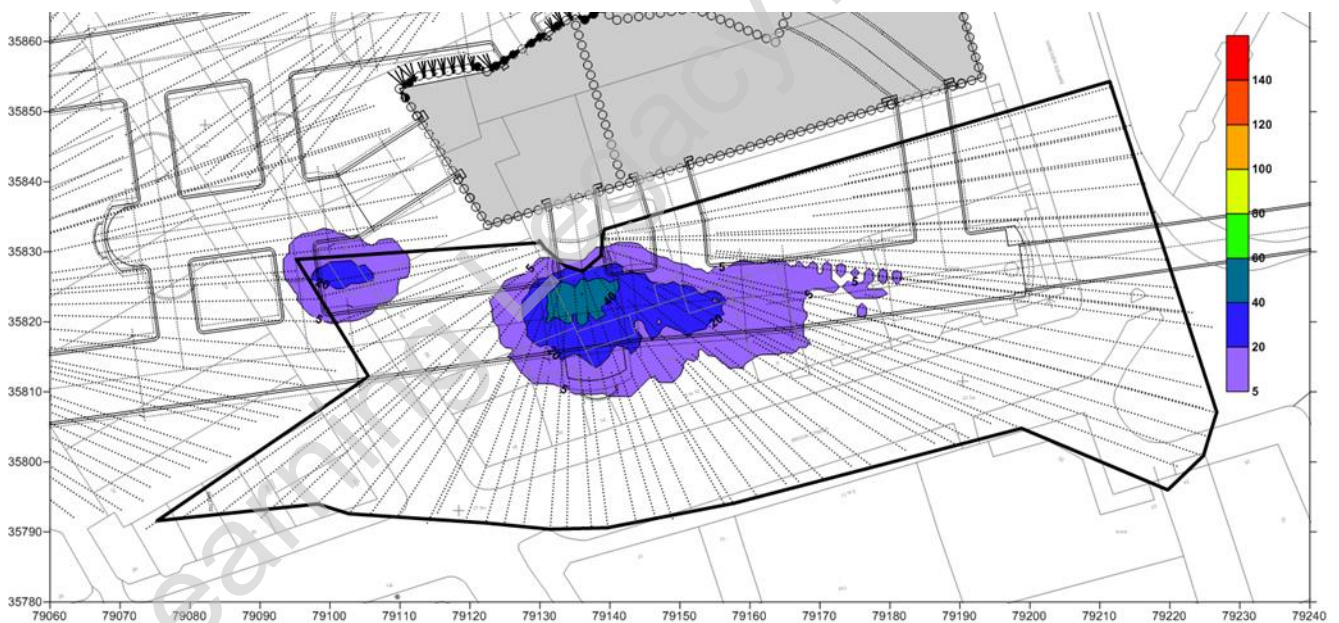


Figure 3.4.1(a) shows that over 60mm volume loss settlement was anticipated for CH3 tunnel and although the tunnel is completely outside the plan extent of the GS5 arrays up to 50mm settlement is indicated at the north west extremity.

Figure 3.4.1(b) shows the recorded settlement with a maximum of 12mm over CH3 and 9mm at the extremity of the GS5 array. The movements within the remainder of the GS5 area were less than 5mm in Period C. At the end of Period C the cumulative movements (Figure 3.4.1(c)) show that the -20mm contour covers an extended area encompassing CH3 but that the area with over 30mm settlement had reduced.

Figure 3.4.2 shows the concurrent grouting undertaken for CH3 from GS5. The majority of the grouting was undertaken from GS2. Comparison of Figures 3.4.1(c) and 3.4.3 confirms that additional grout jacking was undertaken in the area of maximum total settlement. Grout jacking was also undertaken in conjunction with GS2 for the residual settlement from CH3.

3.5. Period D: (No tunnelling)

Figure 3.5.1 Period D: (a) Volume loss settlement. (b) Change in measured settlement. (c) Total measured settlement

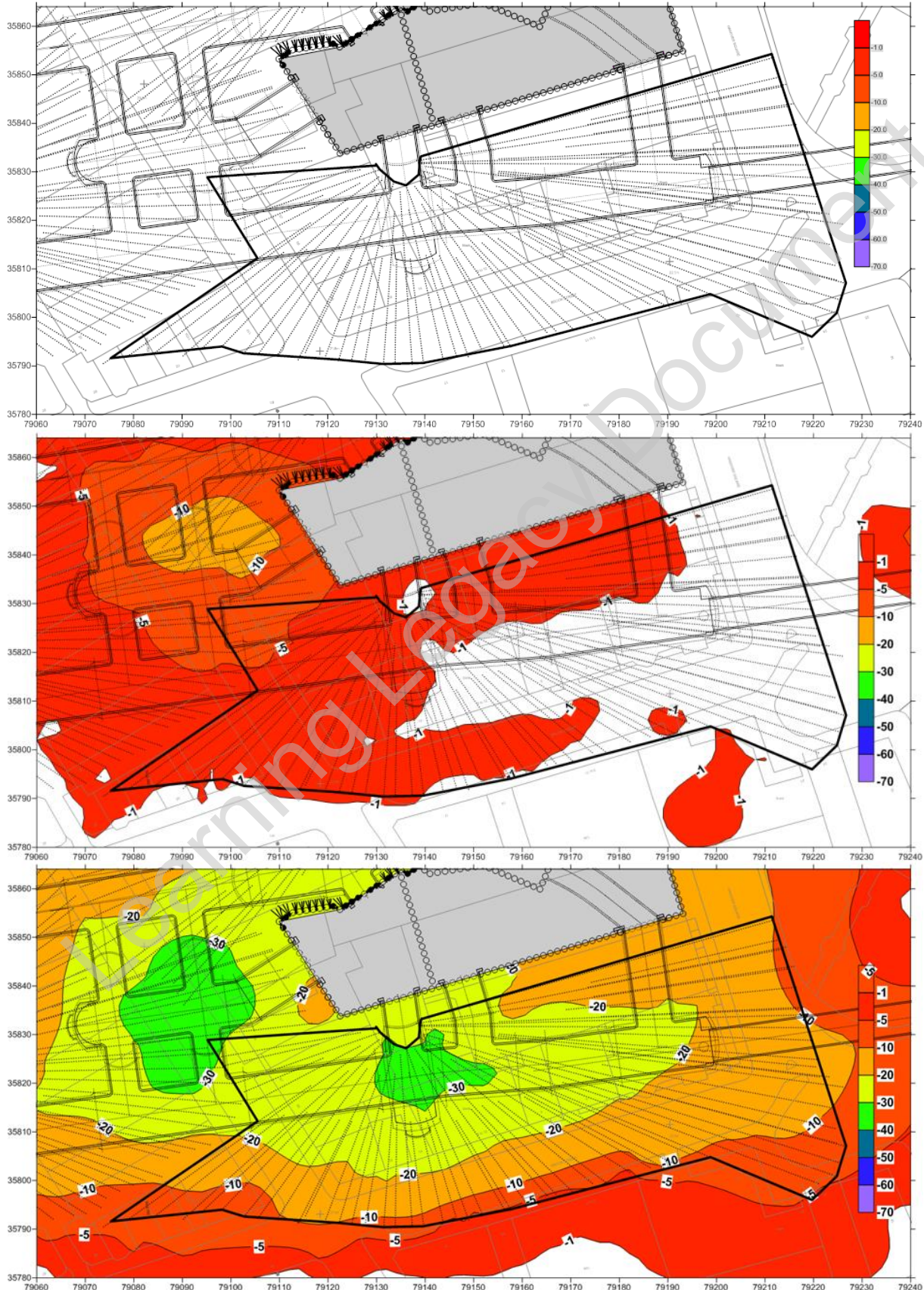
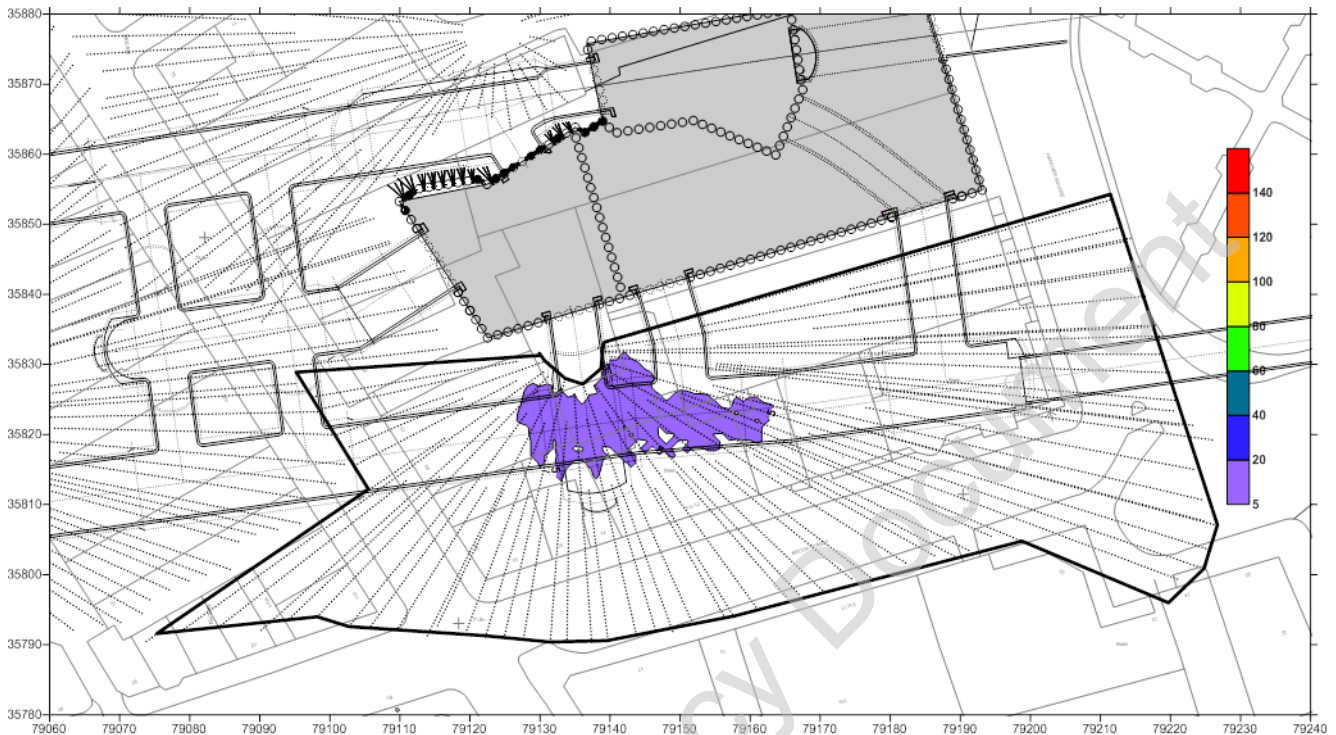


Figure 3.5.2 Period D: Distribution of grout injected from GS5: Concurrent grouting. None – no tunnelling in Period D

Figure 3.5.3 Period D: Distribution of grout injected from GS5: Grout jacking. Grout Intensity (mm).



There was no tunnelling within the extent of the arrays for GS5 in Period D. The maximum increase in settlement was at the north west extremity and amounted to about 7mm (Figure 3.5.1(b)), associated with works remote from GS5 (CP7 and CP9). Within the remainder of the area, settlement increased by less than 5mm. The extent of the zone with over 30mm total settlement (Figure 3.5.1(c)) increased somewhat despite further grout jacking in this location (Figure 3.5.3).

3.6. Period E: PTW enlargement (west of AP3A), CP10 (from PTW)

Figure 3.6.1 Period E: (a) Volume loss settlement. (b) Change in measured settlement. (c) Total measured settlement

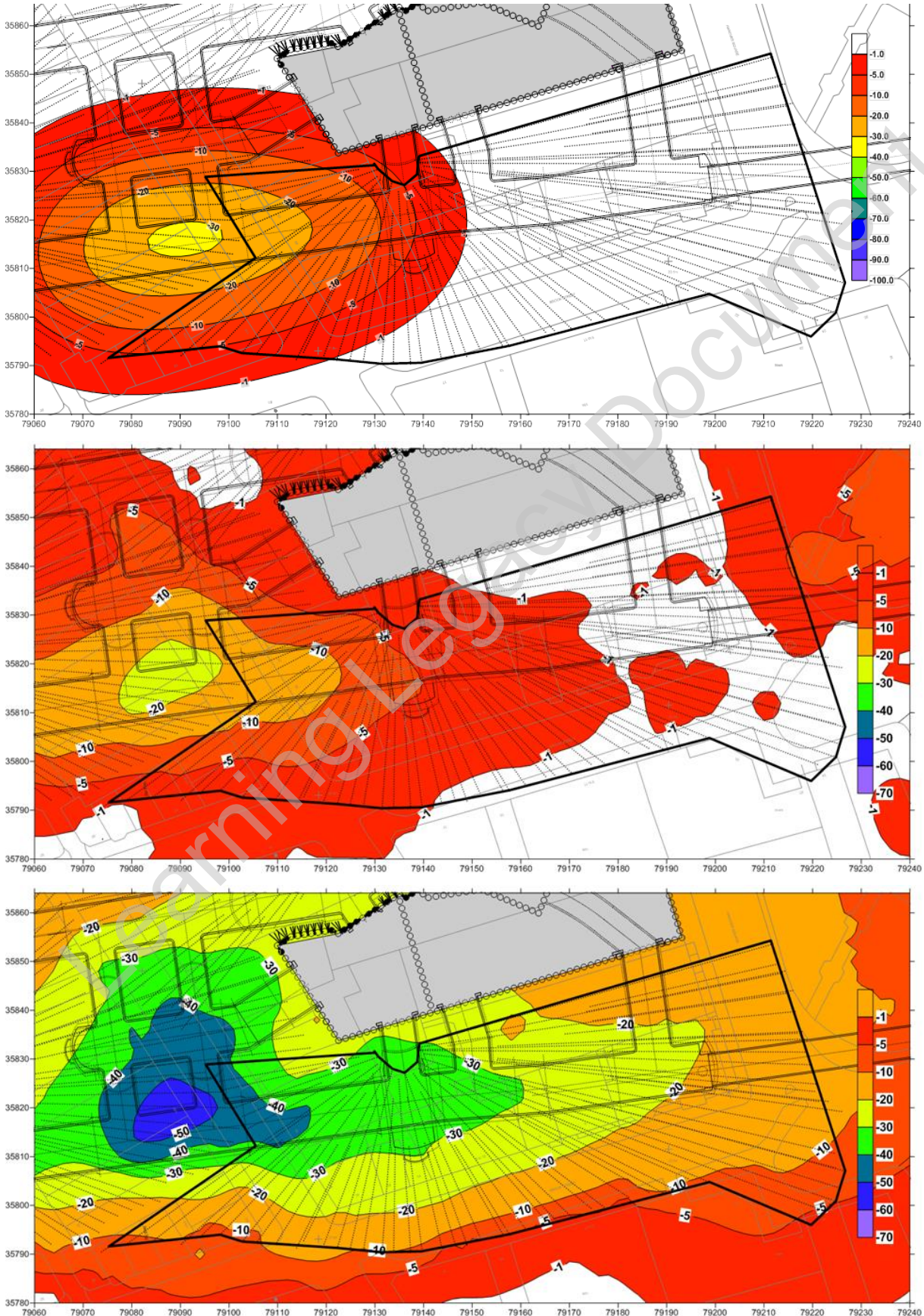
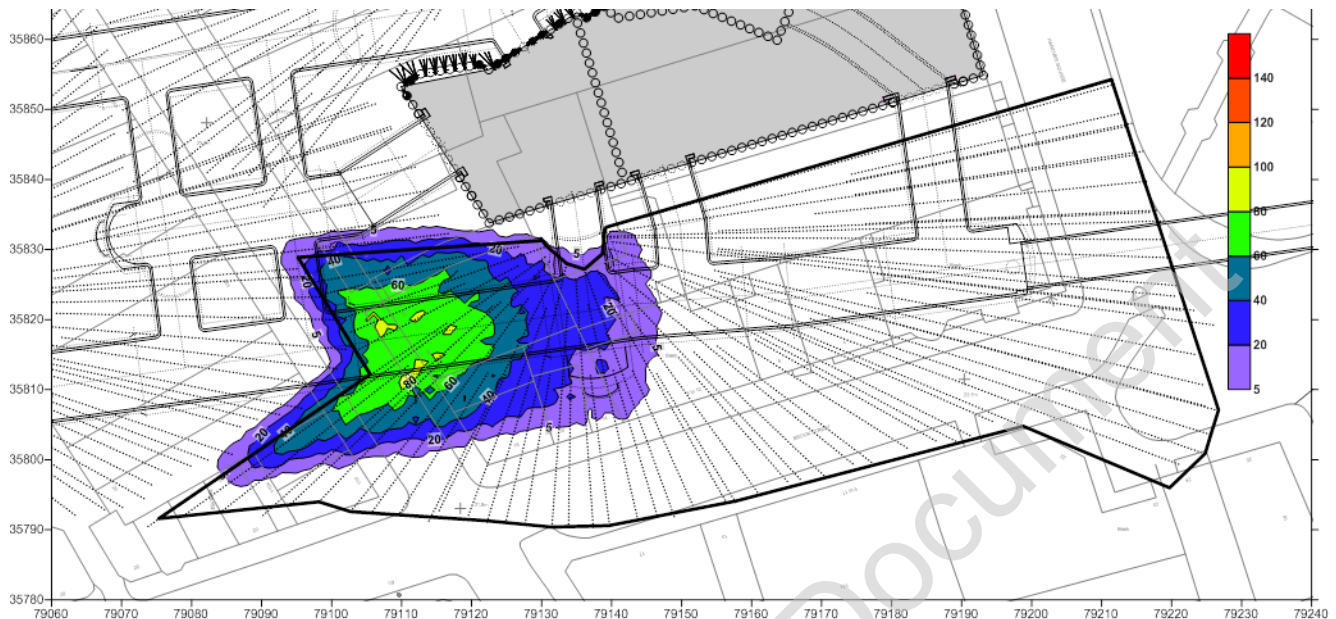


Figure 3.6.2 Period E: Distribution of grout injected from GS5: Concurrent grouting. Grout Intensity (mm).



It should be noted that Period E includes a 3 month period after the main construction activity of PTW. The stub tunnels for CP8 and CP10 are included in the volume loss contour (Figure 3.6.1(a)) but contribute a maximum of less than 5mm. The volume loss for the PTW is based on 1.25% as specified for enlargements from running tunnels. The maximum calculated volume loss settlement is just over 30mm. Excavation of the ETH by others commenced during Period E but no allowance for this is included.

The actual settlements are shown in Figure 3.6.1(b) and give a maximum of 24mm outside the extent of GS5 arrays. It is noted that the -20mm contour is more aligned with the party walls of properties on the west side of New Bond Street than with the PTW tunnel. This behaviour is examined in more detail in the report for GS2. Within the GS5 area the maximum settlement is ~17mm reducing to the east to ~5mm at AP3A. The total settlements increased significantly in Period E with a maximum approaching -50mm at the western extremity over PTW and over 30mm over the constructed length of PTW.

The concurrent grouting for PTW is illustrated in Figure 3.6.2 and shows that an intensity of over 60l/m², locally exceeding 80l/m² was injected ahead of the front exclusion zone for the breakout. No grout jacking was undertaken in Period E.

3.7. Period F: PTW (east of AP3A), VD3 & VD4

Figure 3.7.1 Period F: (a) Volume loss settlement. (b) Change in measured settlement. (c) Total measured settlement

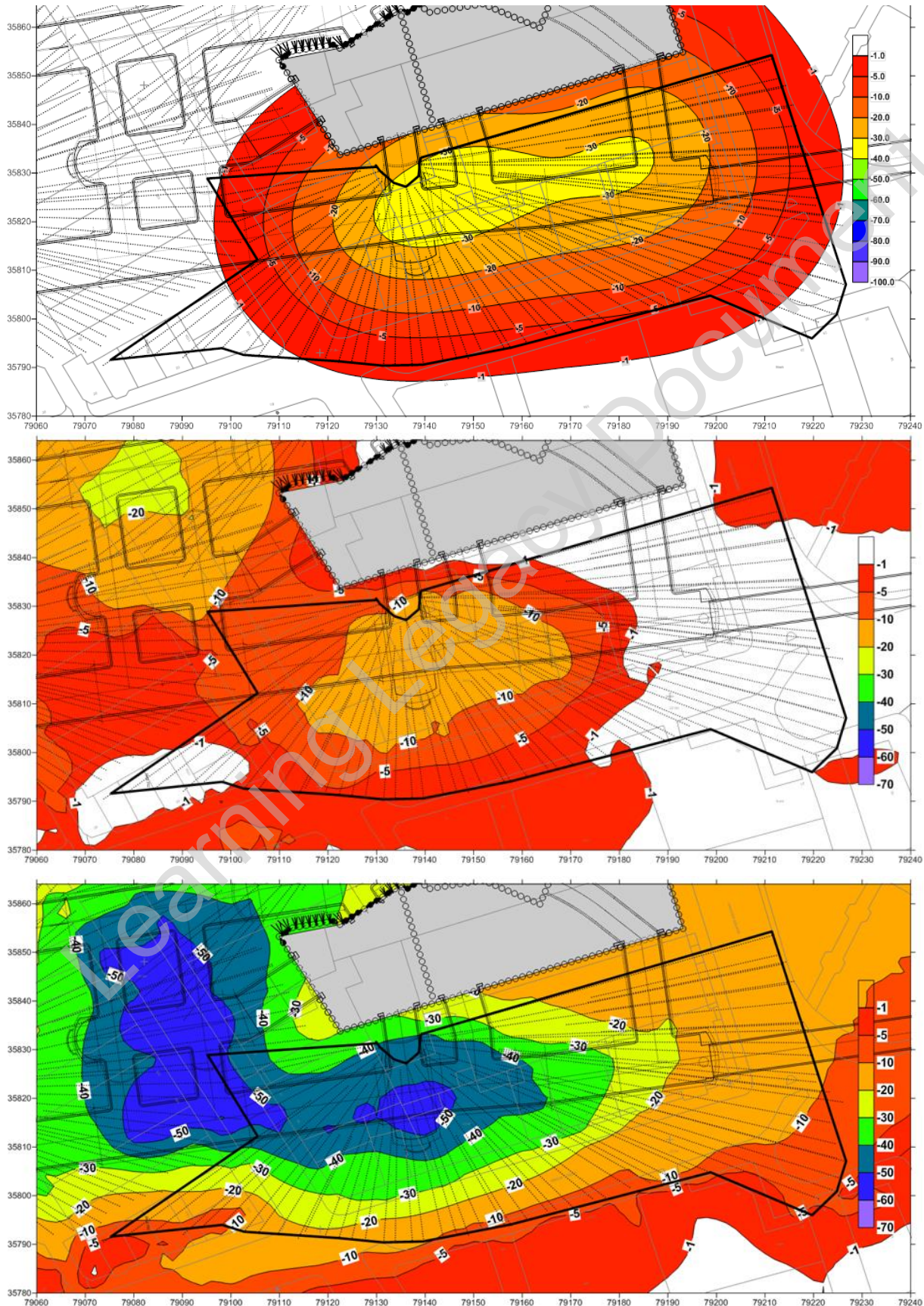


Figure 3.7.2 Period F: Distribution of grout injected from GS5: Concurrent grouting. Grout Intensity (mm).

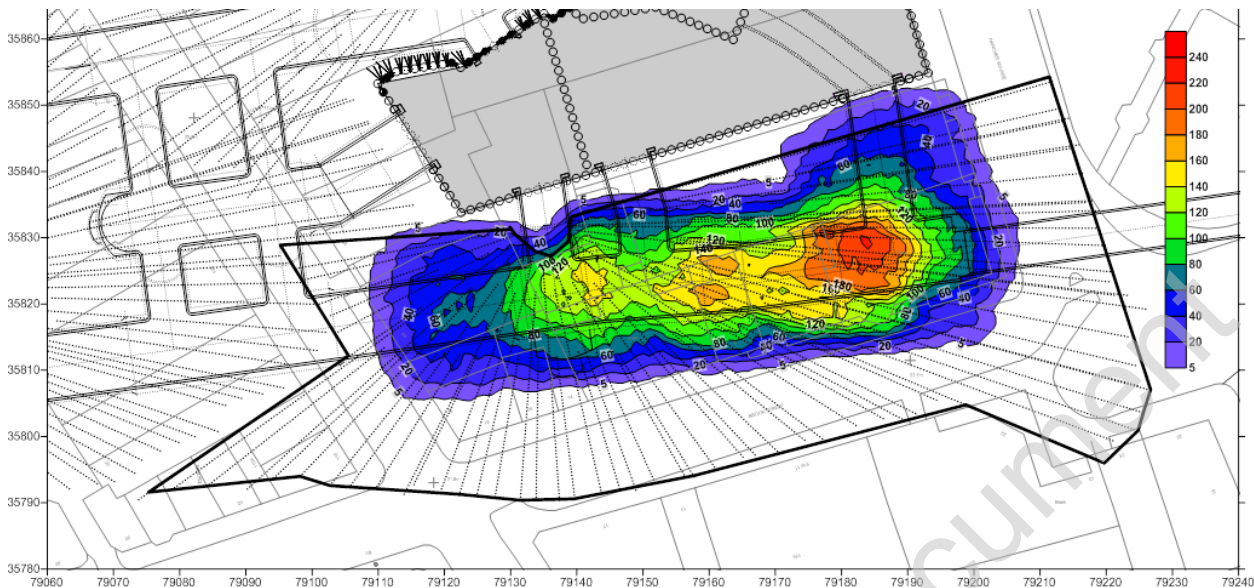
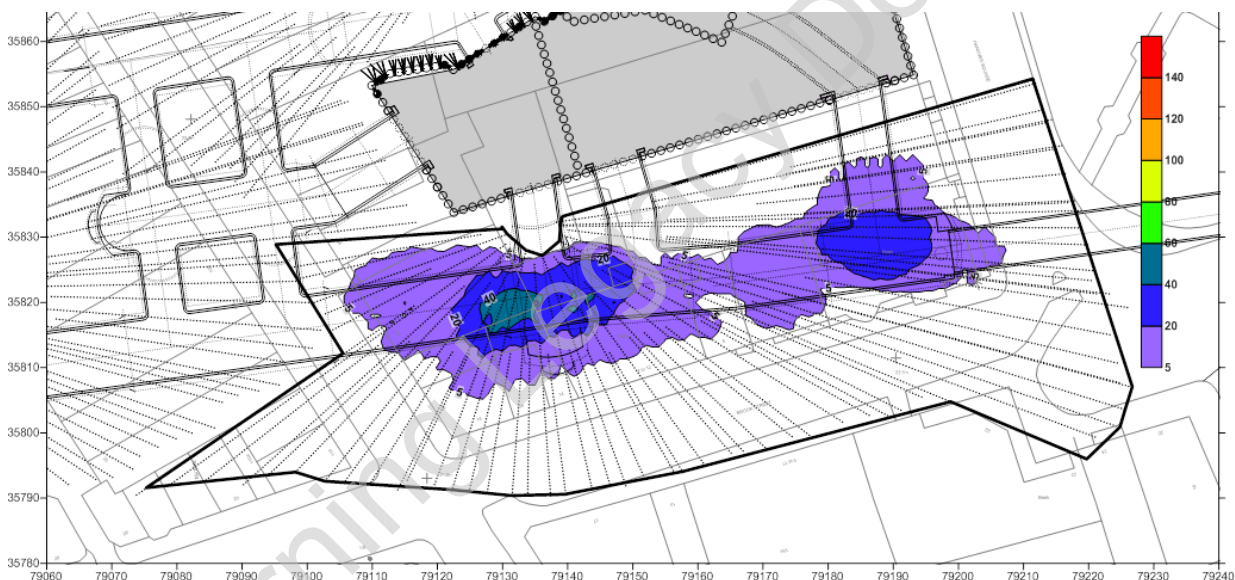


Figure 3.7.3 Period F: Distribution of grout injected from GS5: Grout jacking. Grout Intensity (mm).



It should be noted that Period F includes a period of over 4 months prior to the commencement of PTW (east). Excavation of the remaining tunnels including VD3 and VD4 was completed in two months at the end of Period F. The volume loss for the PTW is based on 1.25% as specified for enlargements for running tunnels. The maximum calculated volume loss settlement (Figure 3.7.1(a)) is just over 35mm. Excavation of the ETH by others continued and reached -2 level during Period F but no allowance for this is included in the contour. A maximum settlement of ~17mm would be calculated using the empirical method used by C122 (see Figure 3.8.2) reducing to zero at a distance of about 40m from the wall (south side of Brook Street).

The actual settlements are shown in Figure 3.7.1(b) and give a maximum of over 20mm outside the extent of GS5 arrays associated with other works. Within the GS5 area the maximum settlement is ~15mm over AP3A & VD4 junctions reducing to the east to <1mm at VD3. The total settlements increased significantly in Period F with a maximum over 50mm over the PTW / AP3A junction. It is noted that there was very small settlement along the party wall with the ETH.

The concurrent grouting for PTW and VD3 is illustrated in Figure 3.7.2 and shows that an intensity of over 140l/m², locally exceeding 200l/m² was injected ahead of the front exclusion zone for the breakout. Grout jacking was undertaken in Period F as shown in Figure 3.7.3, which targeted the area of maximum movement and over the PTW / AP3A junction area. A smaller episode was also undertaken prior to VD3 within the exclusion zone of the break-out. No grout jacking was undertaken for VD4.

3.8. Period G. No tunnelling (ETH to -3 level)

As noted in Sections 3.6 and 3.7 the ETH excavation was commenced in Period E and continued throughout Period F to -2 level. Excavation has continued since the completion of tunnelling and has reached -3 level at 10/05/15. The final excavation level (-5) is programmed for completion in August 2015. The contour plot shown in Figure 3.8.1 has been supplied by CRL (C122) as a conservative estimate of the settlement for the full depth of the ETH excluding the Masterplan and NW shafts.

Figure 3.8.2 uses the simple empirical data to estimate the magnitude of movement for the excavation completed in Periods E and F and that remaining in Period G and subsequently. The “final excavation” curve is taken from the contour in Figure 3.8.1. The “excavation -2 level” curve utilises the assumptions that the movements and the extent of movement are both proportional to the excavation depth. A maximum of about 15mm is shown at the wall for both stages, but the deeper part of the excavation produces a much wider flatter settlement trough.

Figure 3.8.1 Period G: ETH C122 contour of settlement for ETH excavation (excluding MasterPlan & North-

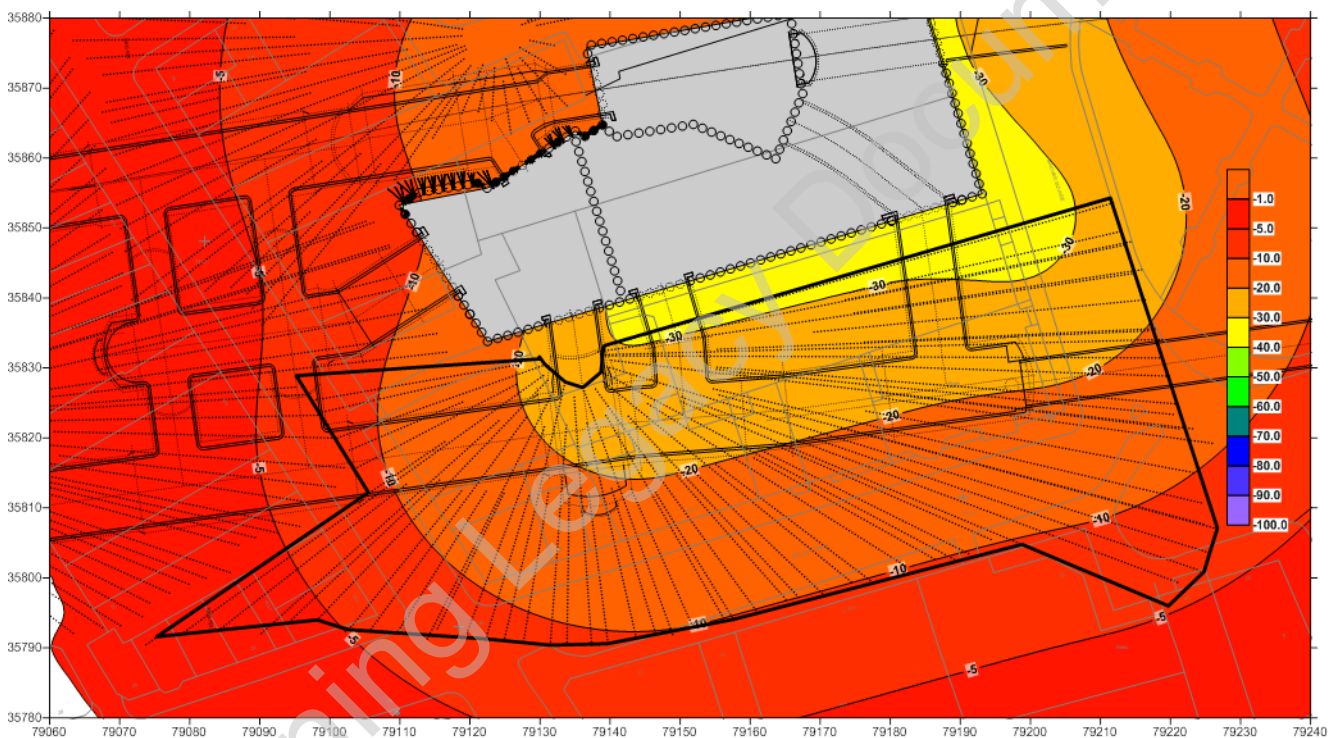
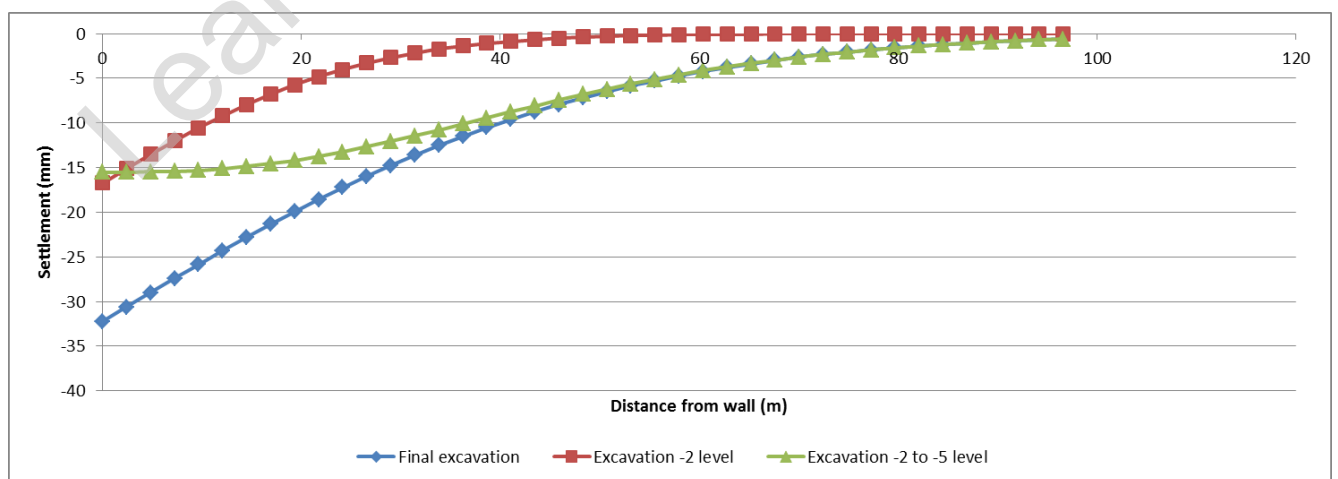


Figure 3.8.2 Period G: Estimate of settlement for ETH excavation post tunnelling



Waterproofing and secondary lining work within the tunnels has been completed within the GS5 area in Period G. Figure 3.8.3 gives the dates for individual sections of tunnel and indicates that the work was completed by the end of 2014.

Figure 3.8.3 Period G: Progress of tunnel waterproofing and secondary lining works

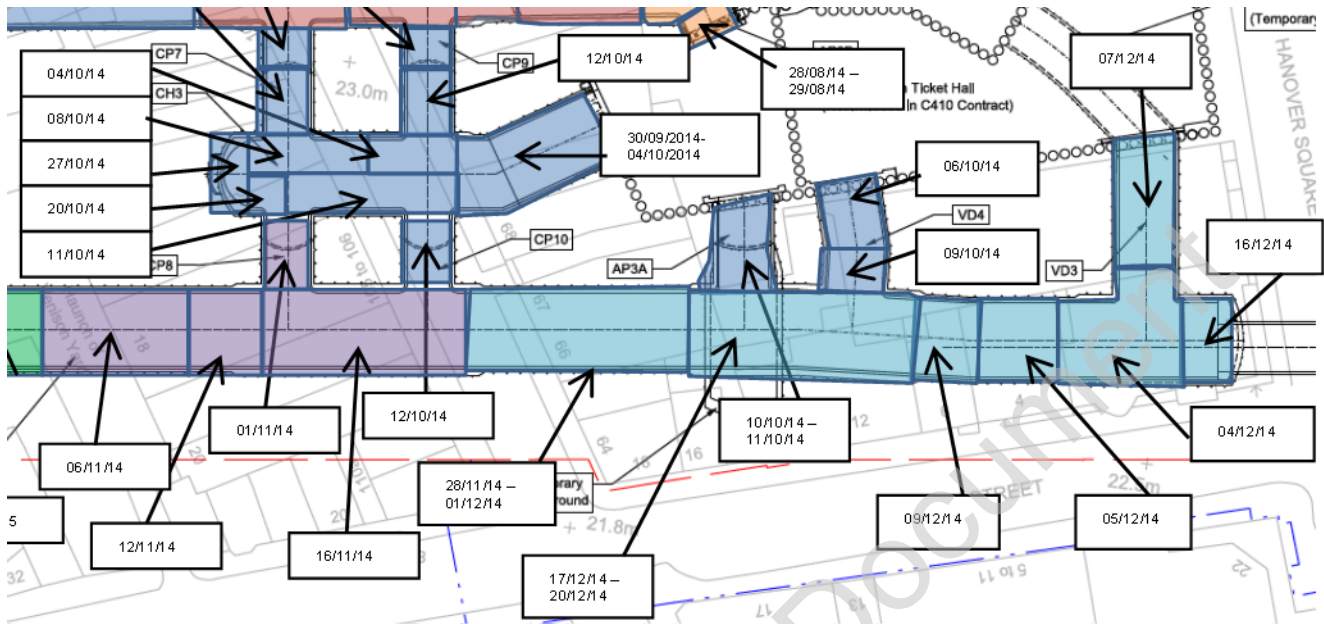


Figure 3.8.4(a) shows an increase of settlement of up to 20mm during the 8½ months since the completion of tunnelling from a combination of consolidation settlement and the on-going excavation work within the ETH. The maximum movement is located above the PTW / VD3 junction. It is again noteworthy that settlement of the party wall with the ETH is negligible.

Figure 3.8.4(b) shows the change in settlement over the last 3 months: this shows a uniform increase of 3mm over most of the area reducing to 1mm at the south of Brook Street and on the ETH party wall.

The total settlement at the end of Period G is shown on Figure 3.8.4(c) (refer to Section 3.1).

There was no concurrent grouting in Period G since tunnelling had been completed. An episode of grout jacking was undertaken at the PTW / VD3 junction where the maximum rate of settlement was observed at the beginning of Period G.

Figure 3.8.4 Period G: (a) Observed settlement in Period G; (b) change over last 3 months; (c) Total settlement

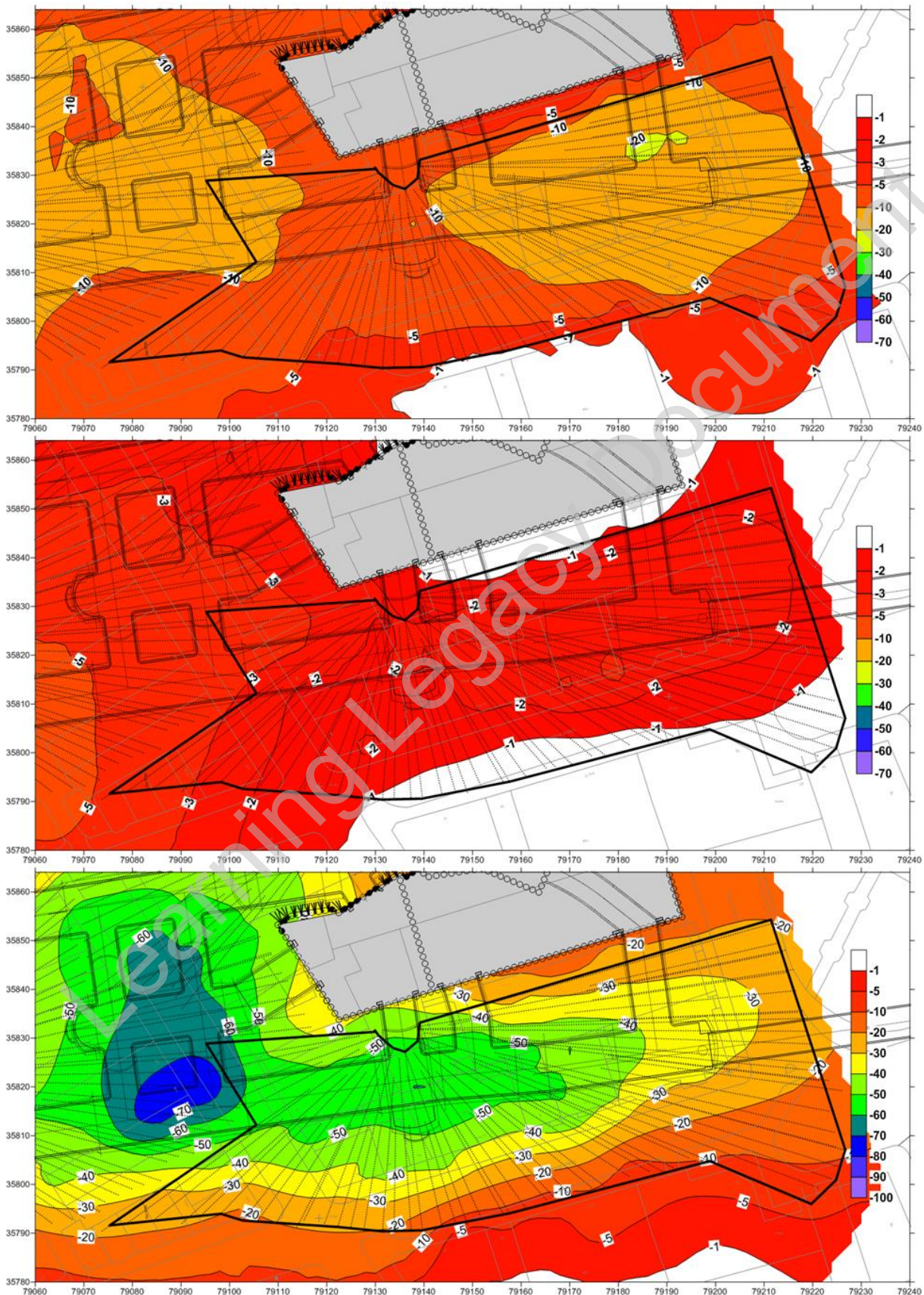
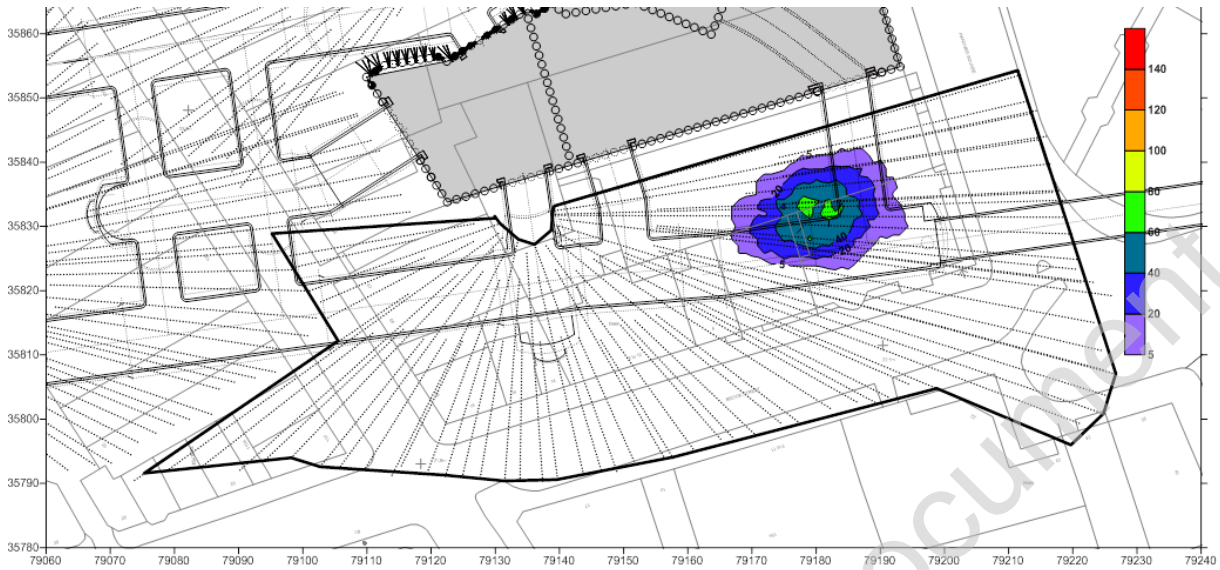


Figure 3.8.5 Period G: Distribution of grout injected from GS5: Grout jacking. Grout Intensity (mm).



Learning Legacy Document

4. BUILDING SETTLEMENT AND SLOPES

4.1. Slope triggers

The locations where slope triggers have been exceeded are shown for BRE monitoring of building facades and HLC monitoring of party walls on Figure 4.1. A larger version of Figure 4.1 is included in Appendix B. Details are given in Table 4.1.

Slope triggers are generally as follows:

- GREEN 1:1250 0.8mm/m
- AMBER 1:1000 1.0mm/m
- RED 1:500 2.0mm/m

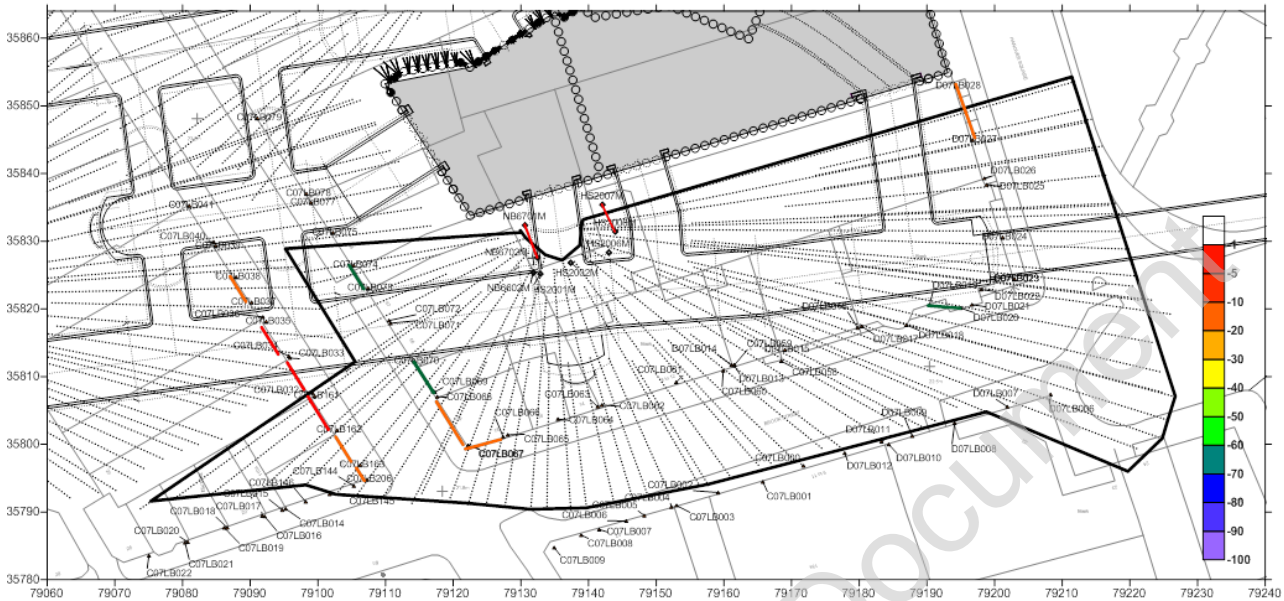
Within the GS5 area exceptions are made for the RED trigger which is 1:800 (1.25mm/m) for the following buildings:

- 20 Hanover Square,
- 21 Hanover Square
- 67-68 New Bond Street
- 69 New Bond Street

Table 5.1 Details of Amber and Red trigger breaches on BRE & HLC

| BUILDING FACADES & PARTY WALLS | | Comment | Date exceeded | Maximum (mm/m) | Current (mm/m) |
|--------------------------------|-------------|--|---------------|----------------|----------------|
| New Bond Street - West | | | | | |
| C07LB038 - C07LB037 | Amber | Borderline latest Green | 23/12/13 | 1.23 | 0.91 |
| C07LB035 - C07LB034 | Red | Stable ± 0.1 over 12 months | 02/12/13 | 2.76 | 2.72 |
| C07LB033 - C07LB032 | Red | Latest reading high: Mean $\sim 2.0 \pm 0.1$ over 14 months | 08/05/14 | 2.20 | 2.20 |
| C07LB161 - C07LB162 | Red | Latest reading high: Mean $\sim 1.9 \pm 0.1$ over 11 months | 19/02/15 | 2.05 | 2.05 |
| C07LB162 - C07LB163 | Amber | Increasing at reducing rate | 17/06/14 | 1.25 | 1.25 |
| C07LB163 - C07LB206 | Amber | Only 2 outliers > 1.0 : Green | 29/07/14 | 1.08 | 0.84 |
| New Bond Street - East | | | | | |
| C07LB067 - C07LB068 | Amber | Increasing at reducing rate | 05/01/14 | 1.62 | 1.62 |
| C07LB069 - C07LB070 | Amber | Reduced in Period F; 4 of 5 readings in Period G below Green | 24/11/13 | 1.92 | 1.01 |
| Brook Street - North | | | | | |
| C07LB067 - C07LB066 | Amber | Stable ± 0.1 over 6 months | 15/07/13 | 1.39 | 1.16 |
| Hanover Square - West | | | | | |
| D07LB027 - D07LB028 | Amber | Increasing at reducing rate | 13/11/14 | 1.16 | 1.16 |
| Dering Yard | | | | | |
| NB6702M – NB6701M | Red (1:800) | Stable ± 0.1 over 6 months | 31/07/14 | 1.68 | 1.63 |
| HS2007M – HS2008M | Red (1:800) | Continuing to increase gradually due to party wall support off ETH piles | 12/07/14 | 2.22 | 2.22 |

Figure 4.1. Locations where building slope triggers have been exceeded.

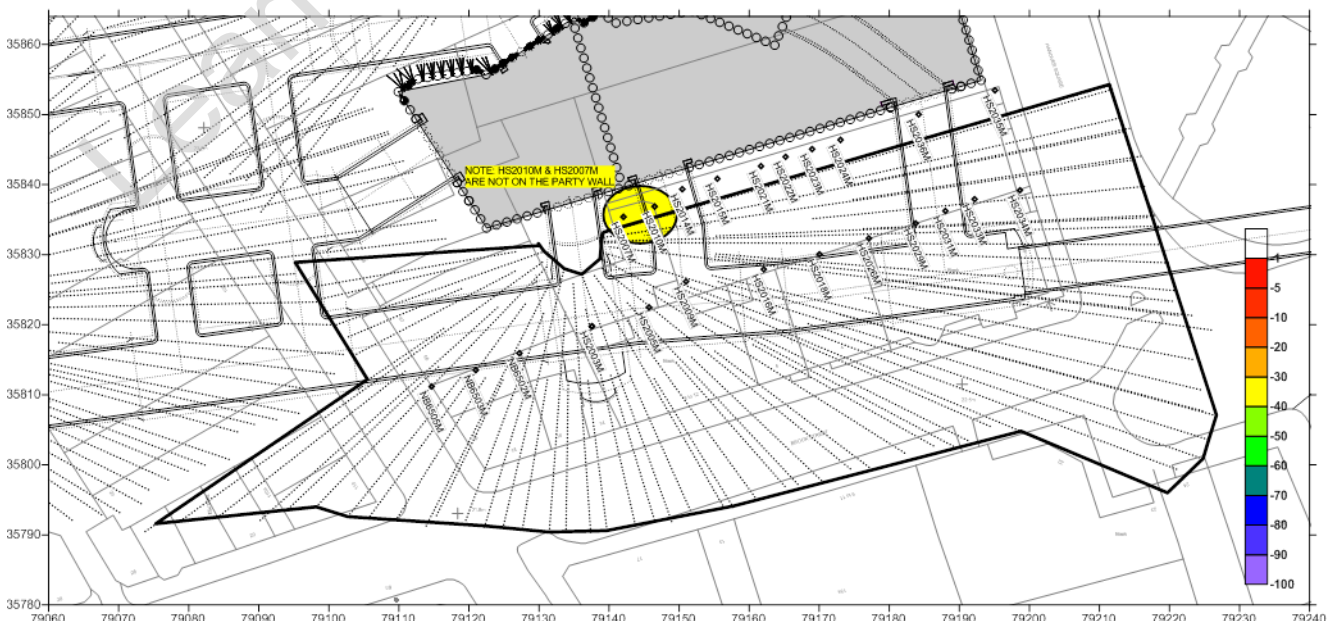


BRE monitoring data from the facades within the footprint of GS 5 are presented in the following sections, namely New Bond Street east and west, Brook Street north and south and the front façade of 20 and 21 Hanover Square. The plots presented for each comprise:

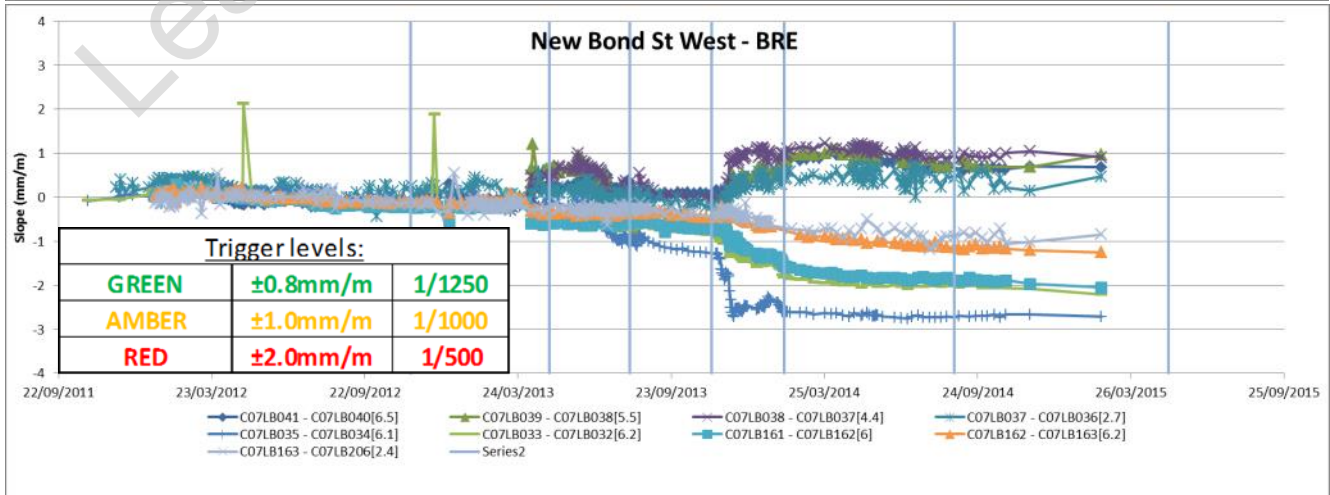
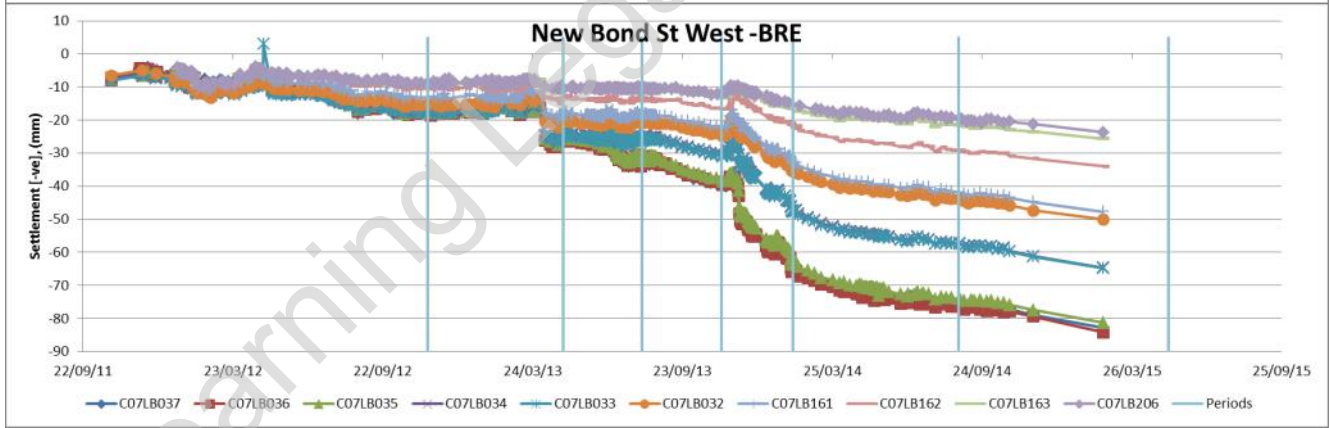
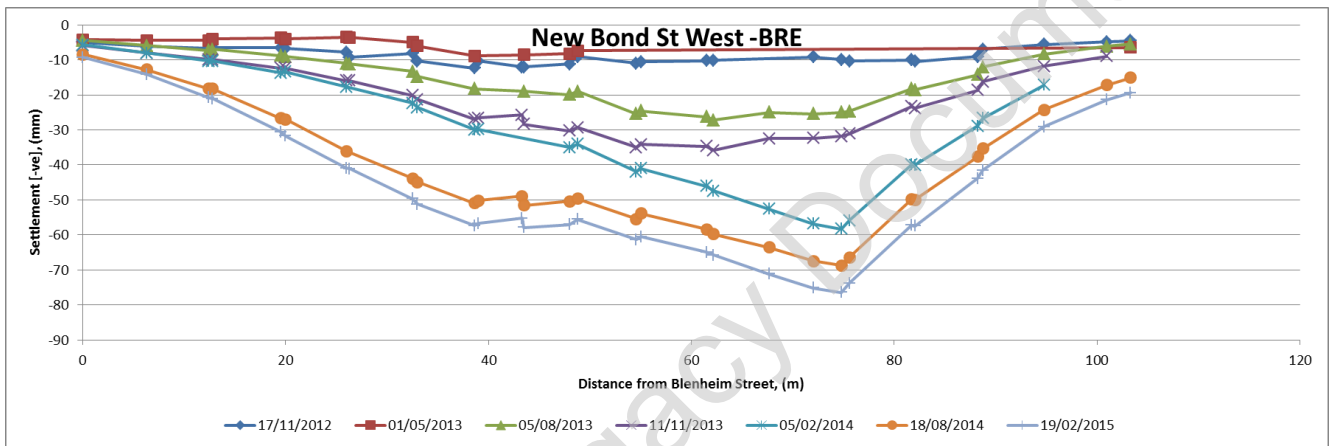
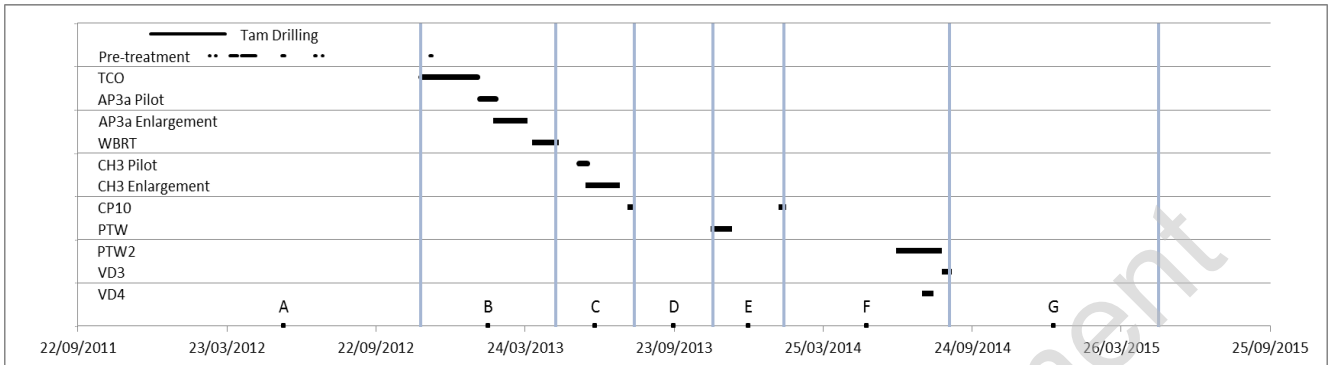
1. Summary of tunnel construction and associated construction periods
2. Time settlement history
3. Settlement profile plots with series as close to the end of each construction period as is available
4. Time slope history over the full construction period with the distances between the points in metres shown in the legend in square brackets
5. Time slope history since the completion of tunnelling i.e. construction period G

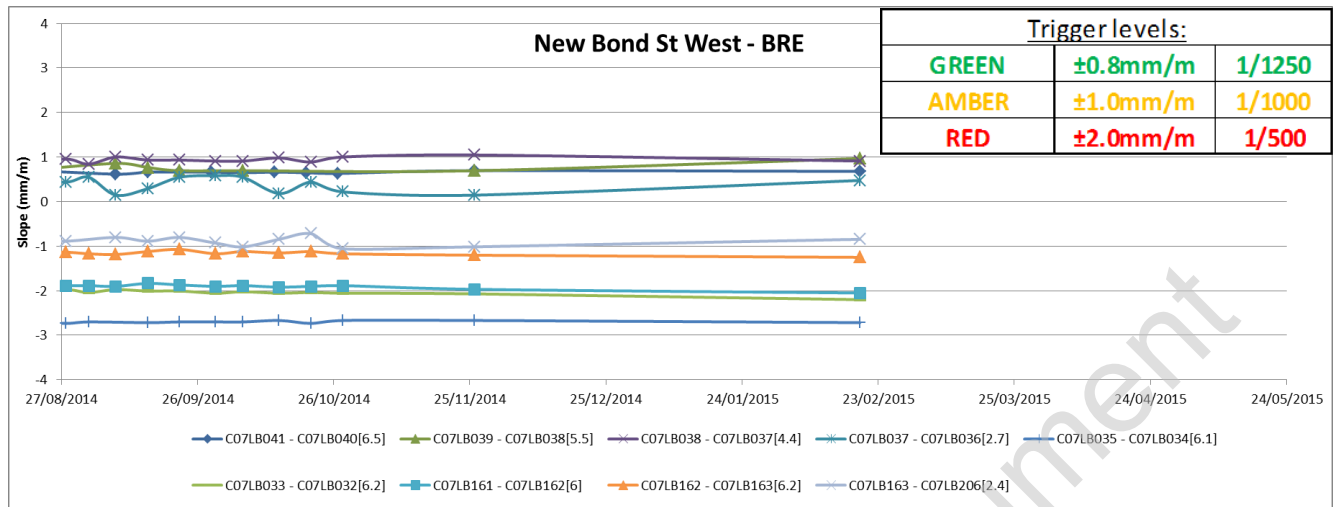
HLC data is used where no BRE data is available; namely, Dering Yard, the party wall between 20 Hanover Square and the ETH and the south party wall between 20 Hanover Square and the properties on the north side of Brook Street. The locations of the HLC on party walls are shown on Figure 4.2. All HLC data presented is based on daily means.

Figure 4.2. Locations of HLC on party walls



4.2. New Bond Street - West

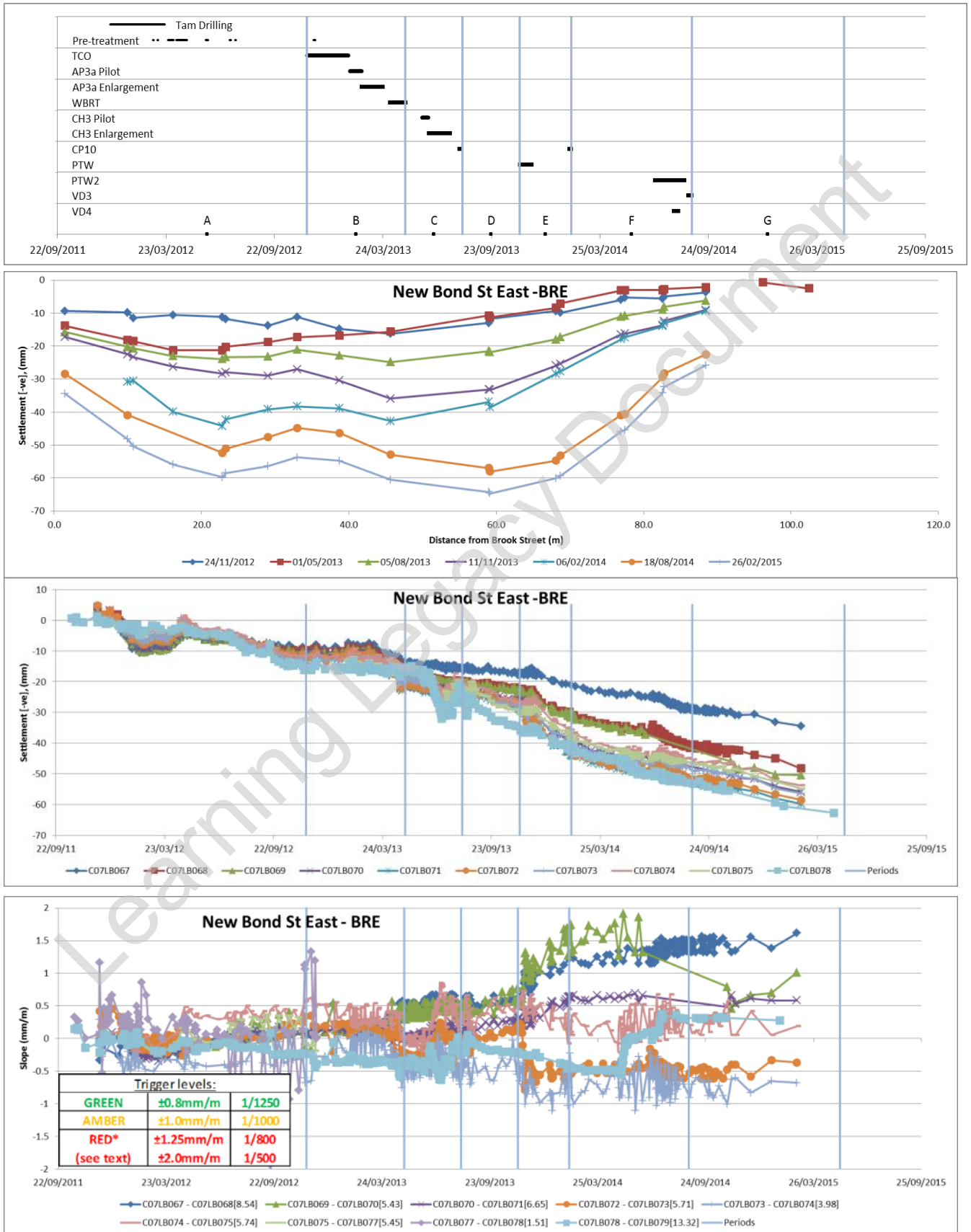


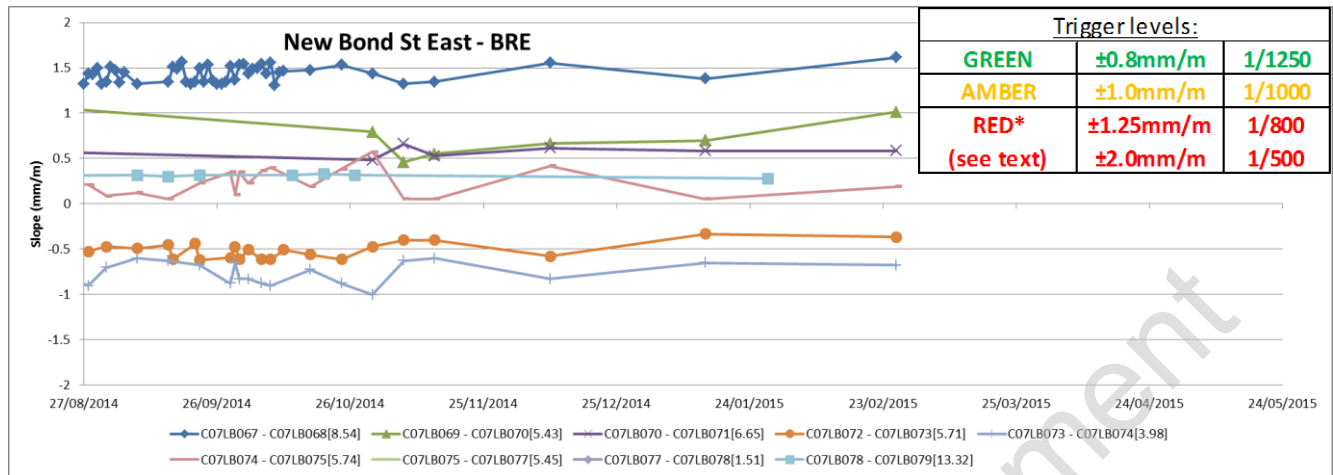


The following points are noted:

- Only the most southerly part of the façade is within the GS5 array (from distance 90m): data from points at distance 75m and greater are presented.
- The key events are the WBRT in Period B; CH3 enlargement in Period C and PTW in Period E. It is noted that at the end of these activities the settlement was less than 50mm and that there has been 30mm consolidation settlement over a period of 17 months.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G there has been a small increase albeit confirmed by few sets of readings. ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken in Period G.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- The maximum settlement is about 15m to the north of the GS5 arrays and is within the GS2 area and this has driven the slope triggers to the south of this location. There is a deflection ratio trigger at a distance of 75m (~1:1500) but this is outside the area of GS5 and will be discussed further in the GS2 report.

4.3. New Bond Street - East

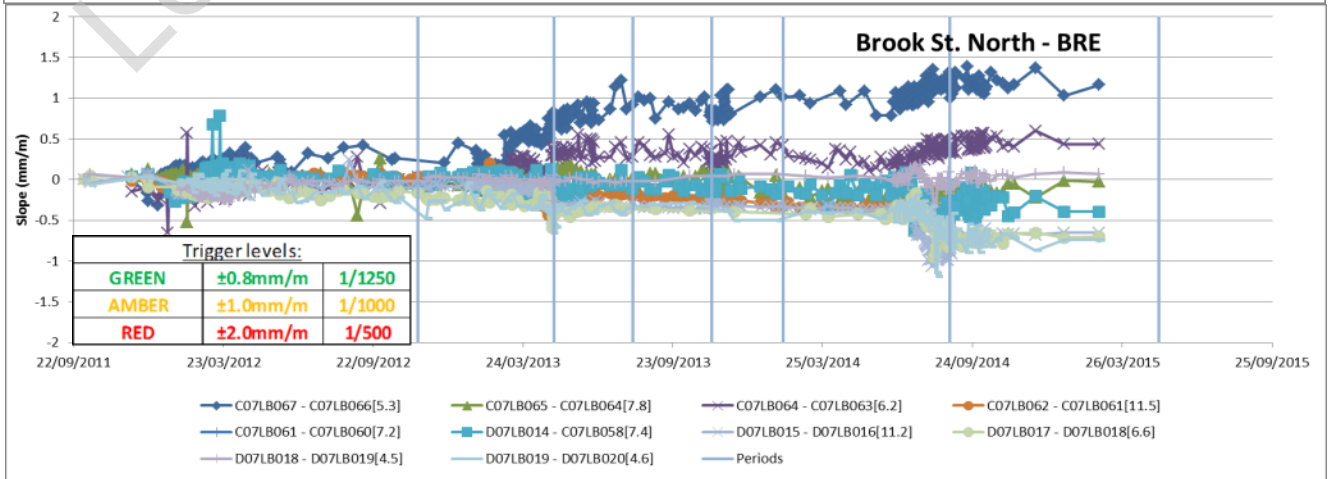
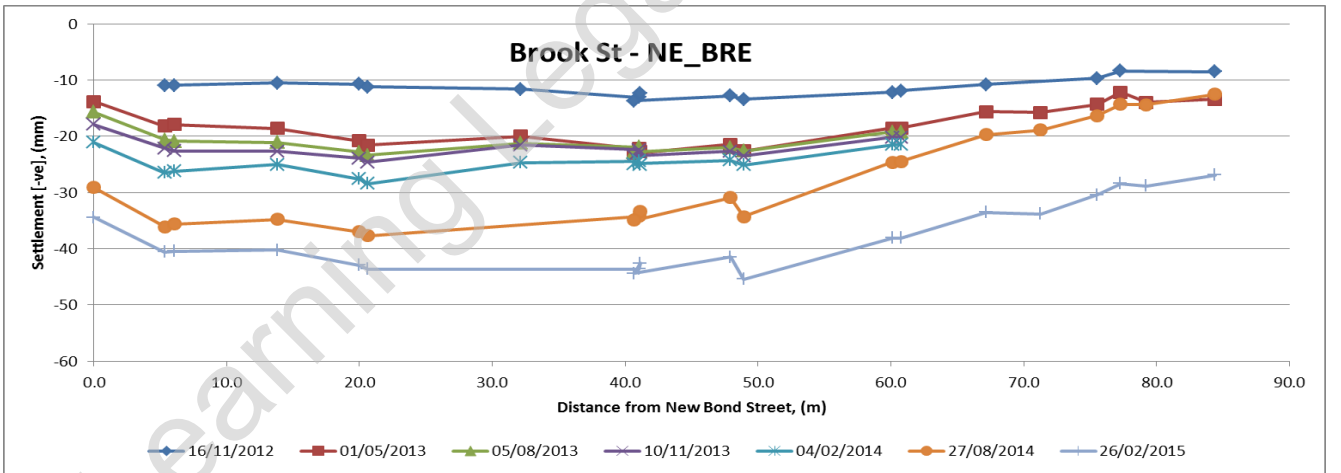
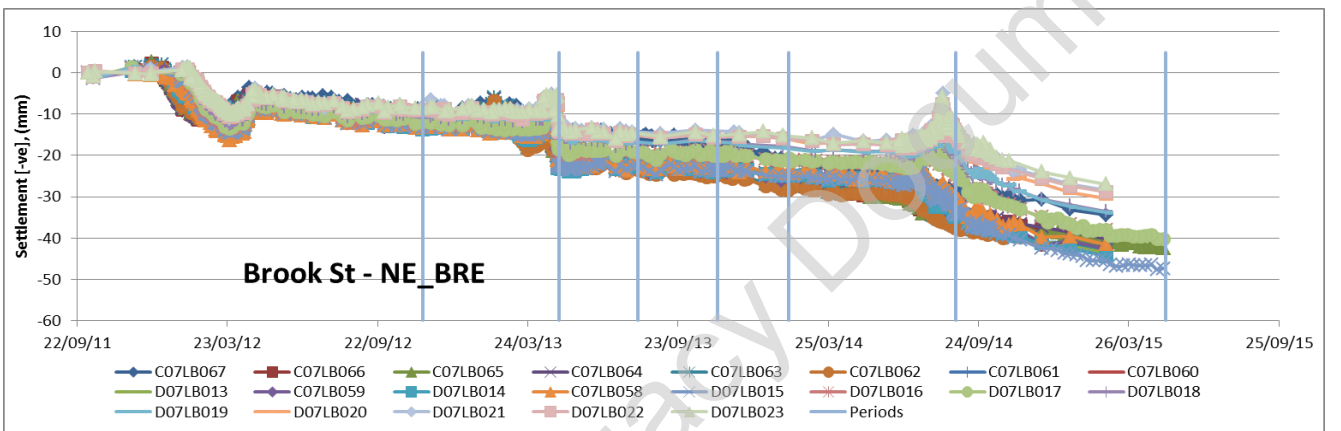
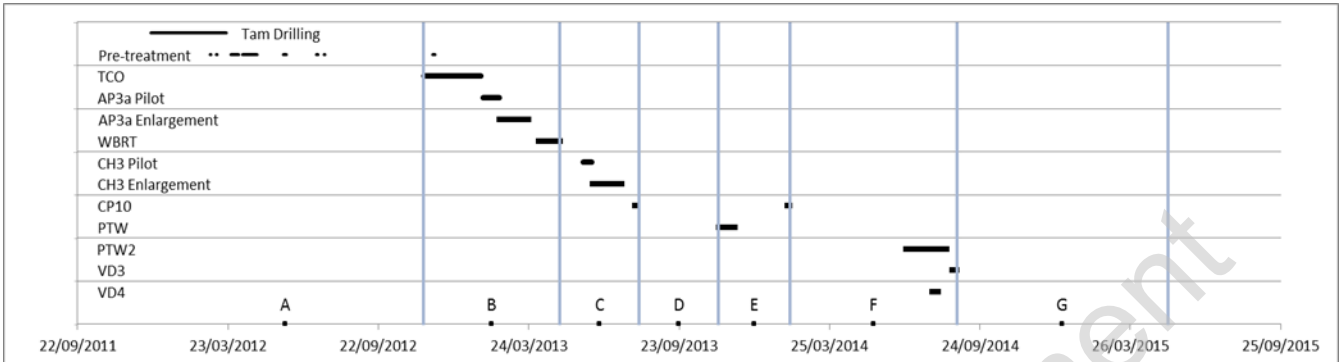


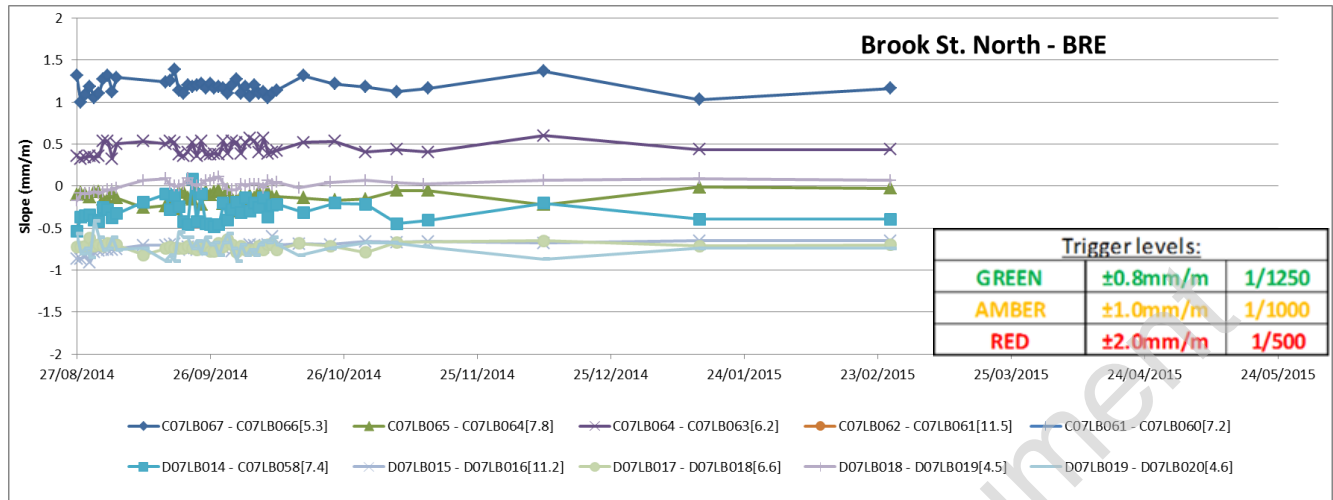


The following points are noted:

- Only the most southerly part of the façade is within the GS5 array (to distance 35m): data from points at distances up to 45m are presented.
- The key events are the WBRT in Period B; CH3 enlargement in Period C and PTW in Period E. It is noted that at the end of these activities the settlement was less than 40mm and that there has been 25mm consolidation settlement over a period of 17 months.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G there has been a more or less constant rate of increase. ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken in Period G.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- The only Amber slope trigger is on the corner with Brook Street as a result of the corner of the building settling less than neighbouring points. By inspection, there are no deflection ratio triggers.

4.4. Brook Street - North

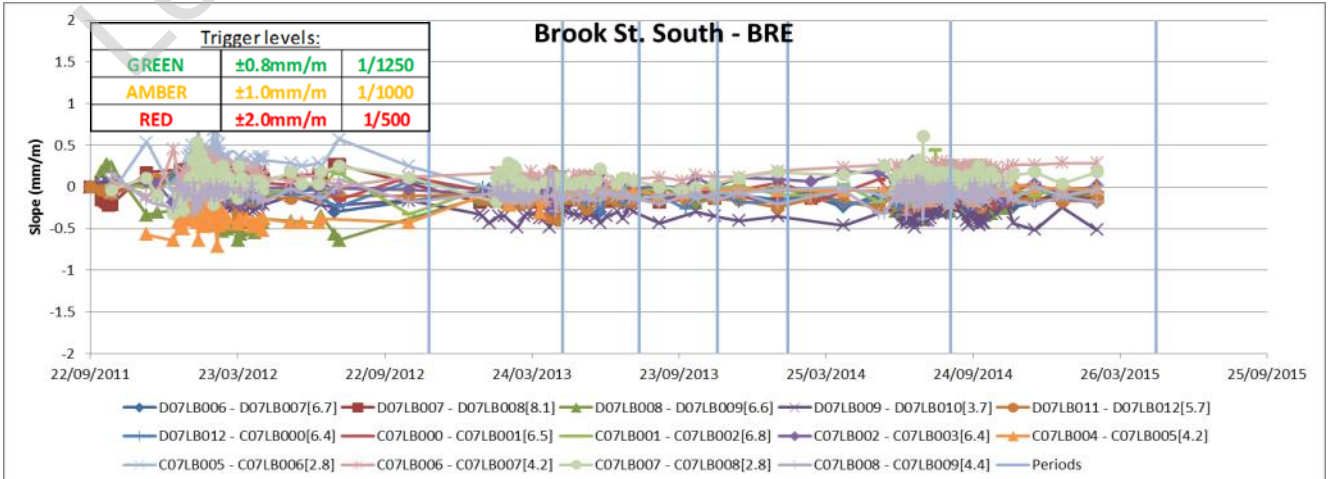
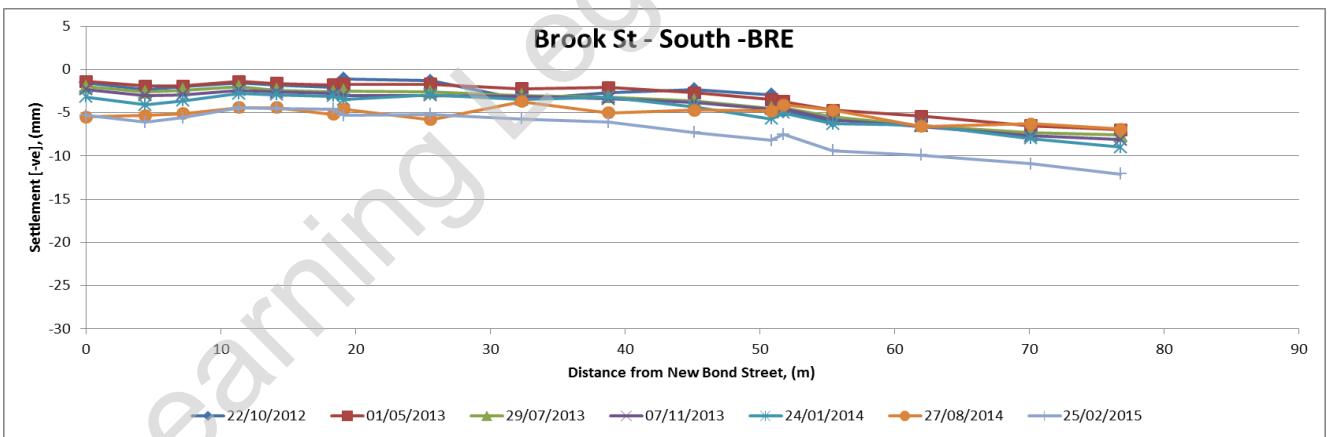
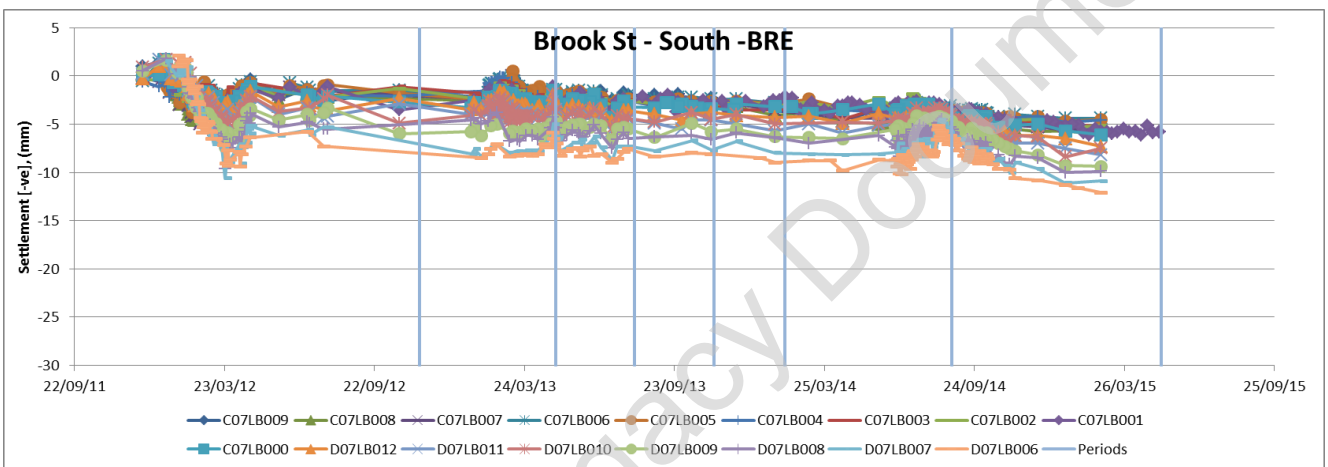
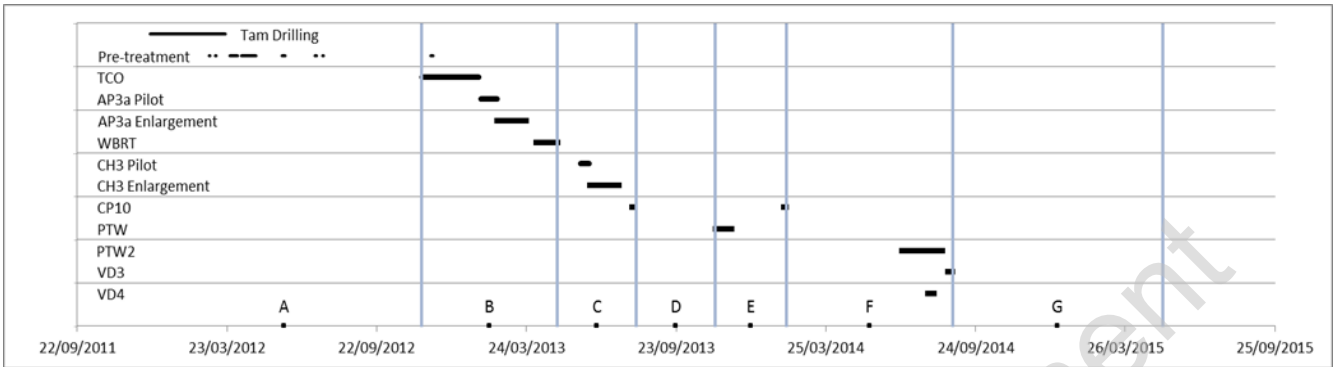


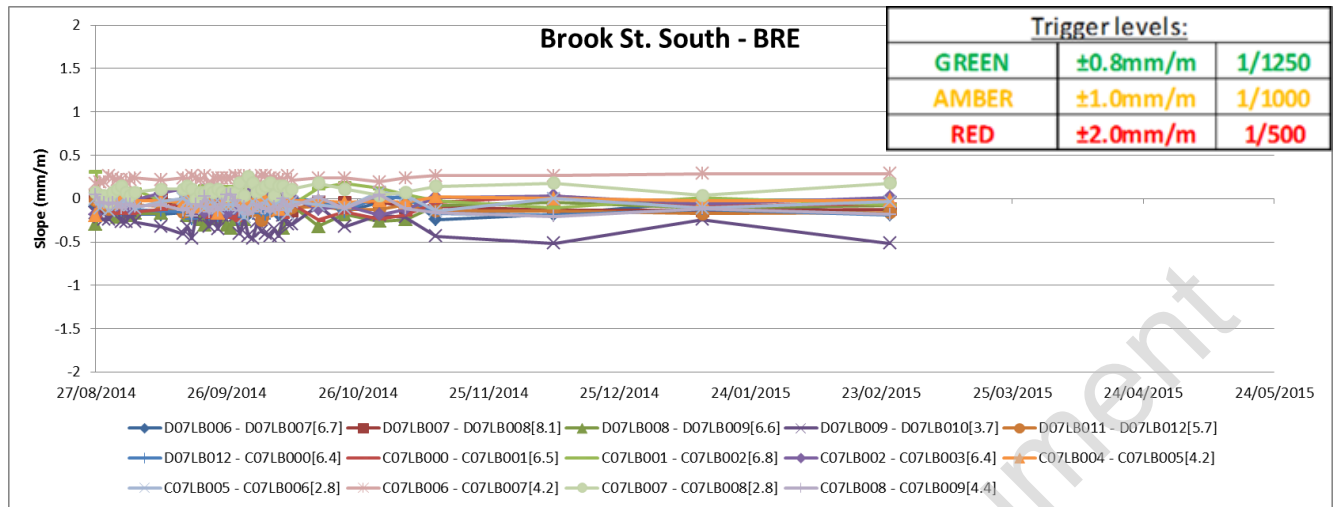


The following points are noted:

- The full length of the façade on the north of Brook Street is within the GS5 array: data from all points at distances are presented.
- The key events are the WBRT in Period B and PTW in Period E. It is noted that at the end of these activities the settlement was around 40mm and that there has been less than 10mm consolidation settlement over a period of 8 months.
- The rate of post construction settlement is continuously reducing through Period G although the ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes and that overall the differential settlement along the façade is reducing.
- The only Amber slope trigger is on the corner with New Bond Street as a result of the corner of the building settling less than neighbouring points. By inspection, there are no deflection ratio triggers.

4.5. Brook Street - South

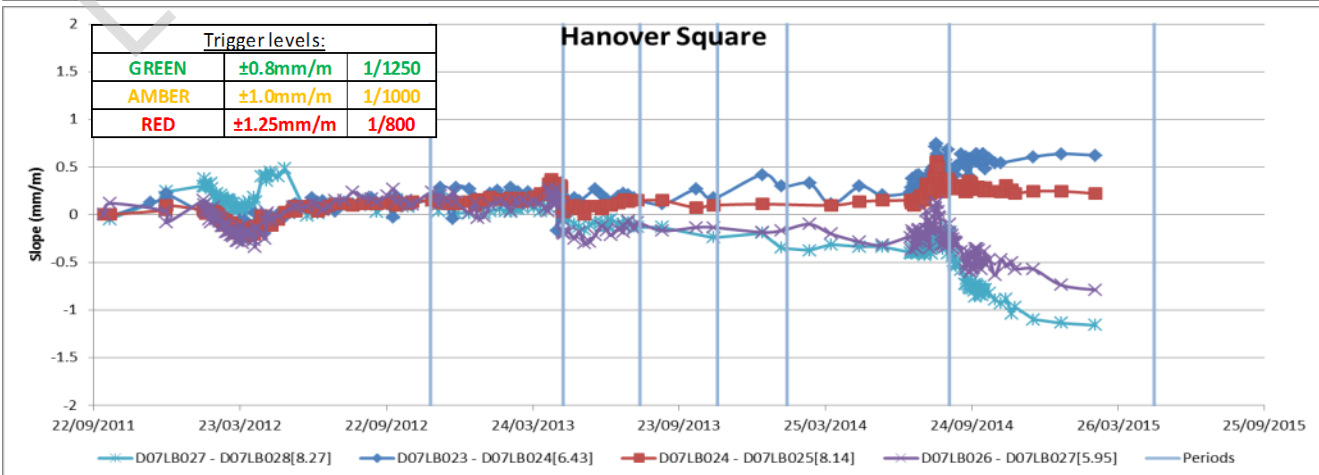
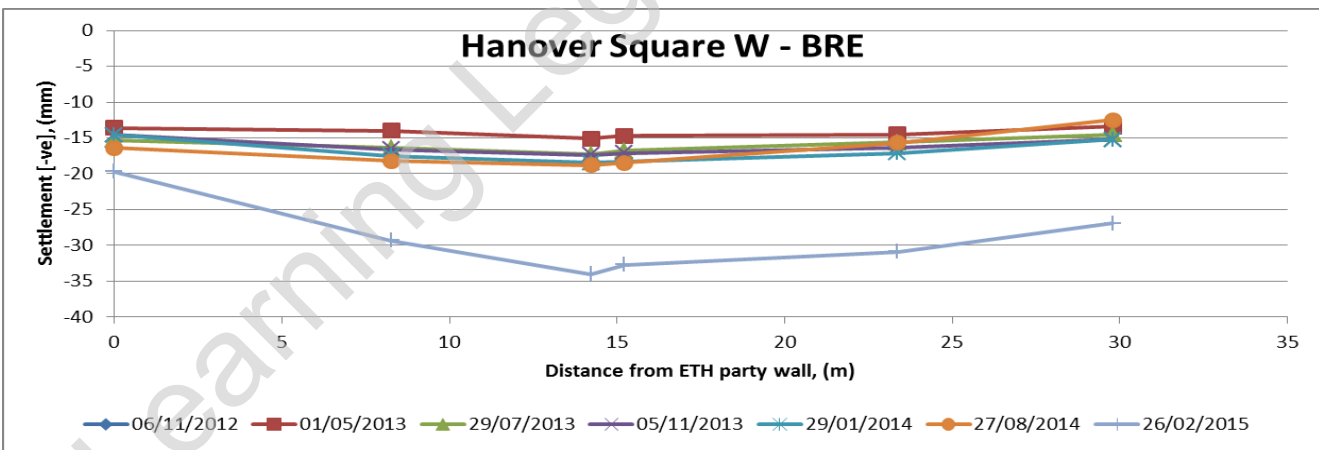
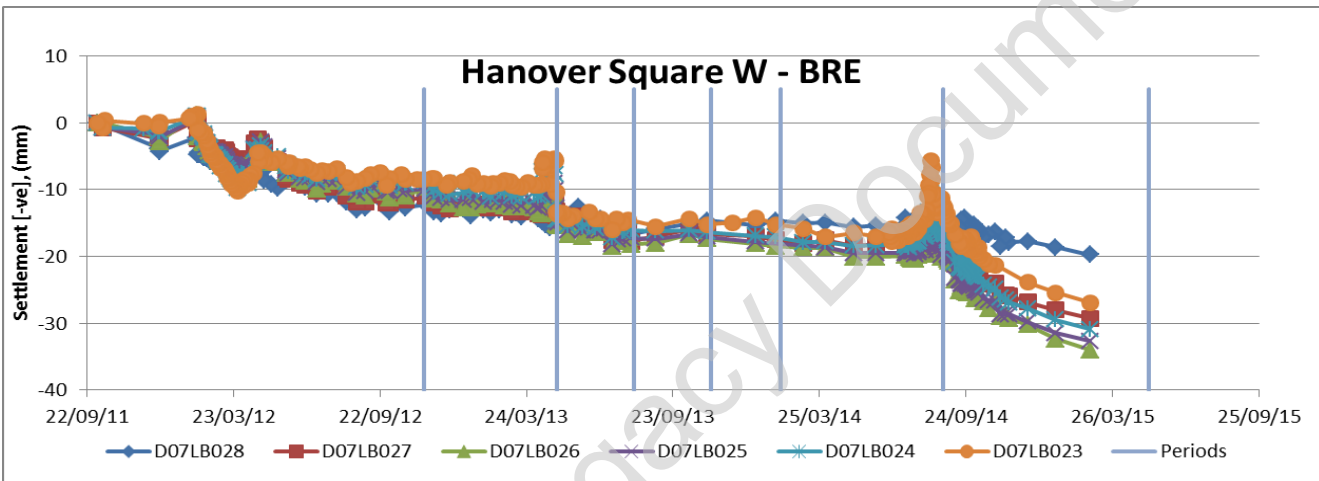
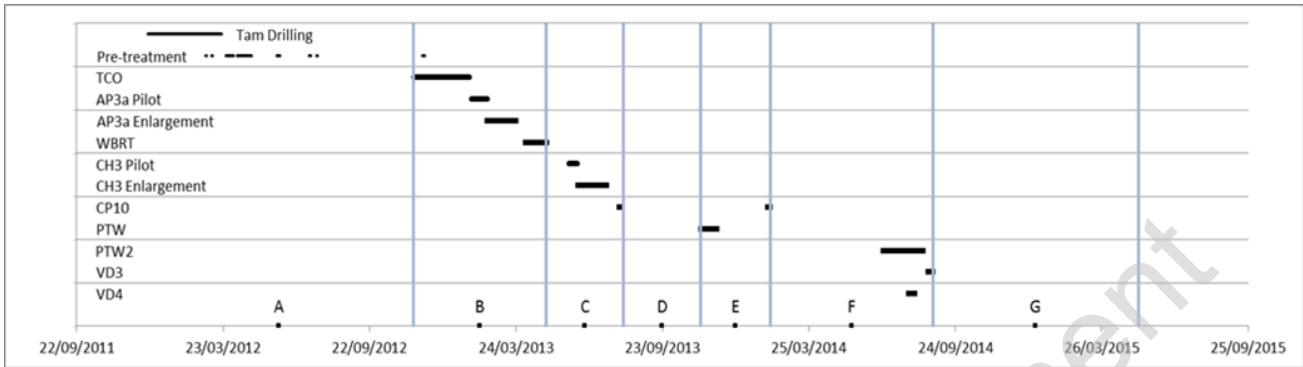


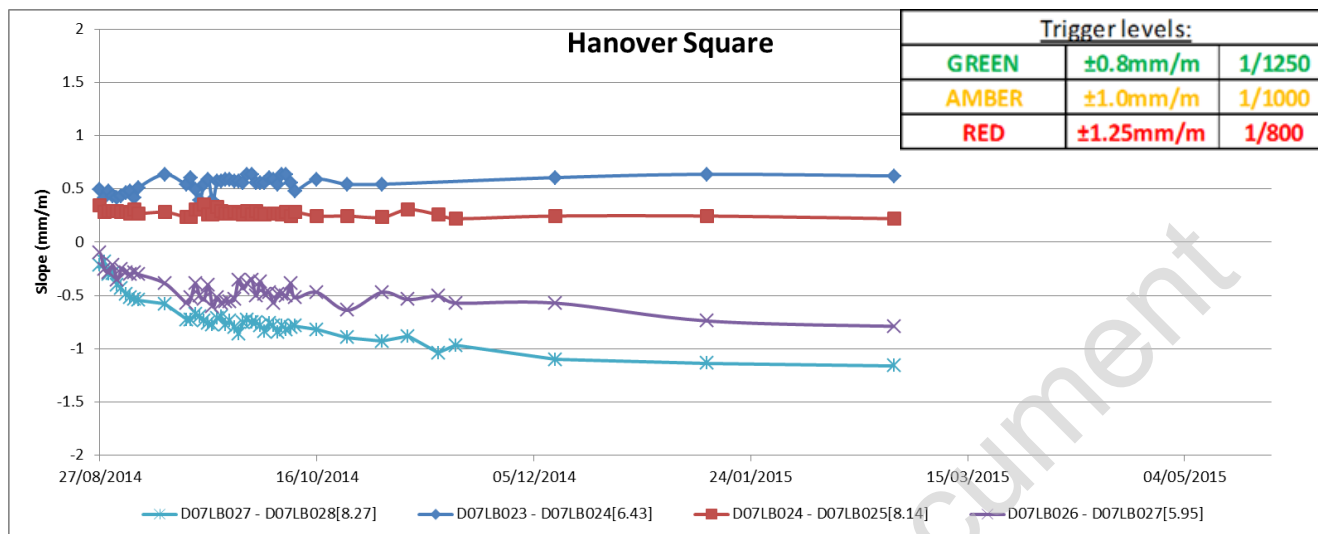


The following points are noted:

- The full length of the façade on the south of Brook Street is on the perimeter of the GS5 array: data from all points at distances are presented.
- The key events are the WBRT in Period B and PTW in Period E. It is noted that uplift due to grouting is more apparent than volume loss settlement. At the end of these activities the settlement was around 5mm and that there has been about 7mm post grouting and consolidation settlement over a period of 8 months.
- The rate of post construction settlement is continuously reducing through Period G although the ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- No slope triggers have been exceeded on the Brook Street south façade: the maximum value is about 0.5mm/m or 1:2000. By inspection, there are no deflection ratio triggers.

4.6. Hanover Square - West

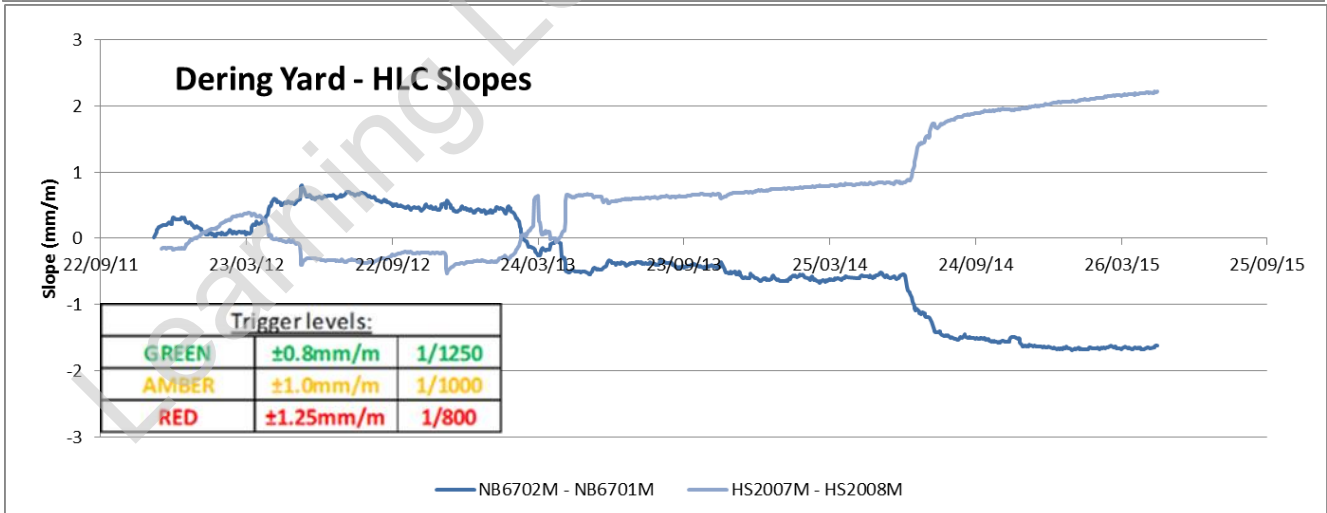
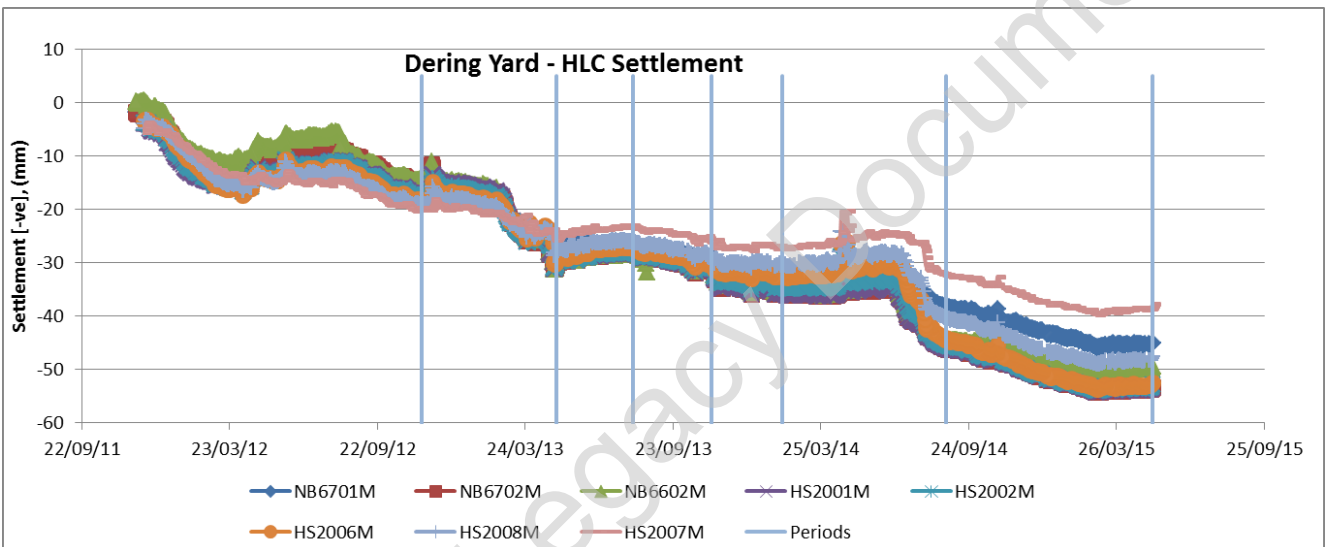
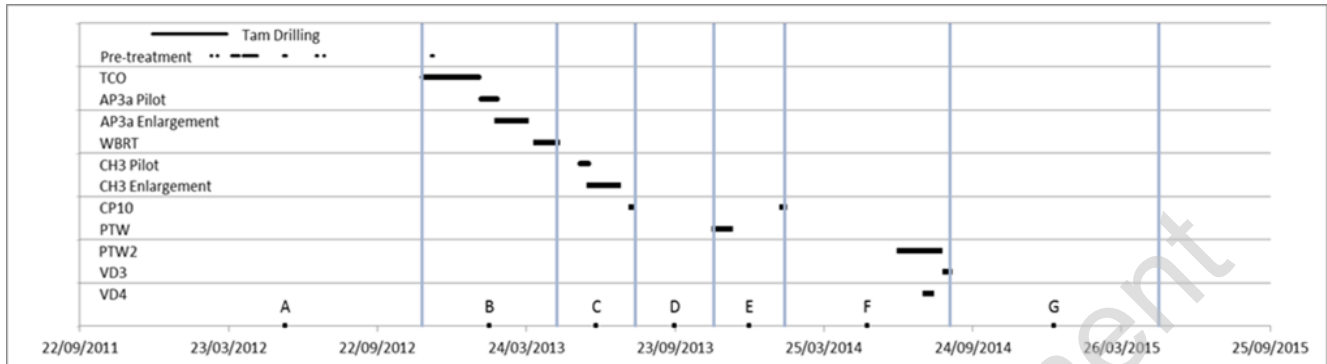




The following points are noted:

- The full length of the façade of 20 and 21 Hanover Square is within the GS5 array: data from all points at distances are presented.
- The key events are the WBRT in Period B and PTW in Period E. It is noted that uplift due to grouting is more apparent than volume loss settlement. At the end of these activities the settlement was relatively uniform at 15 – 20mm.
- Subsequently in Period G there has been about 15mm settlement over a period of 8 months. The rate of post tunnel construction settlement is continuously reducing through Period G although the ETH excavation to level - 3 and secondary lining works in the tunnels have been undertaken.
- The profile plot shows that there is restraint to movement adjacent to the ETH piled wall (at distance 0) which has induced differential movement to develop and an Amber trigger to be exceeded.
- The increase in slope with time is showing a continuous decrease in rate with time and the slopes are now nearly stable.
- There is one Amber slope trigger but, by inspection, there are no deflection ratio triggers.

4.7. Dering Yard (HLC)



| Trigger levels: | | |
|-----------------|-----------|--------|
| GREEN | ±0.8mm/m | 1/1250 |
| AMBER | ±1.0mm/m | 1/1000 |
| RED | ±1.25mm/m | 1/800 |

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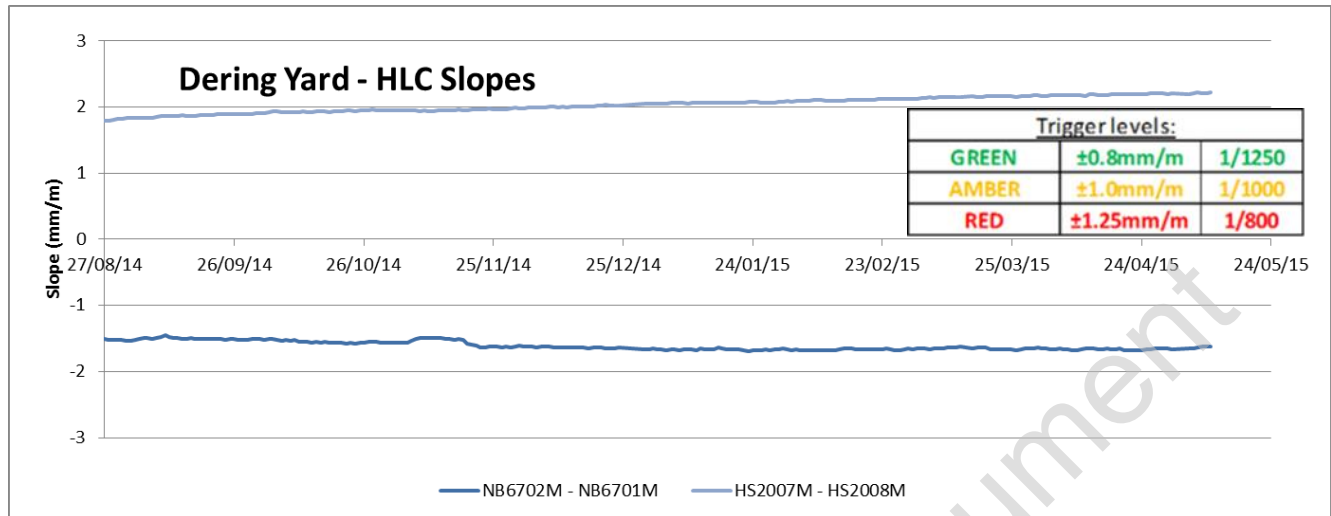


Report:

C300-BFK-C4-RGN-CRT00_ST005-51178 Rev 2.0

Grouting Summary & I & M Final
Report - BOS GS5

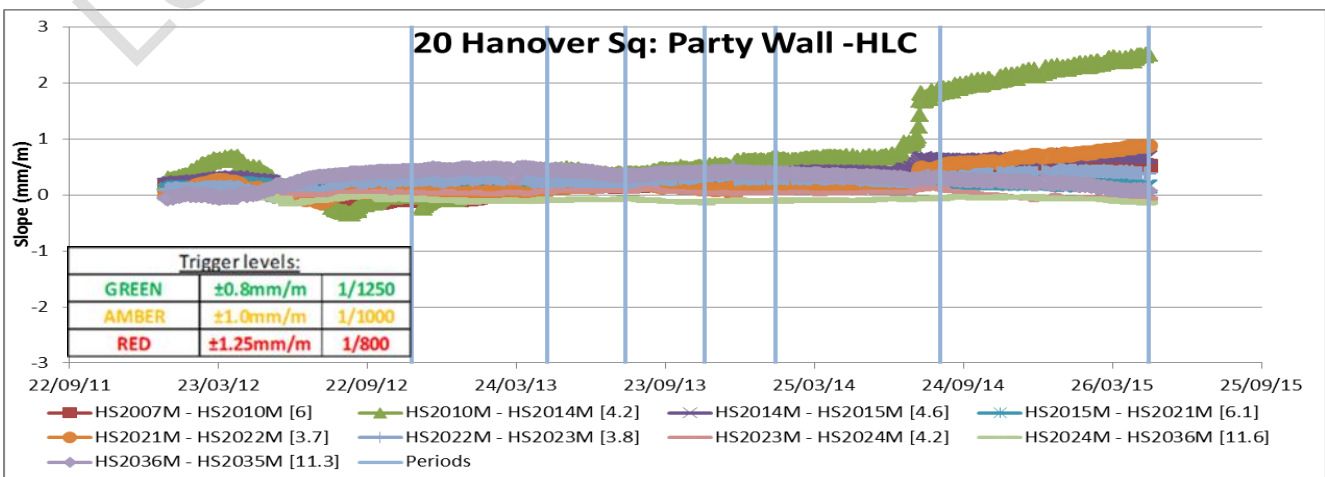
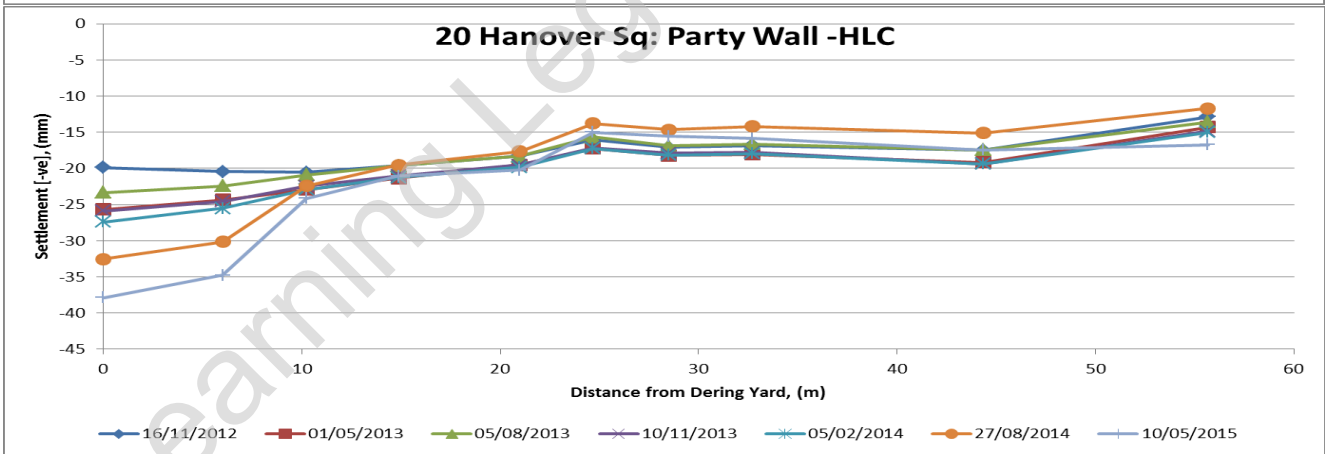
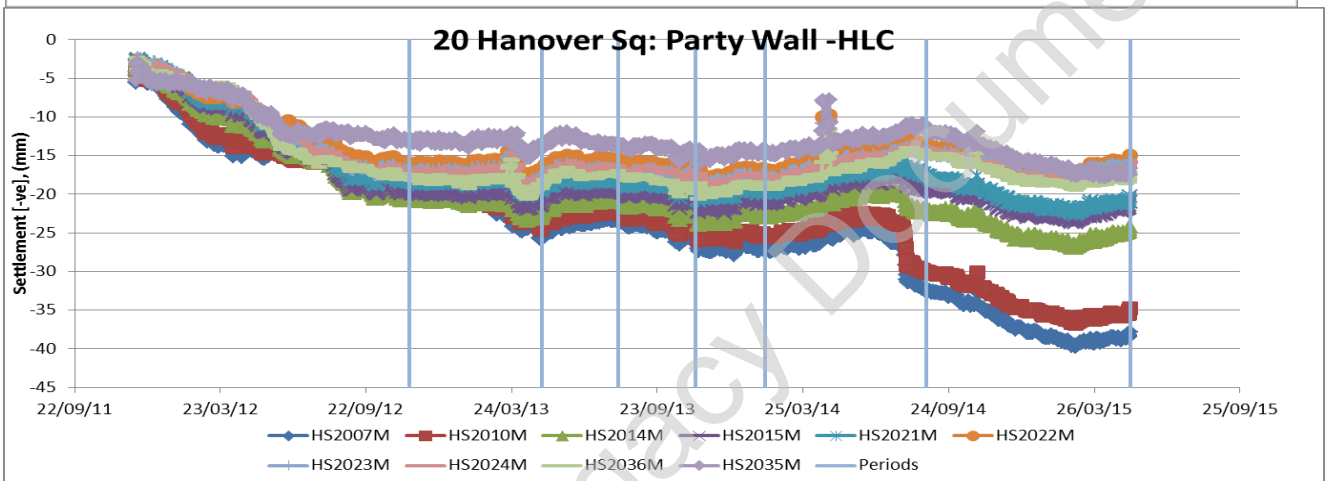
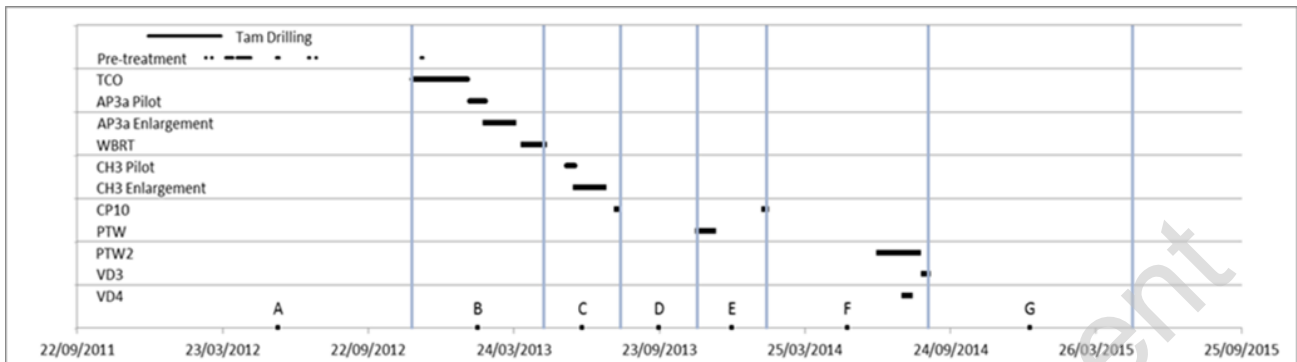
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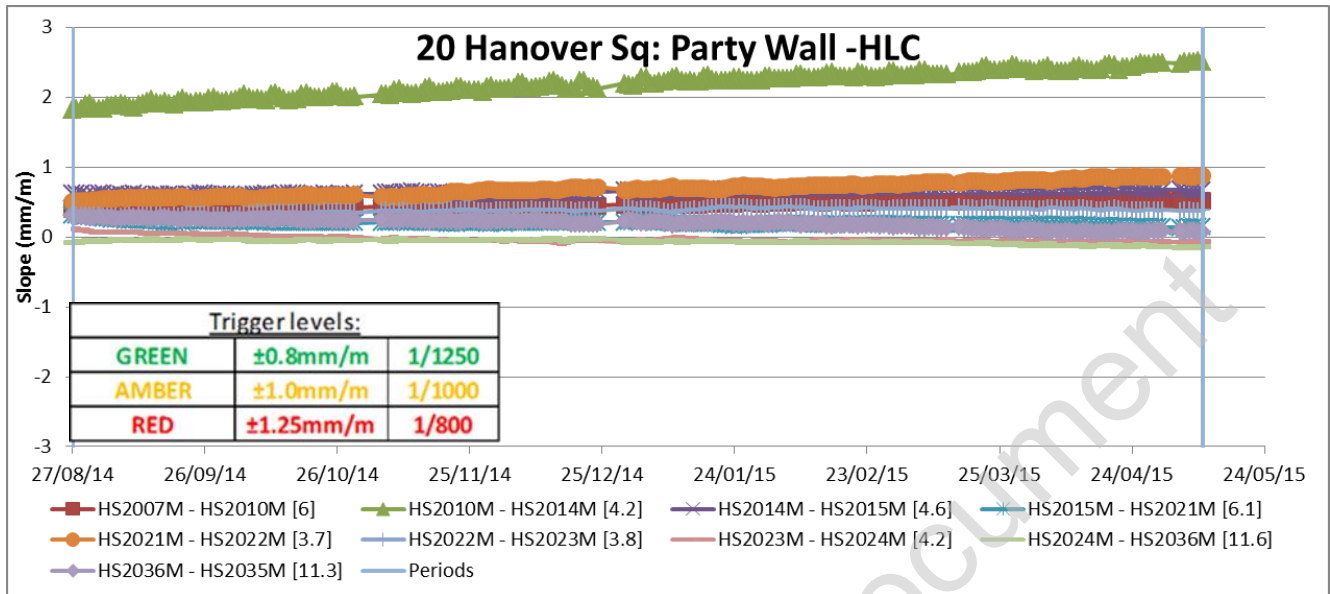


The following points are noted:

- The HLC in Dering Yard are within the buildings bordering 3 sides of the yard within which GS5 was constructed: data from all points are presented but no profile plot is presented since the sensors are not directly located on the external wall in all cases.
- The key events are AP3A and the WBRT in Period B, PTW (west) in Period E and PTW (east) and VD4 in Period F. It is noted that volume loss settlement is apparent for all of these events which reflects the difficulty encountered with controlling movement with grouting in close proximity to the shaft.
- In Period G there has been about 10mm settlement over a period of 8 months. The rate of post tunnel construction settlement was almost constant through the early part of Period G but it then reduced markedly at the beginning of March: it is assumed that this is related to the ETH works although excavation to level -3 is ongoing. Secondary lining works in the tunnels have been undertaken but were complete by the end of 2014.
- Slope – time data is only presented for the two locations where trigger values have been exceeded. The slope on the rear of 67 New Bond Street has stabilised whereas that on the rear of 20 Hanover Square continues to increase. It is considered that the latter is due to the restraint to settlement of the party wall by the ETH structure.

4.8. East Ticket Hall - south party wall

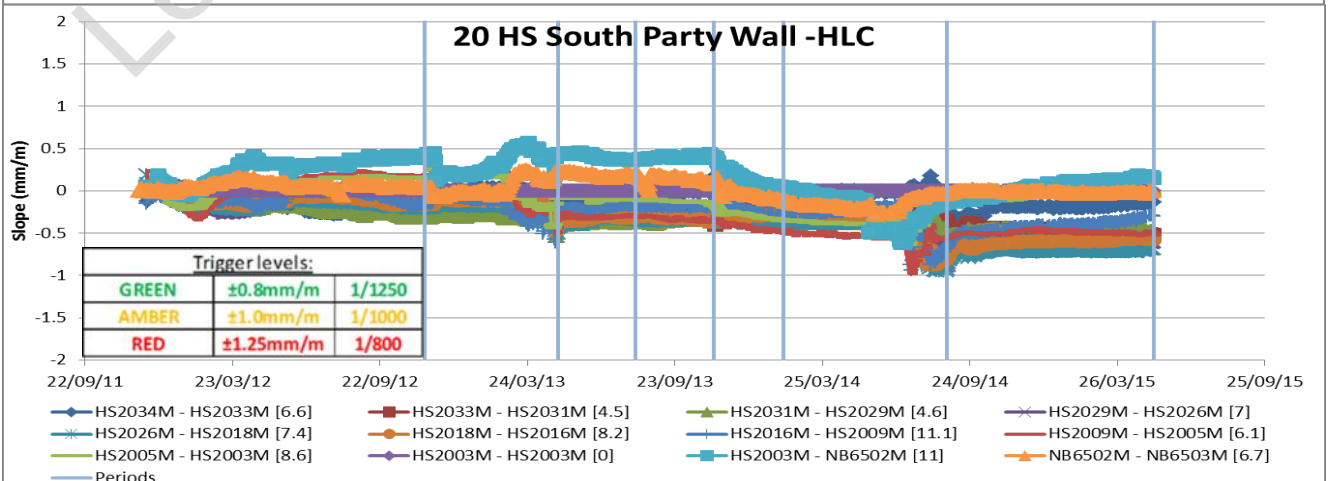
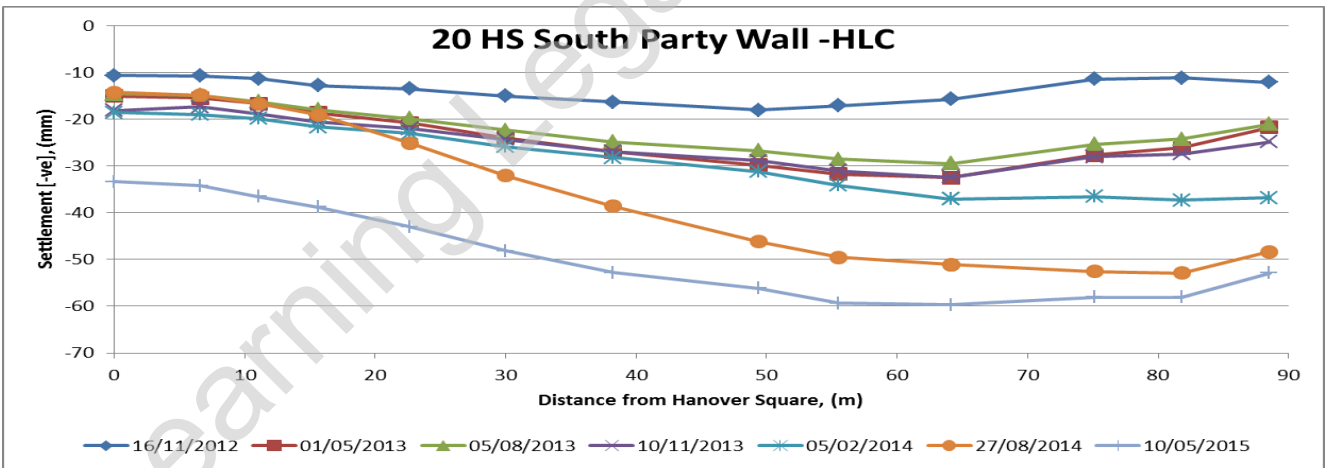
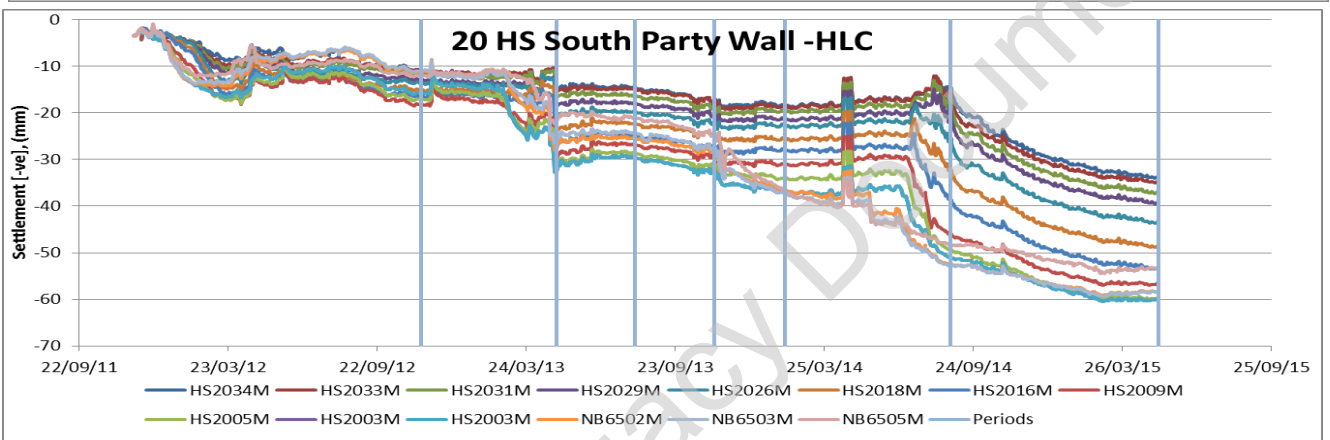
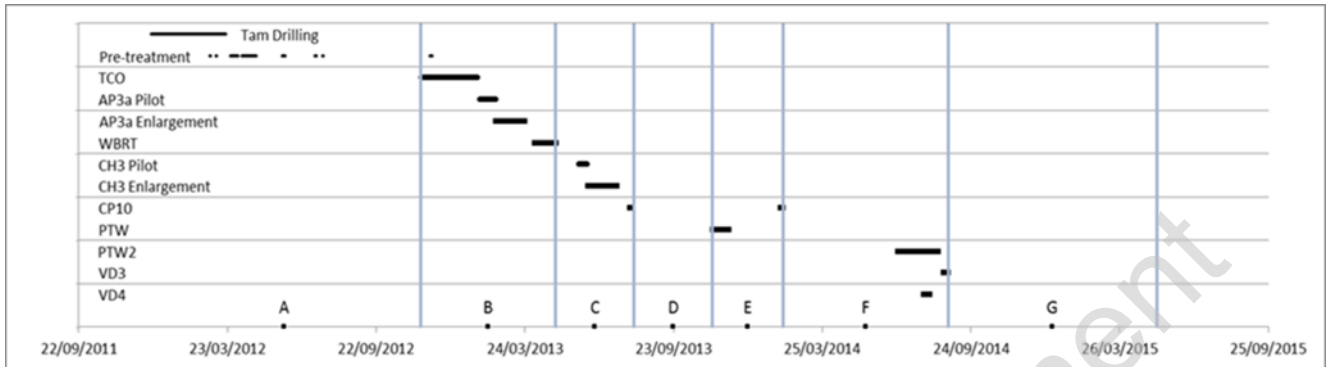


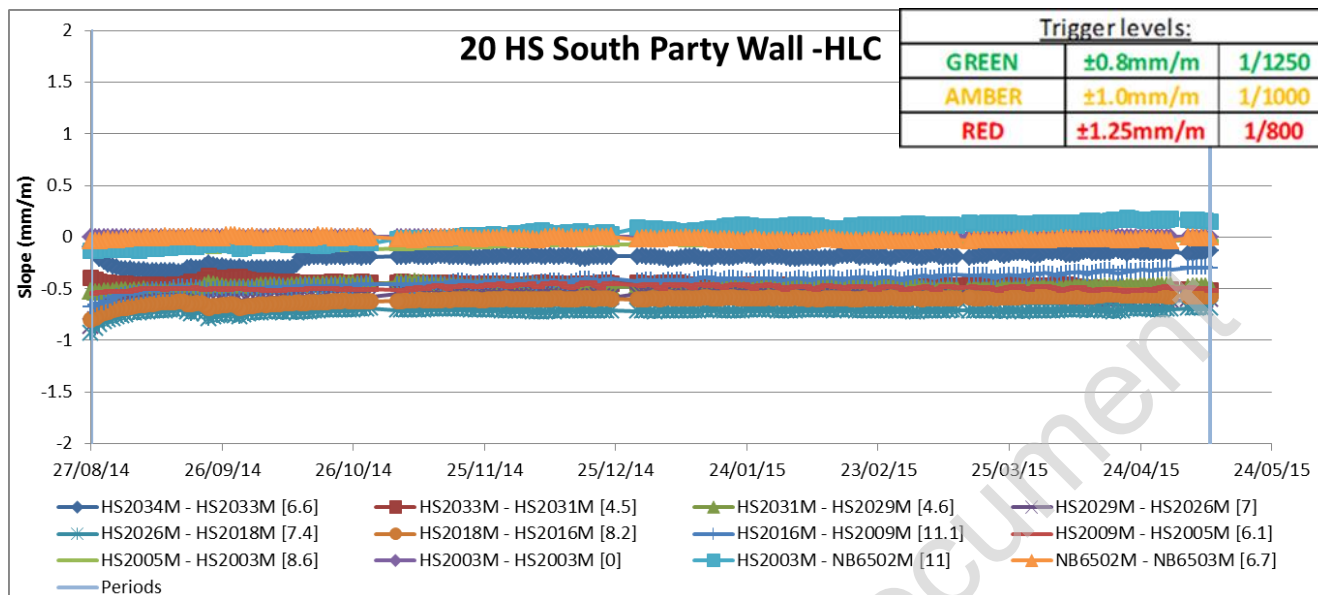


The following points are noted:

- The full length of the party between 20 Hanover Square and the ETH site is adjacent to the GS5 array: data from all points at distances are presented. It is noted that there is a 3m exclusion zone from the piled wall and therefore it is outside the plan extent of the arrays.
- HLC data is presented but it is noted that the two sensors closest to Dering Yard are not on the party wall but are included for completeness and to illustrate the difference in behaviour of these sensors compared to the remainder.
- The key events are AP3A in Period B and VD4 in Period F. The latter in particular caused significant settlement of the two sensors nearest Dering Yard. Effective grouting was not possible due to the exclusion zones around the shaft, ETH piles and the tunnel heading.
- In Period G there has been about 10mm settlement over a period of 8 months. The rate of post tunnel construction settlement was almost constant through the early part of Period G but it then reduced markedly at the beginning of March: it is assumed that this is related to the ETH works although excavation to level -3 is ongoing. Secondary lining works in the tunnels have been undertaken but were complete by the end of 2014.
- It is notable that the profile shows very little change from the end of Period A to date. As noted previously the ETH piled wall is restraining the party wall from movement thereby causing increases in slope perpendicular to the wall.
- The slope – time plots confirm that differential movement perpendicular to the party wall continues to increase gradually.
- There are no slope triggers for sensors along the party wall and, by inspection, there are no deflection ratio triggers.

4.9. 20 Hanover Square – south party wall





The following points are noted:

- The full length of the party between 20 Hanover Square and the buildings on Brook Street extending to New Bond Street along the party wall of number 65 is within the GS5 array: data from all points at distances are presented. HLC data is presented.
- Since this profile extends over virtually the full length of the GS5 array, all of the tunnelling activities had a noticeable effect (with the exception of CH3). Settlement in Period A, prior to tunnelling, was between 10 and 20mm. By the end of Period D the maximum had increased to 30mm but slopes were still less than 0.5mm/m. At the end of Period F settlement was over 50mm and there was a transitory increase in slope to just less than 1mm/m.
- In Period G there has been up to 15mm settlement over a period of 8 months. However, the overall differential movement has decreased and the slopes are now essentially stable.
- There are no slope triggers and, by inspection, there are no deflection ratio triggers.

5. GROUND SETTLEMENT AND SLOPES

5.1. Slope Triggers

The locations where slope triggers have been exceeded are shown for PLP monitoring of ground level on Figure 5.1. A larger version of Figure 5.1 is included in Appendix B. Details are given in Table 5.1.

Slope triggers are as follows:

- GREEN 1:1250 0.8mm/m
- AMBER 1:1000 1.0mm/m
- RED 1:500 2.0mm/m



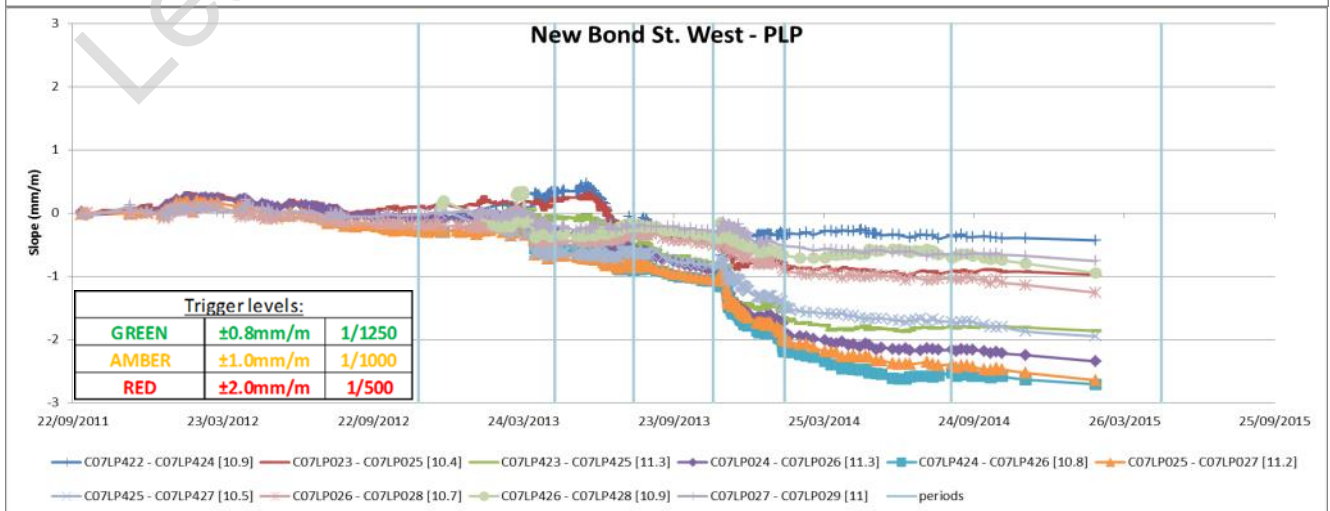
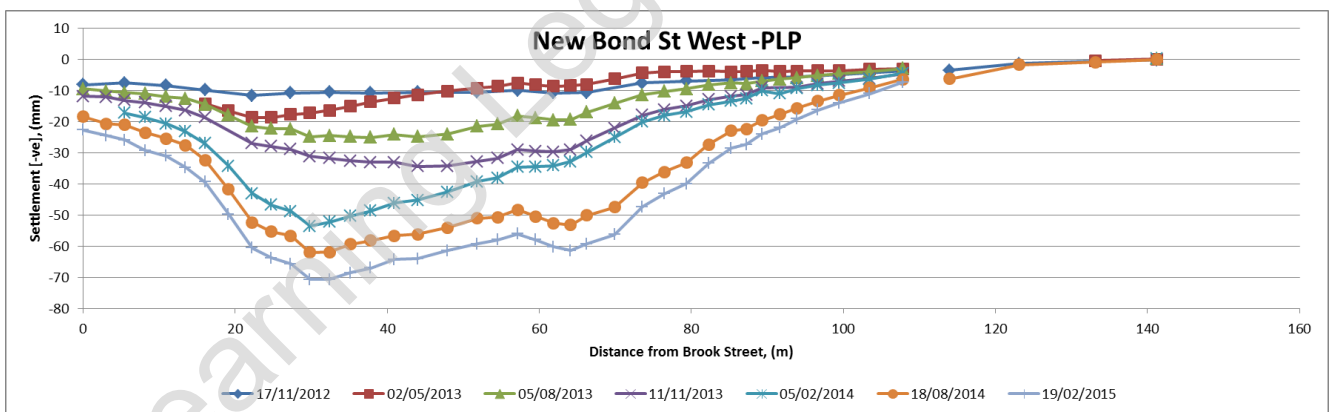
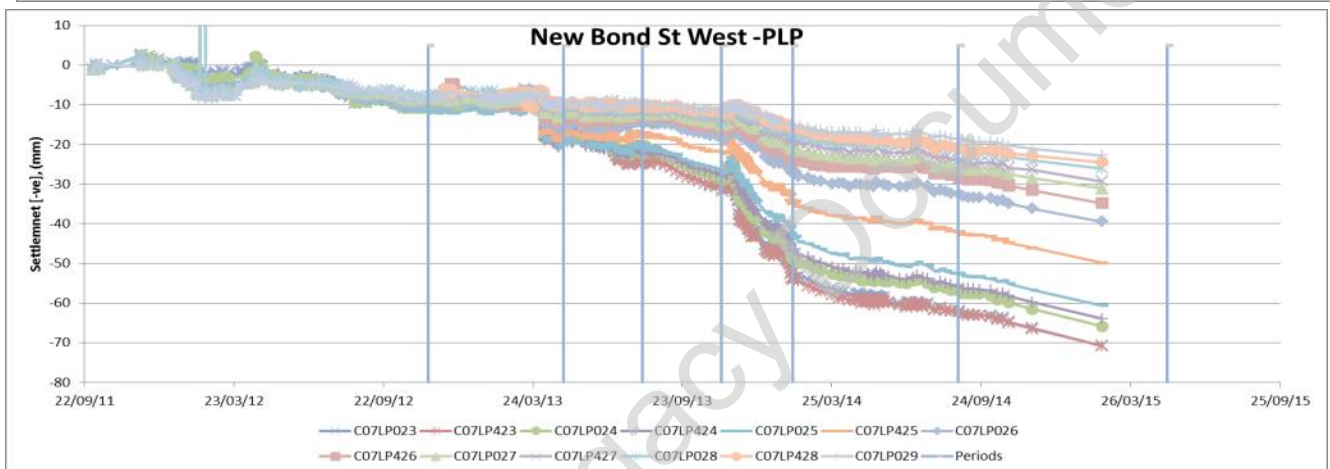
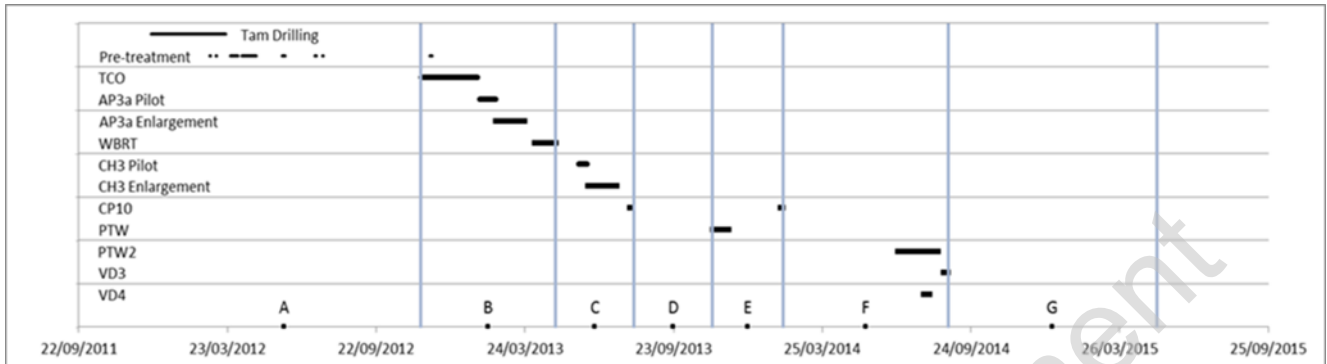
PLP monitoring data from the kerblines within the footprint of GS 5 are presented in the following sections, namely New Bond Street east and west, Brook Street north and south and the in front of the façade of 20 and 21 Hanover Square. The plots presented for each comprise:

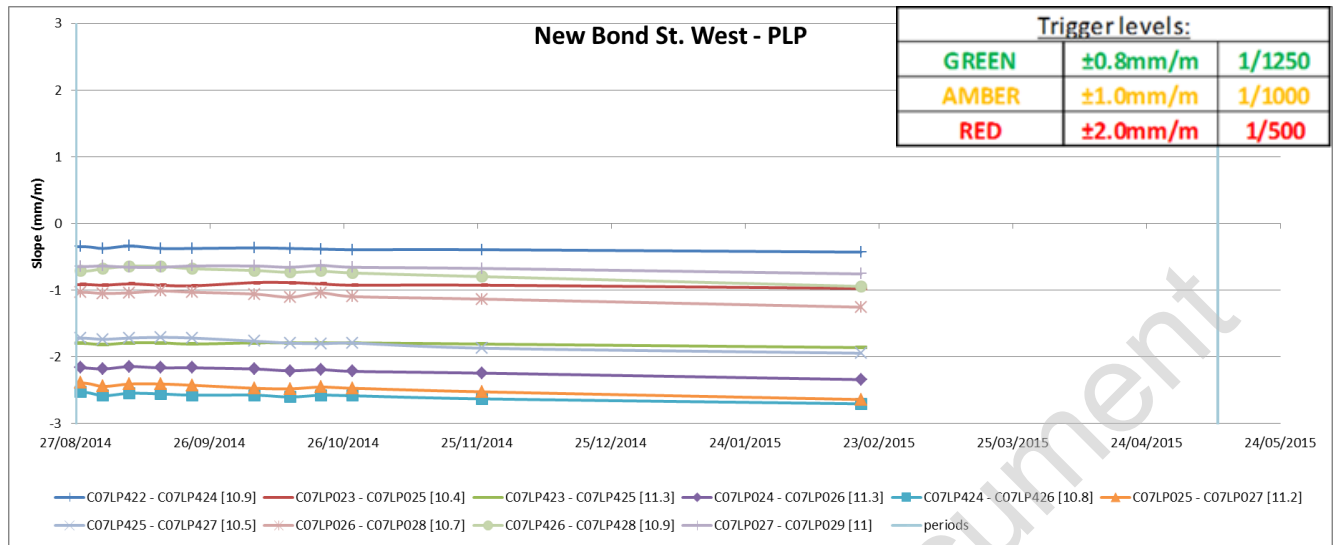
1. Summary of tunnel construction and associated construction periods
2. Time settlement history
3. Settlement profile plots with series as close to the end of each construction period as is available
4. Time slope history over the full construction period with the distances between the points in metres shown in the legend in square brackets
5. Time slope history since the completion of tunnelling i.e. construction period G

Table 5.1 Details of Amber and Red trigger breaches on PLP

| GROUND POINTS | | Comment | Date exceeded | Maximum (mm/m) | Current (mm/m) |
|-------------------------------|-------|--|---------------|----------------|----------------|
| New Bond Street - West | | | | | |
| C07LP423 - C07LP425 | Amber | Stable within ± 0.1 mm/m for 12 months | 04/12/13 | 1.86 | 1.86 |
| C07LP024 - C07LP026 | Red | Slight increase in rate in Period G | 26/03/14 | 2.34 | 2.34 |
| C07LP424 - C07LP426 | Red | Slight increase in rate in Period G | 03/02/14 | 2.71 | 2.71 |
| C07LP025 - C07LP027 | Red | Slight increase in rate in Period G | 05/02/14 | 2.64 | 2.64 |
| C07LP425 - C07LP427 | Amber | Slight increase in rate in Period G | 08/12/14 | 1.95 | 1.95 |
| C07LP026 - C07LP028 | Amber | Slight increase in rate in Period G | 16/04/14 | 1.26 | 1.26 |
| New Bond Street - East | | | | | |
| C07LP120 - C07LP124 | Amber | Stable within ± 0.1 mm/m for 7 months until last reading | 04/02/14 | 1.41 | 1.41 |
| C07LP119 - C07LP123 | Amber | Stable within ± 0.1 mm/m for 7 months until last reading | 03/01/14 | 1.50 | 1.50 |
| C07LP118 - C07LP122 | Amber | Stable within ± 0.1 mm/m for 12 months | 03/01/14 | 1.52 | 1.52 |
| C07LP117 - C07LP121 | Amber | Slight increase in rate in Period G | 21/11/13 | 1.71 | 1.71 |
| C07LP116 - C07LP120 | Amber | Slight increase in rate in Period G | 26/11/13 | 1.50 | 1.50 |
| C07LP115 - C07LP119 | Amber | Slight increase in rate in Period G | 30/01/14 | 1.21 | 1.21 |
| Brook Street - South | | | | | |
| D07LP170 - D07LP172 | Amber | Last reading only – point stability I doubt | 25/02/15 | 1.04 | 1.04 |
| D07LP171 - D07LP173 | Amber | Last reading only – point stability I doubt | 25/02/15 | 1.02 | 1.02 |

5.2. New Bond Street – west

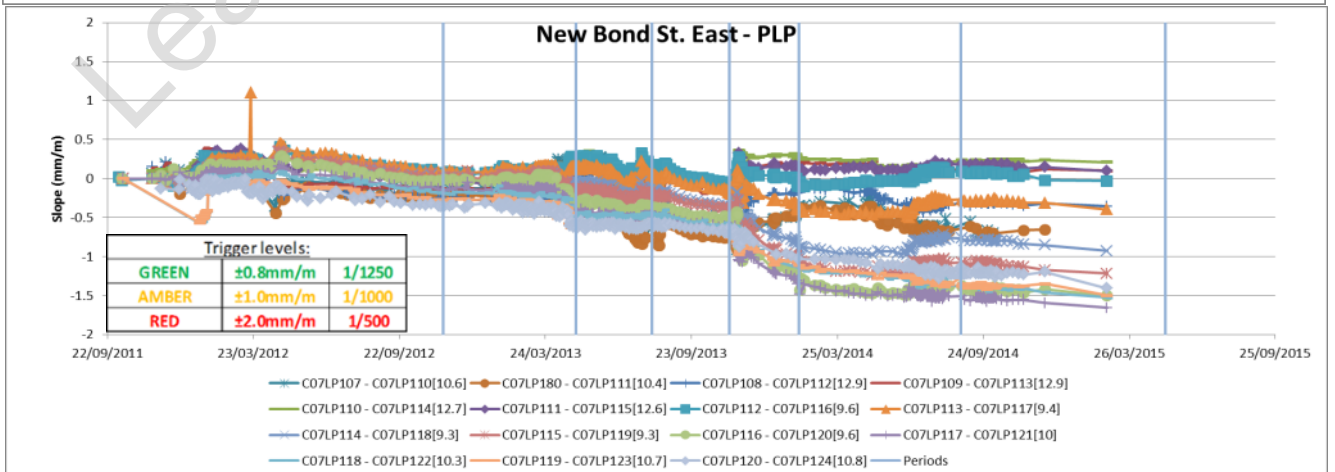
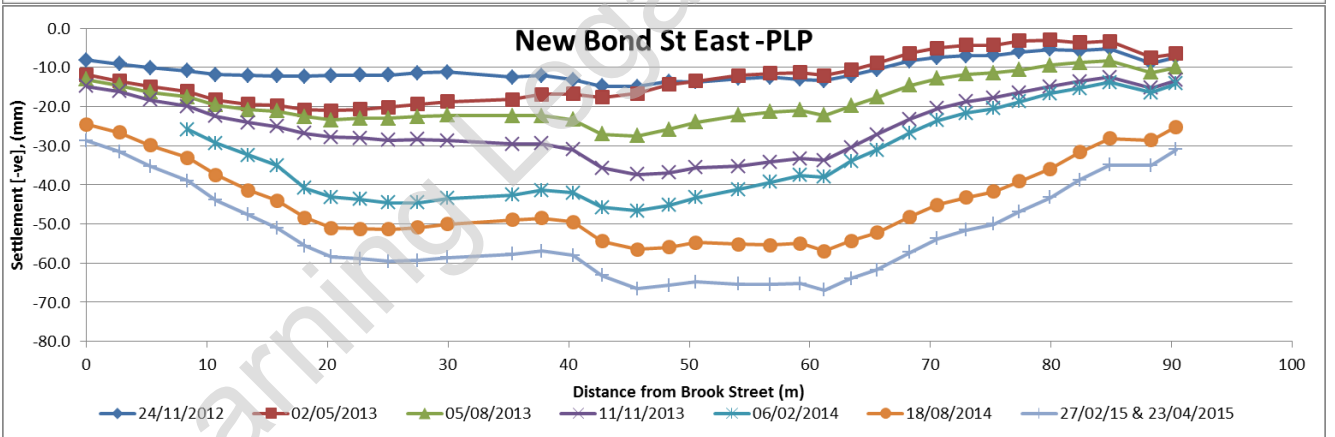
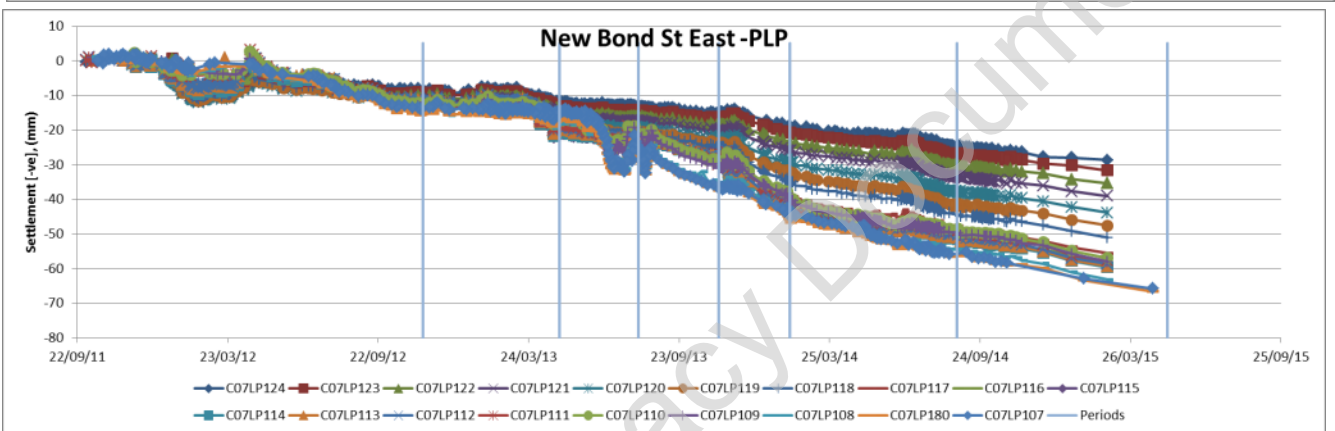
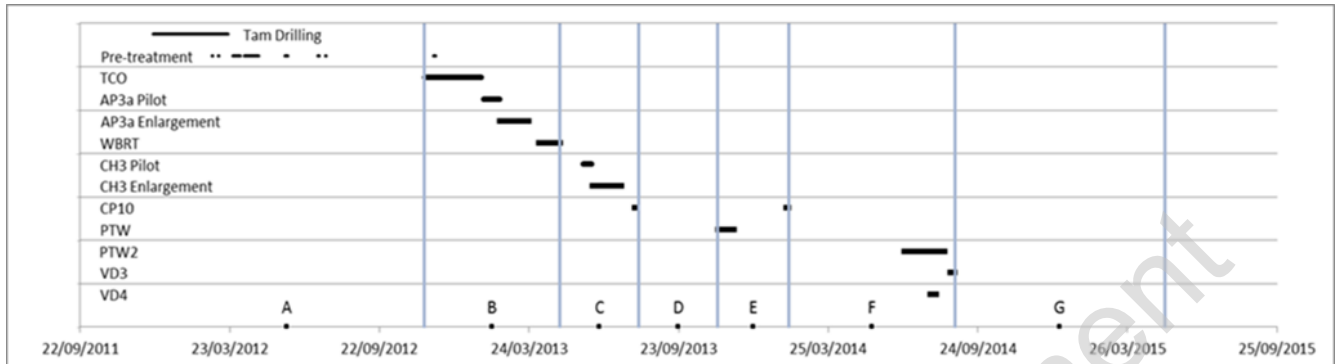


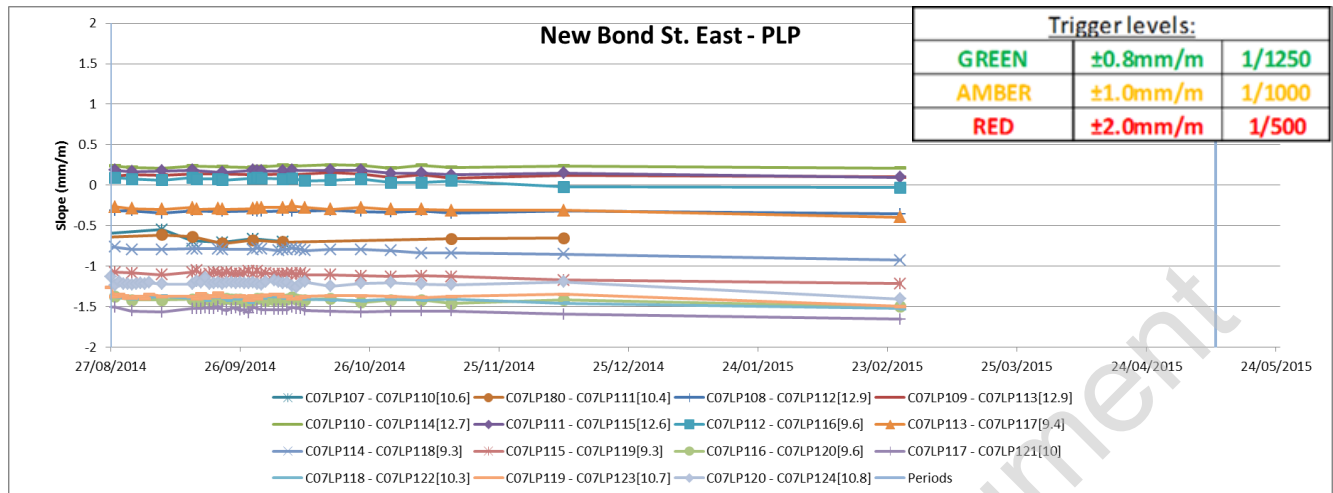


The following points are noted:

- Only the most southerly part of the profile is within the GS5 array: data from points up distance 30m are presented.
- The key events are the WBRT in Period B; CH3 enlargement in Period C and PTW in Period E. It is noted that at the end of these activities the settlement was less than 50mm and that there has been 20mm consolidation settlement over a period of 17 months.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G there has been a small increase albeit confirmed by fewer sets of readings. ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken in Period G.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- The maximum settlement is about 15m to the north of the GS5 arrays and is within the GS2 area and this has driven the slope triggers to the south of this location.
- There are three Amber and three Red slope triggers but there are no deflection ratio triggers with a maximum calculated value of <1:6000.

5.3. New Bond Street – east

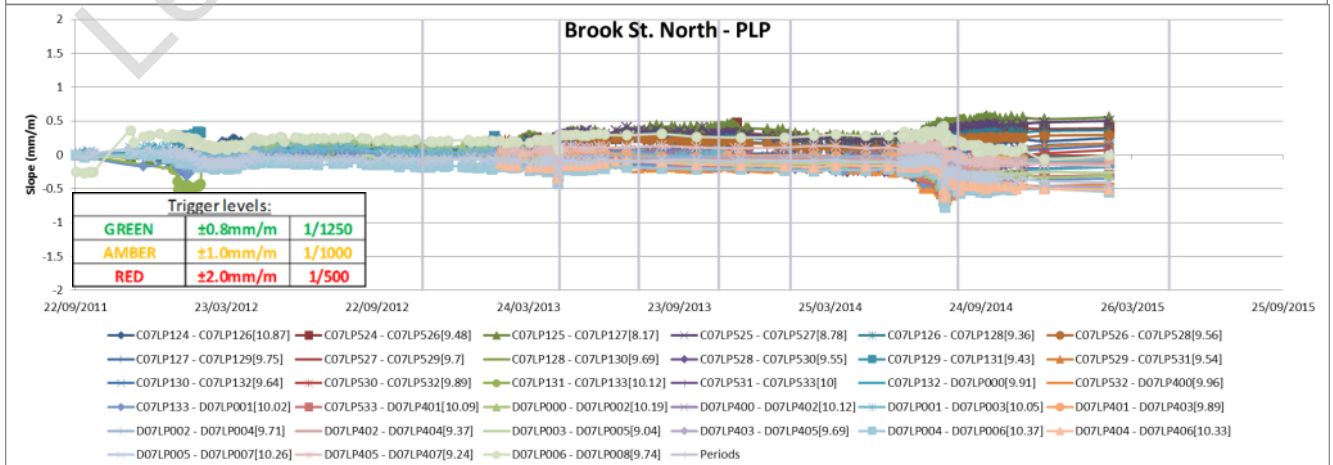
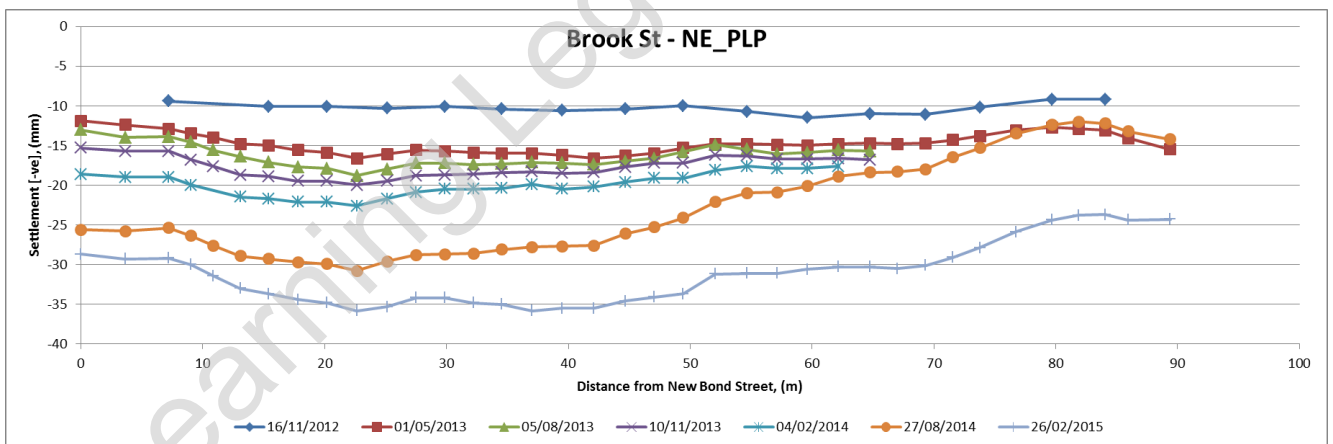
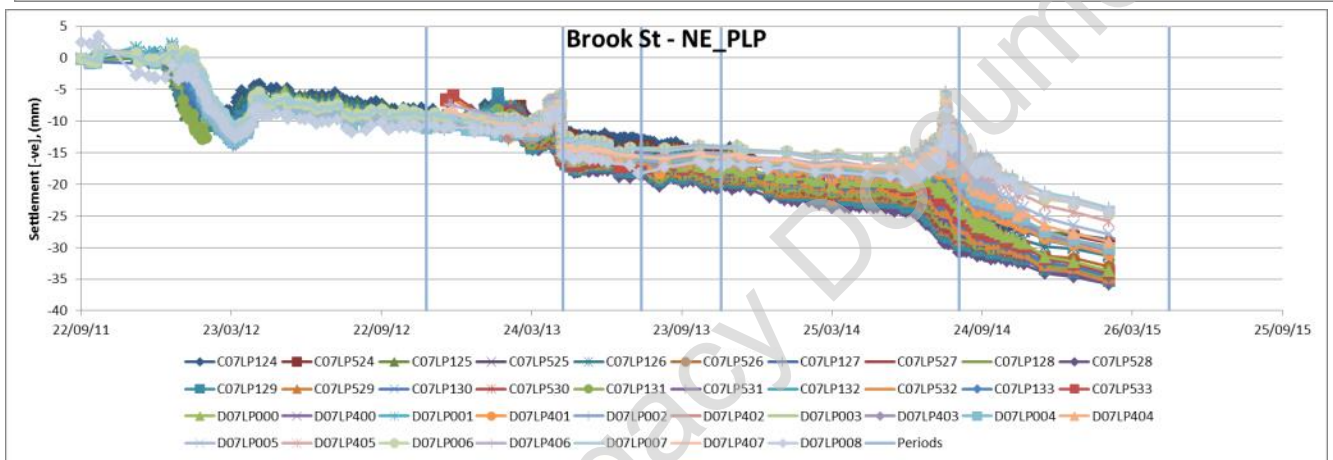
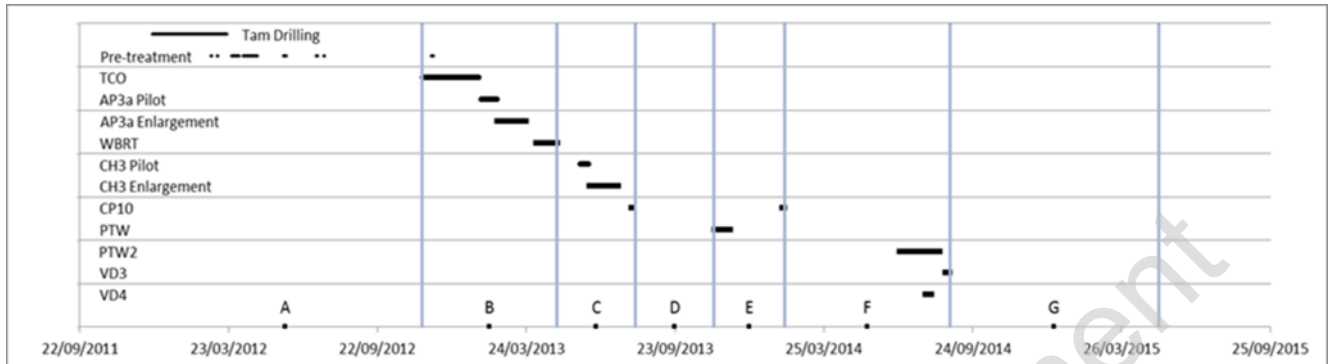


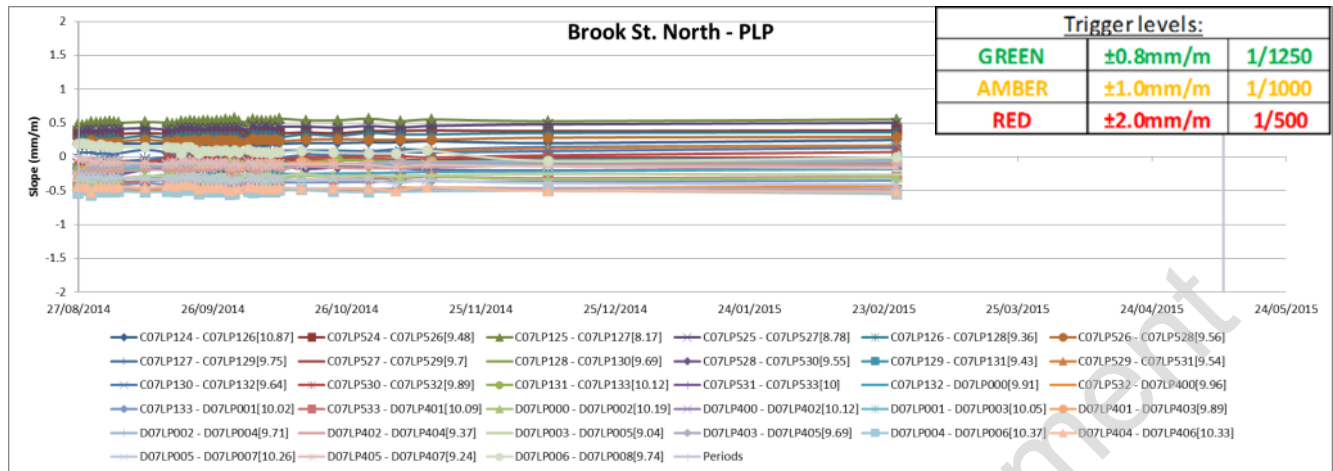


The following points are noted:

- Only the most southerly part of the profile is within the GS5 array (to distance 40m): data from points at distances up to 50m are presented.
- The key events are the WBRT in Period B; CH3 enlargement in Period C and PTW in Period E. It is noted that at the end of these activities the settlement was less than 45mm and that there has been 20mm consolidation settlement over a period of 17 months.
- The rate of post construction settlement has been a more or less constant in Periods F and Period G, although a small increase in rate is noted associated with the tunnelling at the end of Period F. ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken in Period G.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- Amber slope triggers occur over distances 0 to 20m from the corner with Brook Street but are either stable or increasing at a slow rate.
- There are six Amber slope triggers but, by inspection, there are no deflection ratio triggers since the slope is approximately constant.

5.4. Brook Street - north

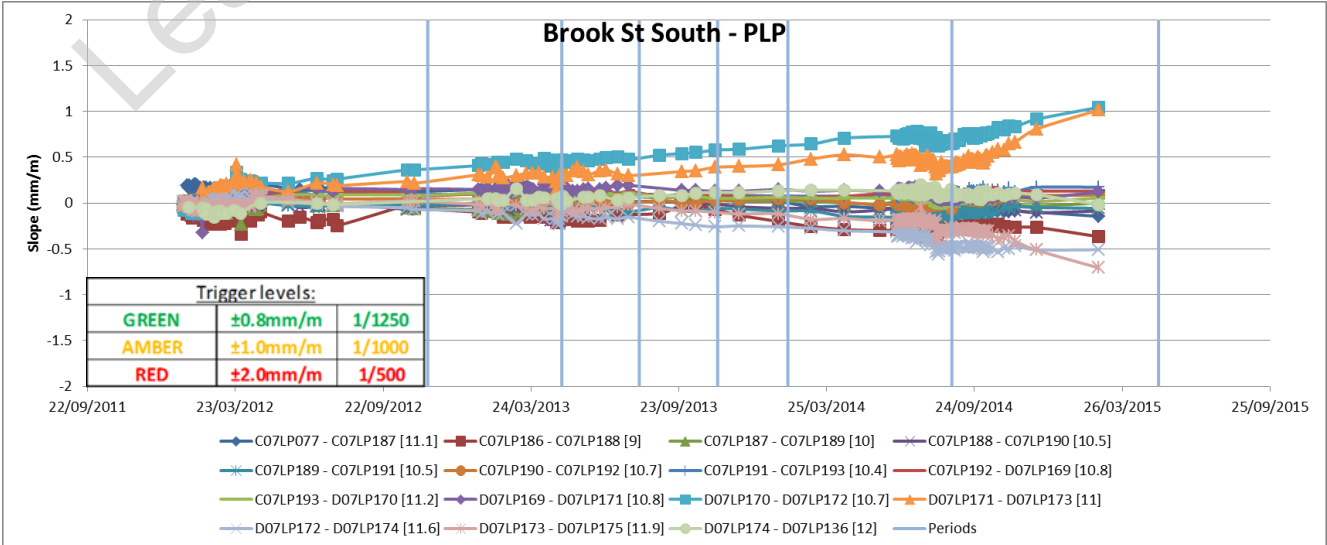
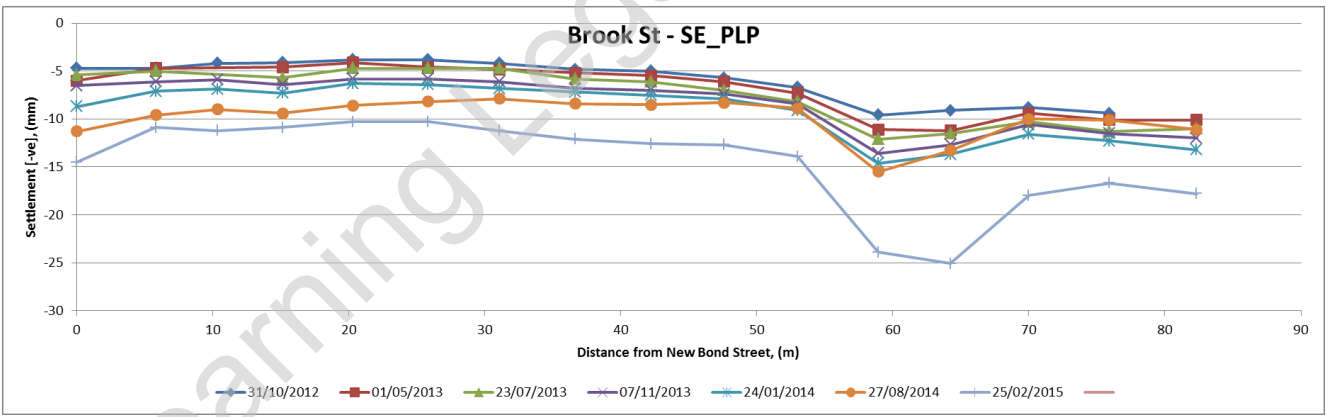
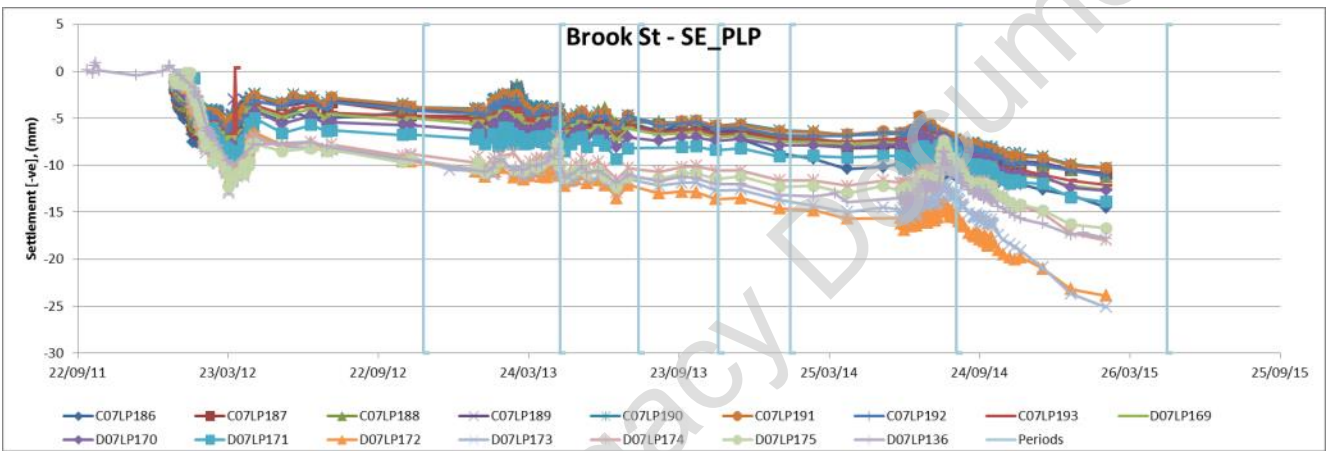
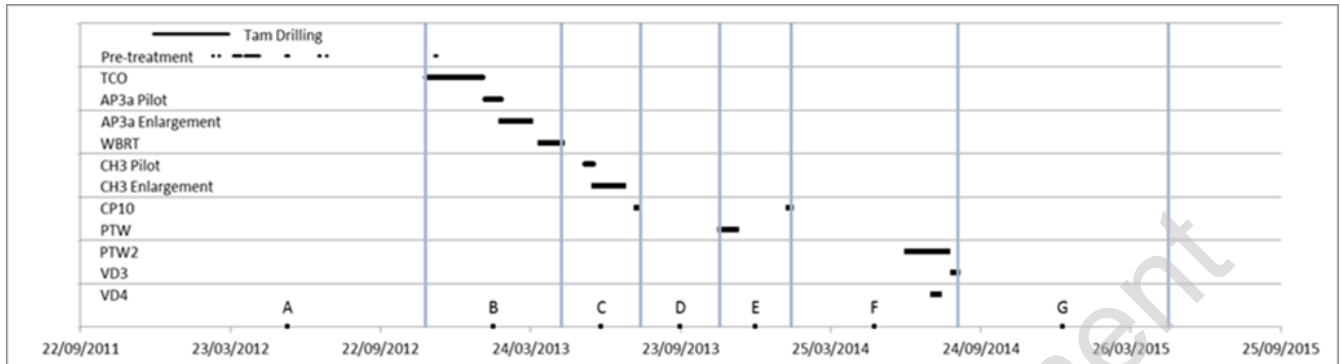


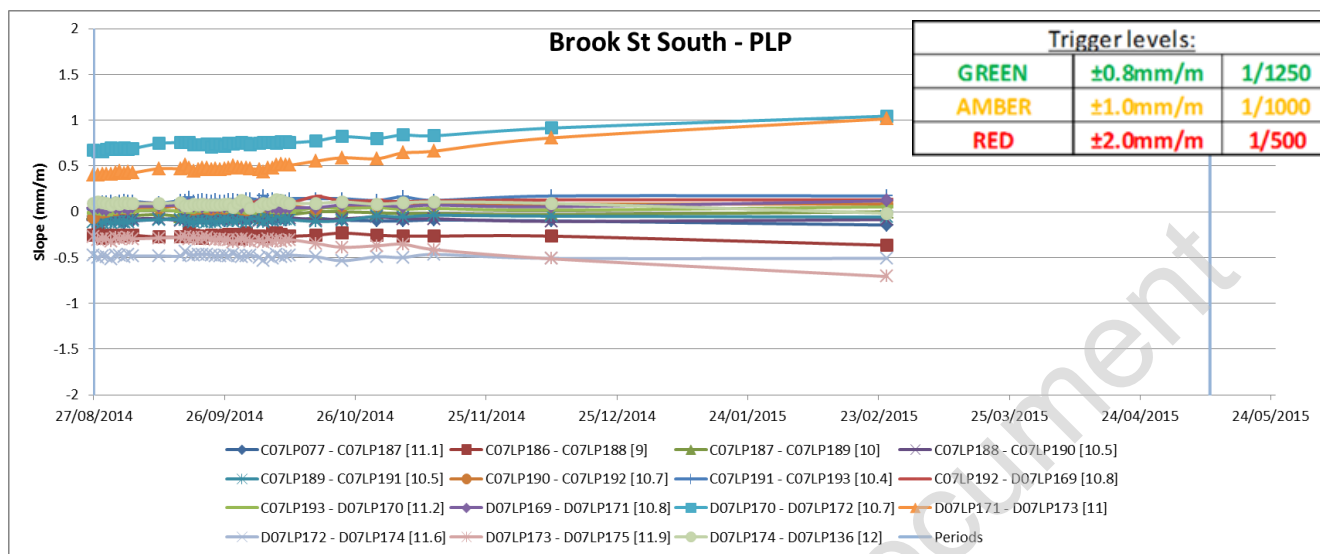


The following points are noted:

- The full length of the PLPs on the north side of Brook Street is within the GS5 array: data from all points at distances are presented.
- The key events are the WBRT in Period B and PTW in Period E. It is noted that at the end of these activities the settlement was around 30mm and that there has been 5 to 10 mm consolidation settlement over a period of 8 months.
- The rate of post construction settlement is approximately constant through Period G: the ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken.
- The profile plot confirms that the consolidation settlement is reducing the overall differential settlement along the profile. The slopes are changing little and are within about ±0.5mm/m, with no trigger levels exceeded.
- There are no slope triggers and, by inspection, there are no deflection ratio triggers.

5.5. Brook Street – south

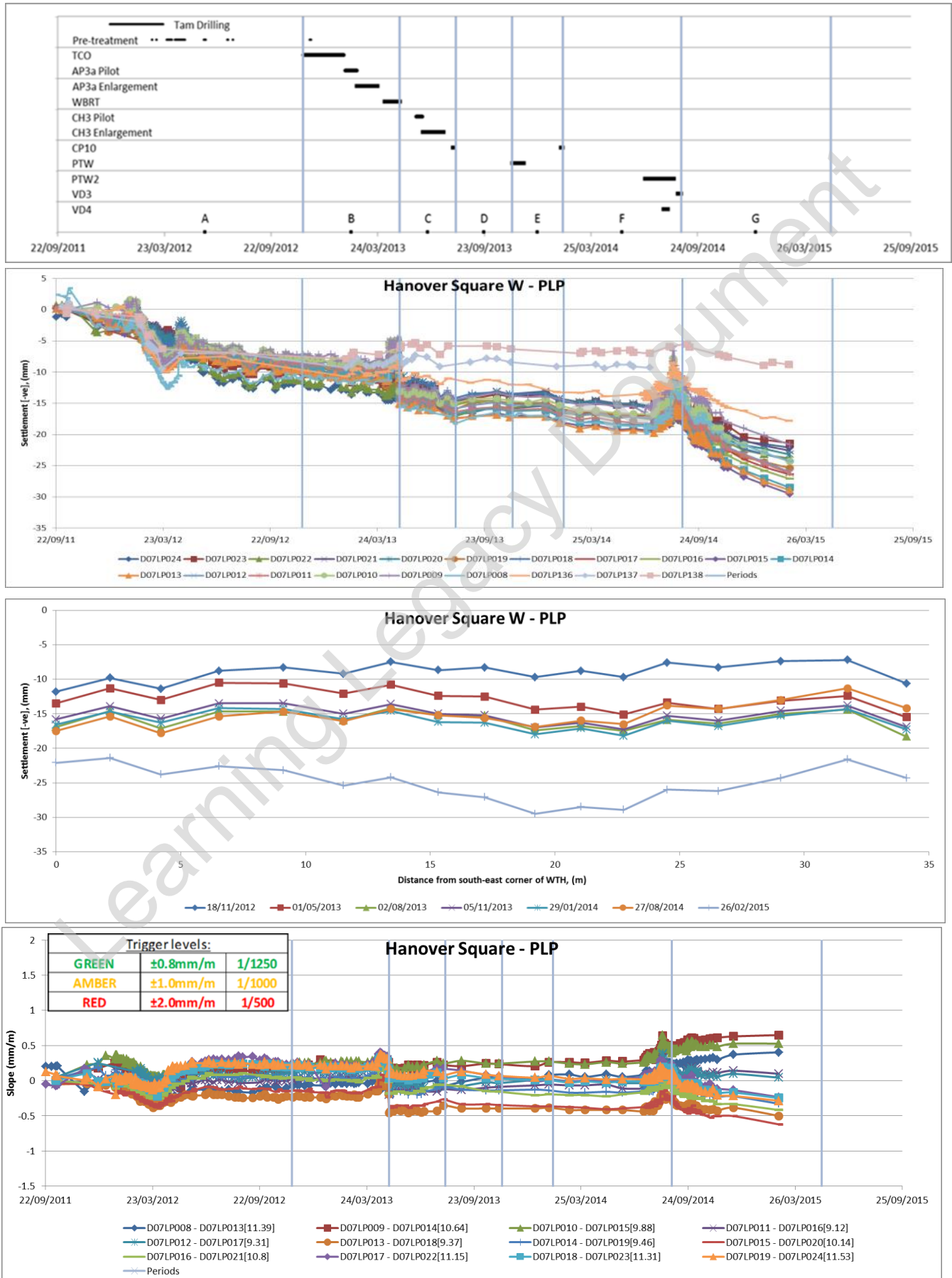


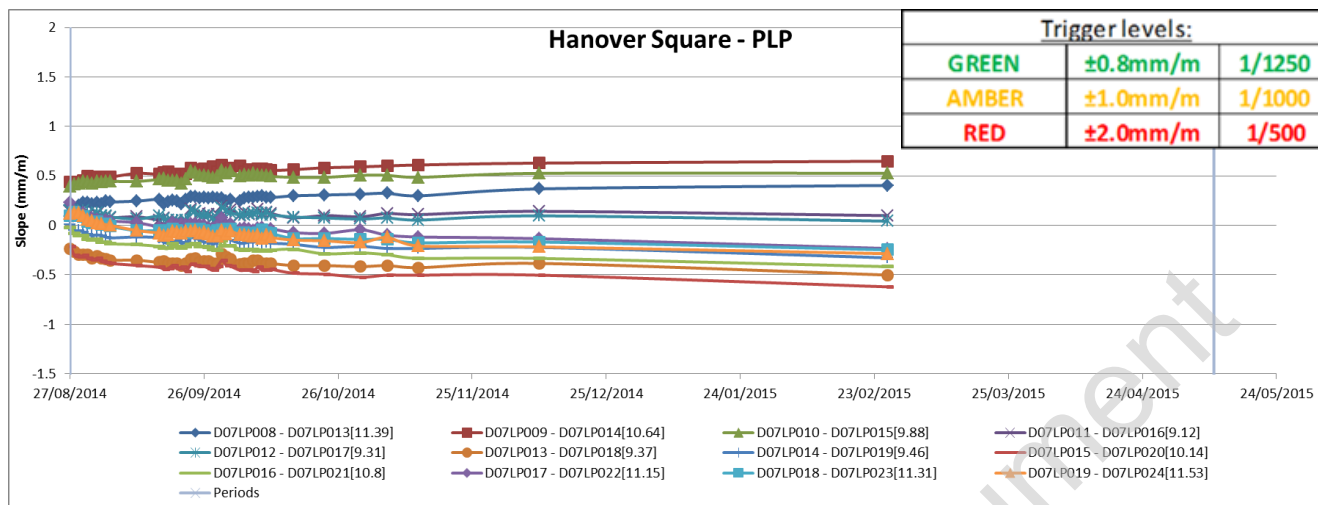


The following points are noted:

- The full length of the points on the south of Brook Street is on the perimeter of the GS5 array: data from all points at distances are presented.
- The key events are the WBRT in Period B and PTW in Period F. It is noted that uplift due to grouting is more apparent than volume loss settlement. At the end of these activities the settlement was around 15mm and that there has been a maximum of about 10mm post grouting and consolidation settlement over a period of 8 months.
- The rate of post construction settlement is relatively consistent through Period G probably due to the ETH excavation to level -3 and secondary lining works in the tunnels.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes, except locally around distance 60m. These are the points each side of the goods entrance to 22 Hanover Square and it is evident from a site inspection that this is due to instability of the kerbs in which the points are installed. Also the corresponding points on the building don't show this trend.
- The slope –time plot suggests that these points have behaved differently from the start of monitoring: an approximately linear increase is shown throughout, approaching the Amber trigger at the most recent reading.
- There are no real slope triggers and, by inspection, there are no deflection ratio triggers.

5.6. Hanover Square - west





The following points are noted:

- The full length of the PLP profile in front of the façade of 20 and 21 Hanover Square is within the GS5 array: data from all points at distances are presented.
- The key events are the WBRT in Period B and PTW and VD3 in Period E. It is noted that uplift due to grouting is more apparent than volume loss settlement. At the end of these activities the settlement was relatively uniform at 15 – 20mm.
- Subsequently in Period G there has been between 5 and 10mm settlement over a period of 8 months. The rate of post tunnel construction settlement is continuously reducing through Period G although the ETH excavation to level -3 and secondary lining works in the tunnels have been undertaken.
- The profile plot shows that there is less restraint to movement adjacent to the ETH piled wall (at distance 0) than on the building façade and the associated slope is much less than the Amber trigger.
- The increase in slope with time is showing a continuous decrease in rate with time and the slopes are now nearly stable.
- There are no slope triggers and, by inspection, there are no deflection ratio triggers.

6. DISCUSSION

The preceding presentation of settlement monitoring data shows that the Compensation Grouting Performance Criteria (CGPC) on slope has been exceeded in a number of locations within the footprint of the arrays installed from Grout Shaft 5. The data also show that, in some locations the slopes continue to increase, albeit generally at a slow and decreasing rate.

It is noted that the use of concurrent compensation grouting to reduce the volume loss settlements associated with tunnelling has been achieved, however, a number of particular issues have become apparent as the works have progressed:

- Significant movements occurred prior to the commencement of tunnelling due to installation of the compensation grouting TaMs as well as from works by others (piling, and excavation of the Masterplan Shaft and North west shaft) ;
- Pre-treatment reversed these movements within the constraints of the Works Information which limits uplift to 5mm.
- The grout shaft location is far from ideal being directly over AP3A and in close proximity to the ETH piled wall and adjacent structures;
- The combination of exclusion zones for the ETH, the grout shaft and the tunnel face placed significant constraints on concurrent grouting for AP3A.
- The contour included in the Settlement Assessment for 20 Hanover Square (C122-OVE-Z-RGN-C125-50007 Rev. 3.0, Figure 5) indicated that, based on a conservative assessment methodology, the maximum movement would be expected adjacent to the ETH piled wall whereas this has provided significant restraint to movement giving a totally different distribution of settlement;
- Grout jacking to reverse settlements although necessary to comply with the CGPR is not always the optimal course of action: the reversal of movements of structure is not a linear elastic situation, there is the potential for significant damage to occur even if the recorded settlements are negligible;
- Although slope triggers have been exceeded, these were intended to be a simple method of ensuring the deflection ratio did not exceed the value associated with Negligible damage (the Amber trigger): this value has not been exceeded;
- Grout jacking has been attempted on numerous occasions to reduce settlements in the immediate vicinity of GS5; up to 400mm equivalent thickness of grout has been injected, the maximum anywhere on the C300.C410 project. This has not been effective for a number of reasons, inter alia,
 - High pressure refusals attributed to the high density of TaMs adjacent to the shaft
 - Connections between TaMs and shaft with loss of grout
 - Restraint to uplift from the shaft itself and from the adjacent piled wall
- Tunnelling was completed in August 2014, almost 8 months ago: the increase in movements has been reviewed on a daily, weekly and monthly basis at SRG and CTC meetings and it has been concluded that further grouting to reduce movements could not be justified and therefore none has been undertaken.

7. CONCLUSION

It is concluded that no further grouting from GS5 will be required and that the Grout shaft can be decommissioned. The key factors leading to this conclusion are:

- It is 8 months since the completion of tunnelling and compensation grouting: ongoing post construction settlements have been under continual review at daily, weekly and monthly review meetings. No grouting has been deemed necessary;
- The potential for additional movements as a result of the ongoing ETH excavation have been considered based on the assessments carried out by C122 for CRL: BFK and CRL agree that the movements are likely to be considerably less than these values based on observed performance to date;



- Settlements which have occurred which caused exceedance of the CGPR does not necessarily require grout jacking to reverse these movements: it has been shown on a number of occasions that damage can worsen even though slopes and deflection ratios are decreased. BFK has always considered that the *raison d'être* of the Specification is to minimise damage notwithstanding the contractual implication of exceeding Performance Criteria.
- The CRL nominated location for GS5 is far from ideal being located directly over one of the largest tunnels and being in very close proximity to the ETH and some of the more sensitive buildings to be protected;
- The majority of the building on which the CGPR have been exceeded are due for demolition;

Learning Legacy Document

Appendix A

Assumptions used to produce contour plots of grout intensity

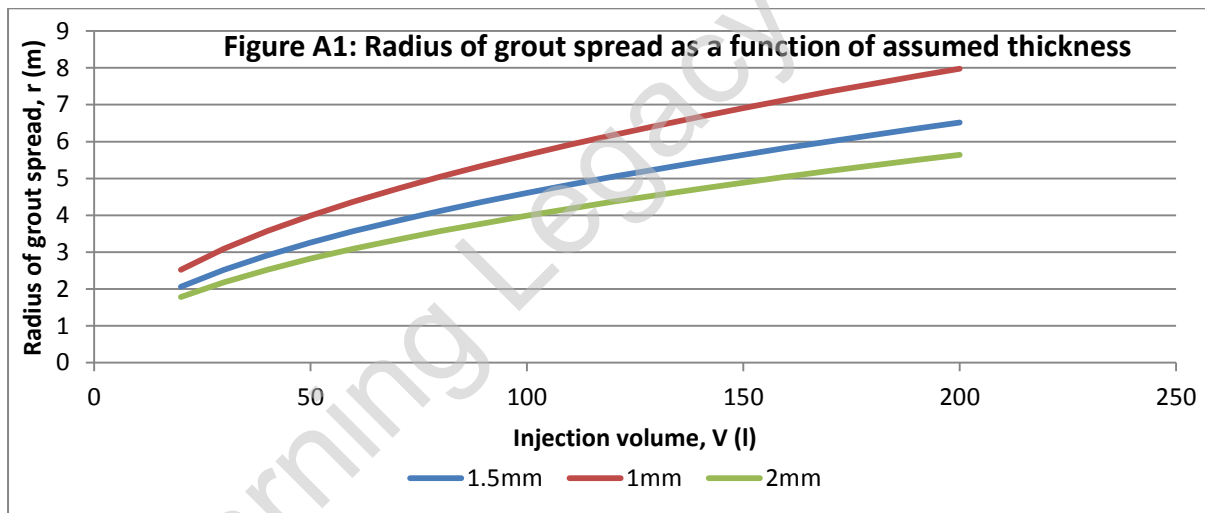
A method of producing a visualisation of the quantity and distribution of grout injected during compensation grouting is useful in interpreting performance. For each injection the volume and the location of the port used are known. The model used is intended to approximate the distribution of grout within the ground at the level of injection not to estimate the potential heave / settlement reduction from the grouting. Of course the actual distribution of grout in the ground cannot be determined since this is determined by the stress conditions at the time of injection which is constantly changing during the construction process. It is known that in London Clay the grout enters the ground by hydrofracturing along pre-existing fissures, but the direction of travel is not fully known.

The model used adopts the simple assumption that the grout spreads uniformly in all directions radially from the point of injection to form a disc of uniform thickness, t . The radius, r , to which the grout spreads from each individual injection point is therefore a function of the grout volume, V , according to the relationship:

$$V = \pi r^2 t$$

Or, rearranging:

$$r = \sqrt{\left(\frac{V}{\pi t}\right)}$$

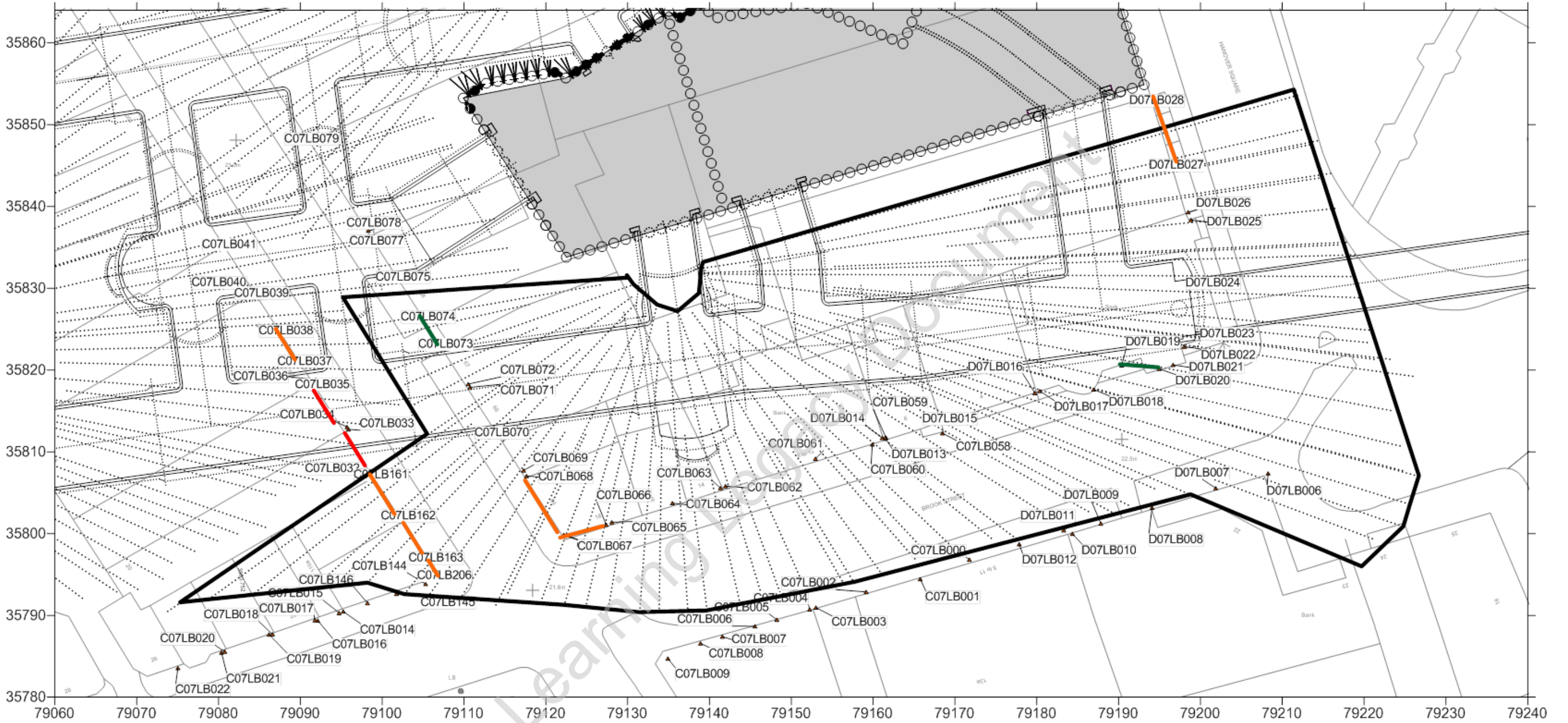


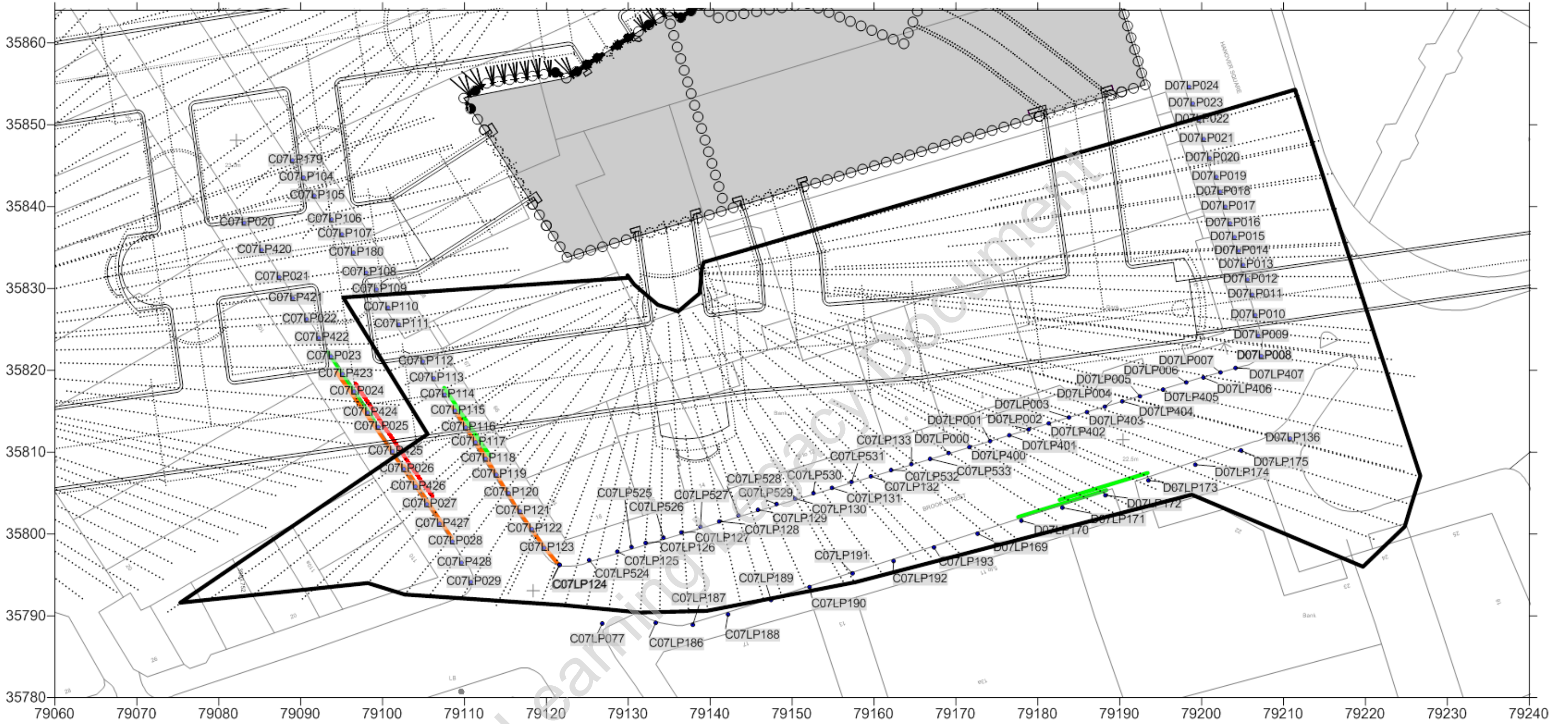
Observations of grout in the ground suggests that a thickness of 1 – 2mm is predominantly achieved. All of the plots included in this report are based on an assumed thickness of 1.5mm. Figure A1 shows the variation in radius for thicknesses of 1.0, 1.5 and 2.0mm.

The contribution of each injection within a specified data set are summed at each node within a grid. This grid file is then contoured within Surfer.

Appendix B

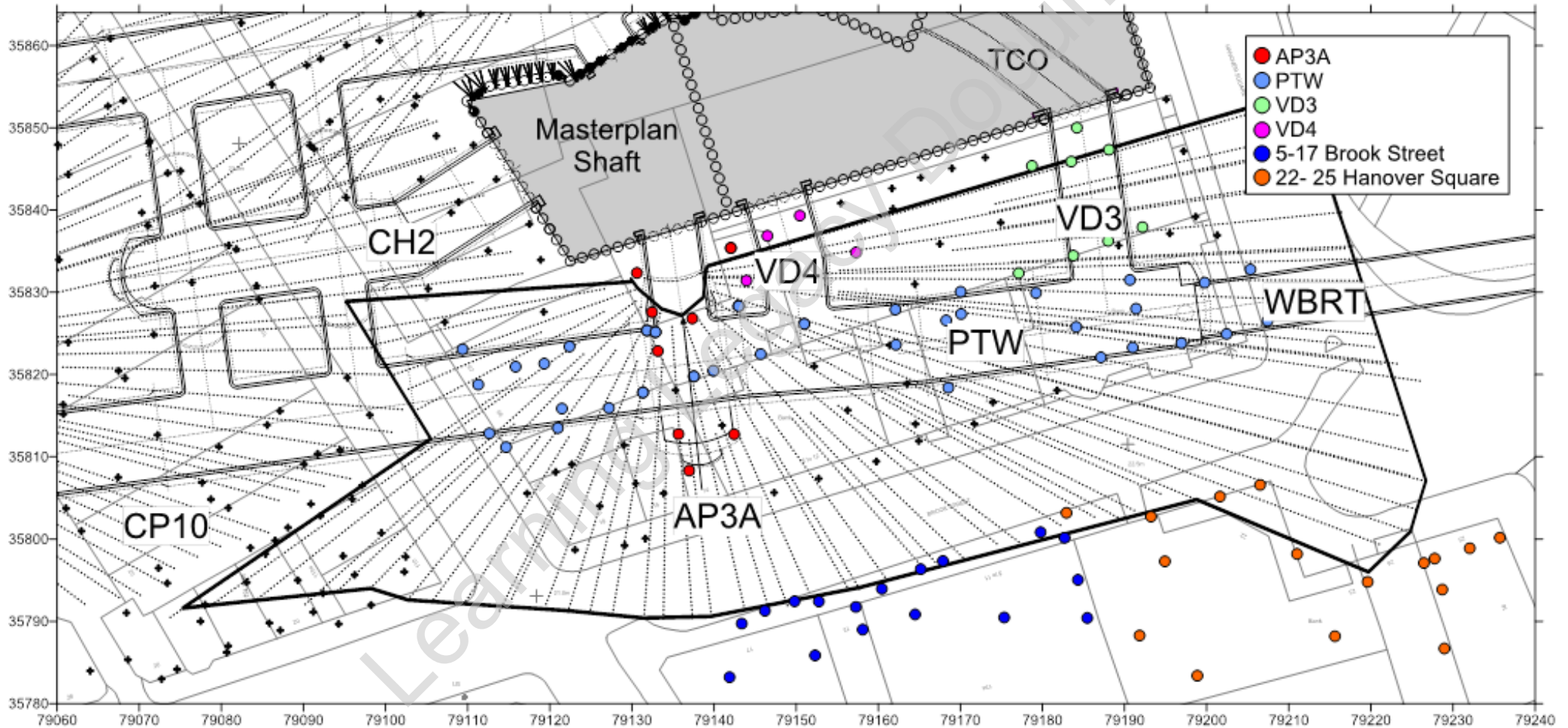
Enlarged version of Figures 4.1 and 5.1 showing location of monitoring point and slope triggers



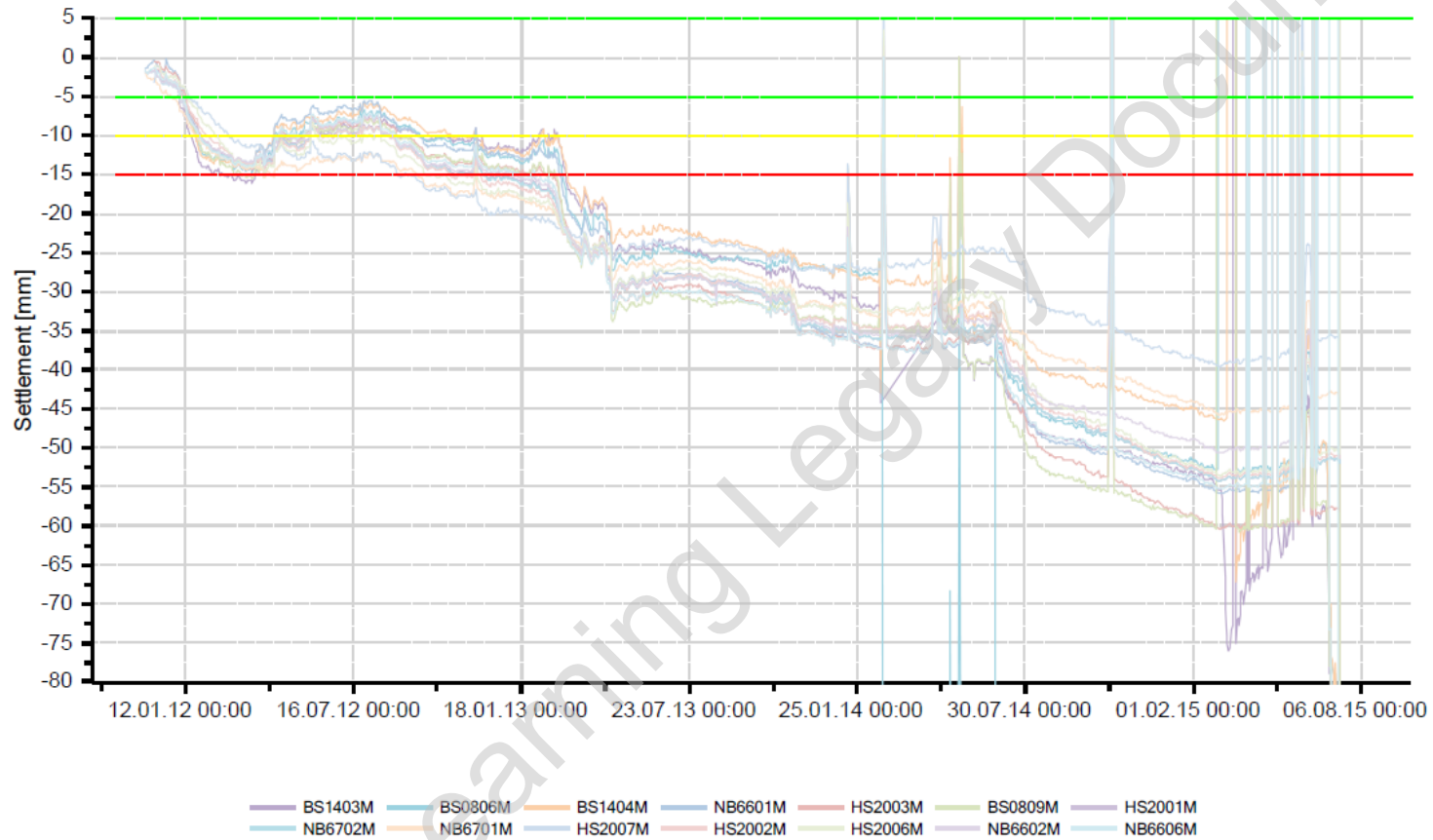


Appendix C

Examples of HLC time plots from Gtc database: Location of sensors

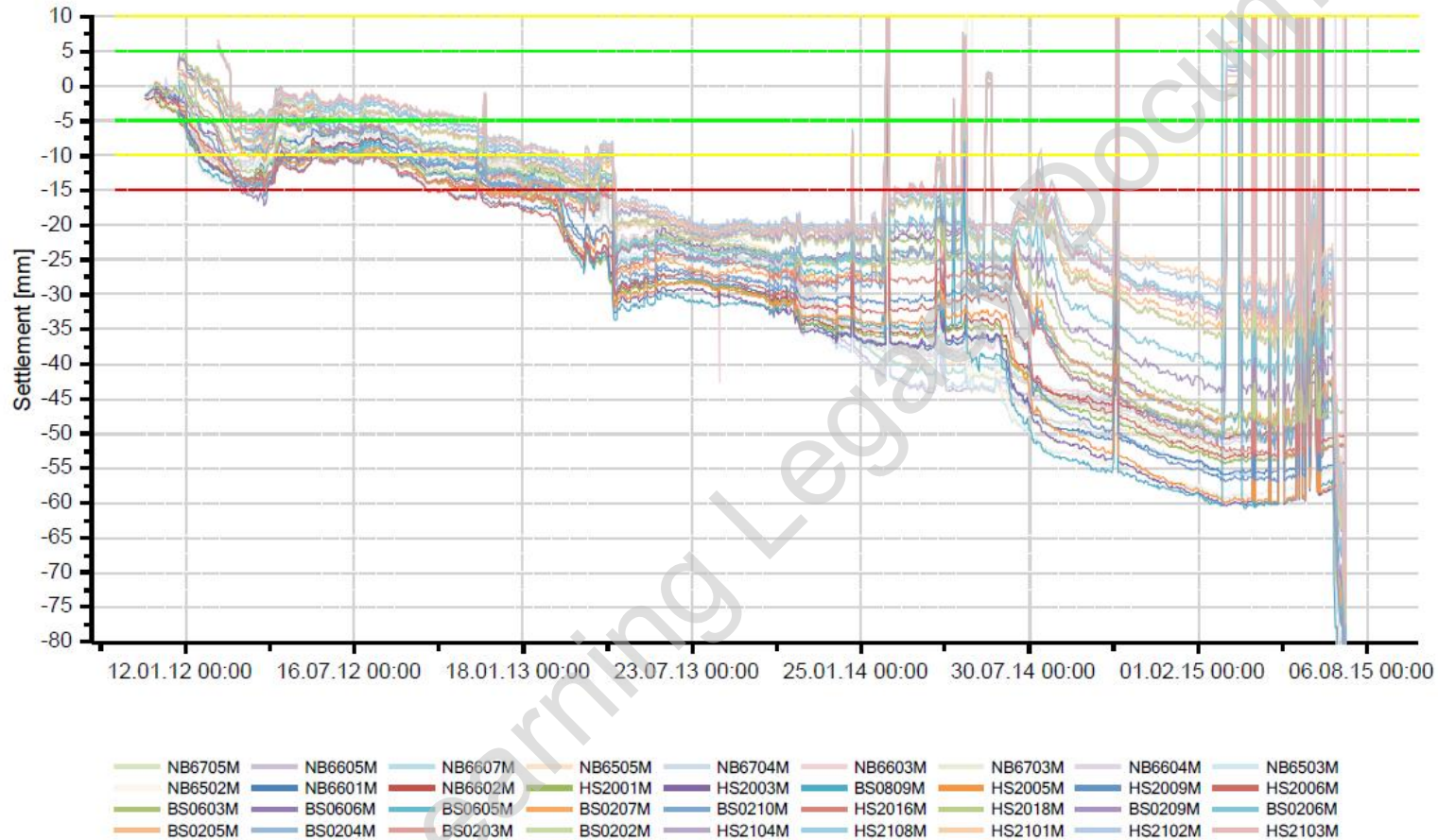


AP3A



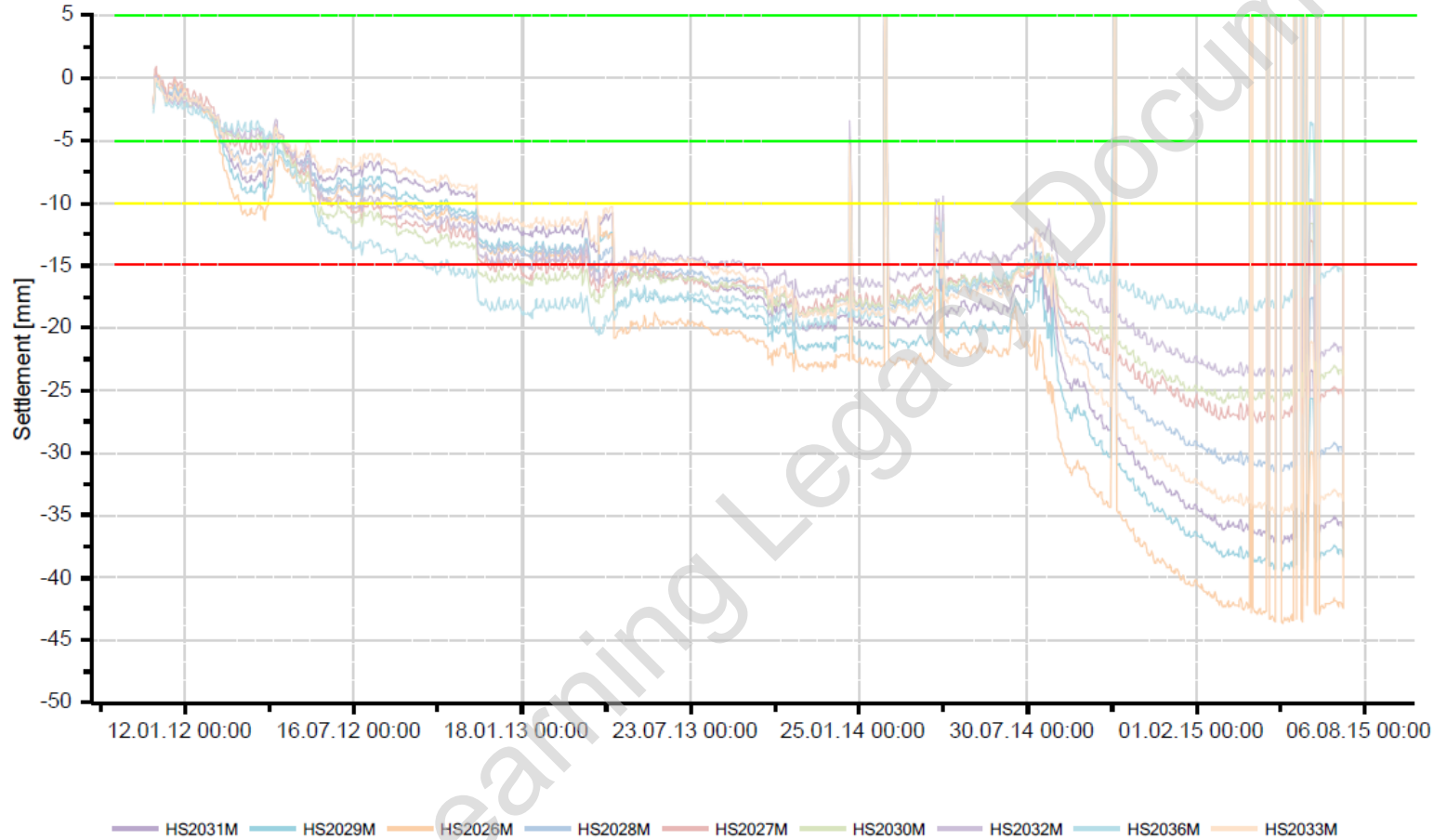
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Date of Measurement: 10.10.2015 09:12

PTW

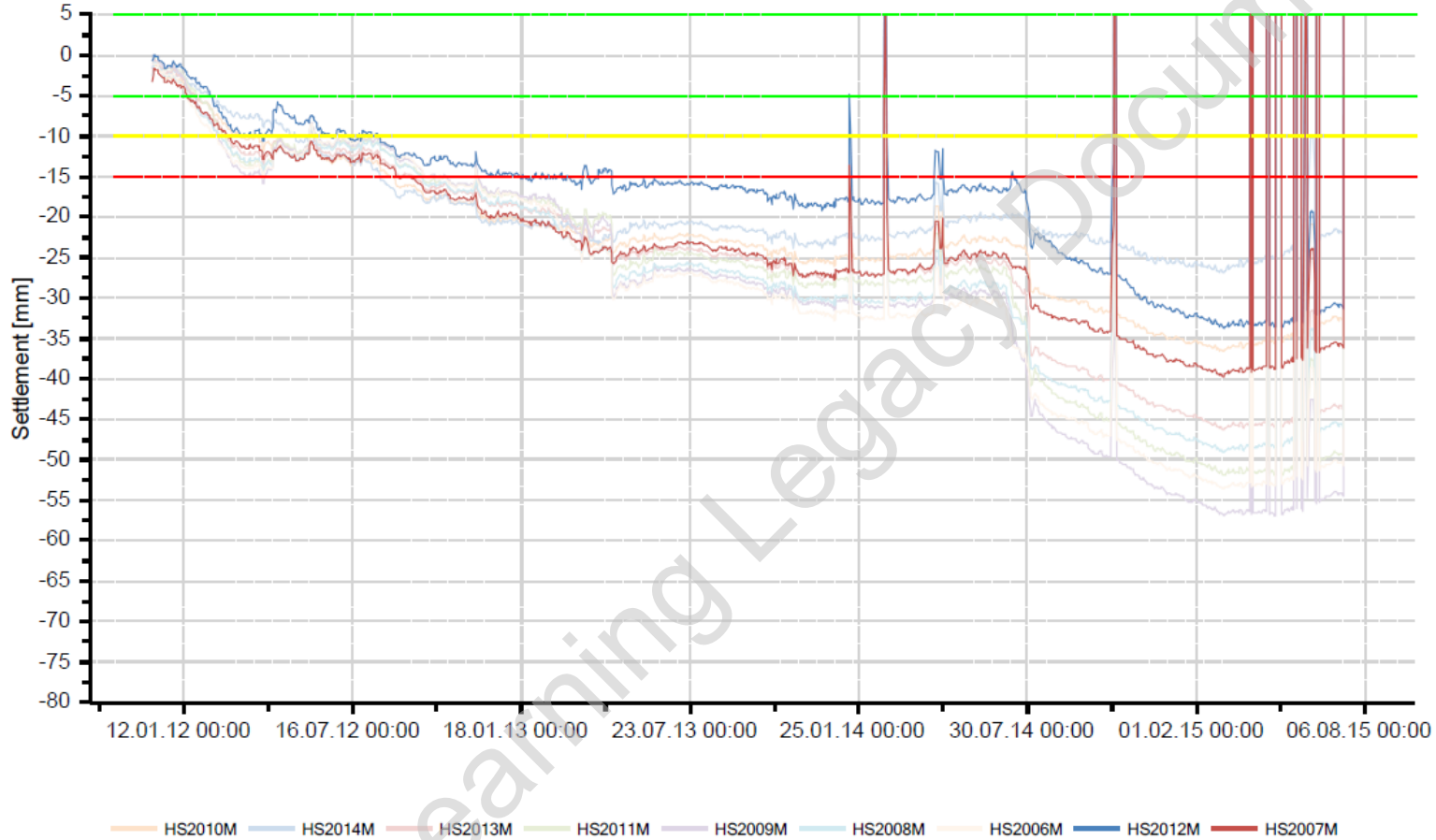


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VD3

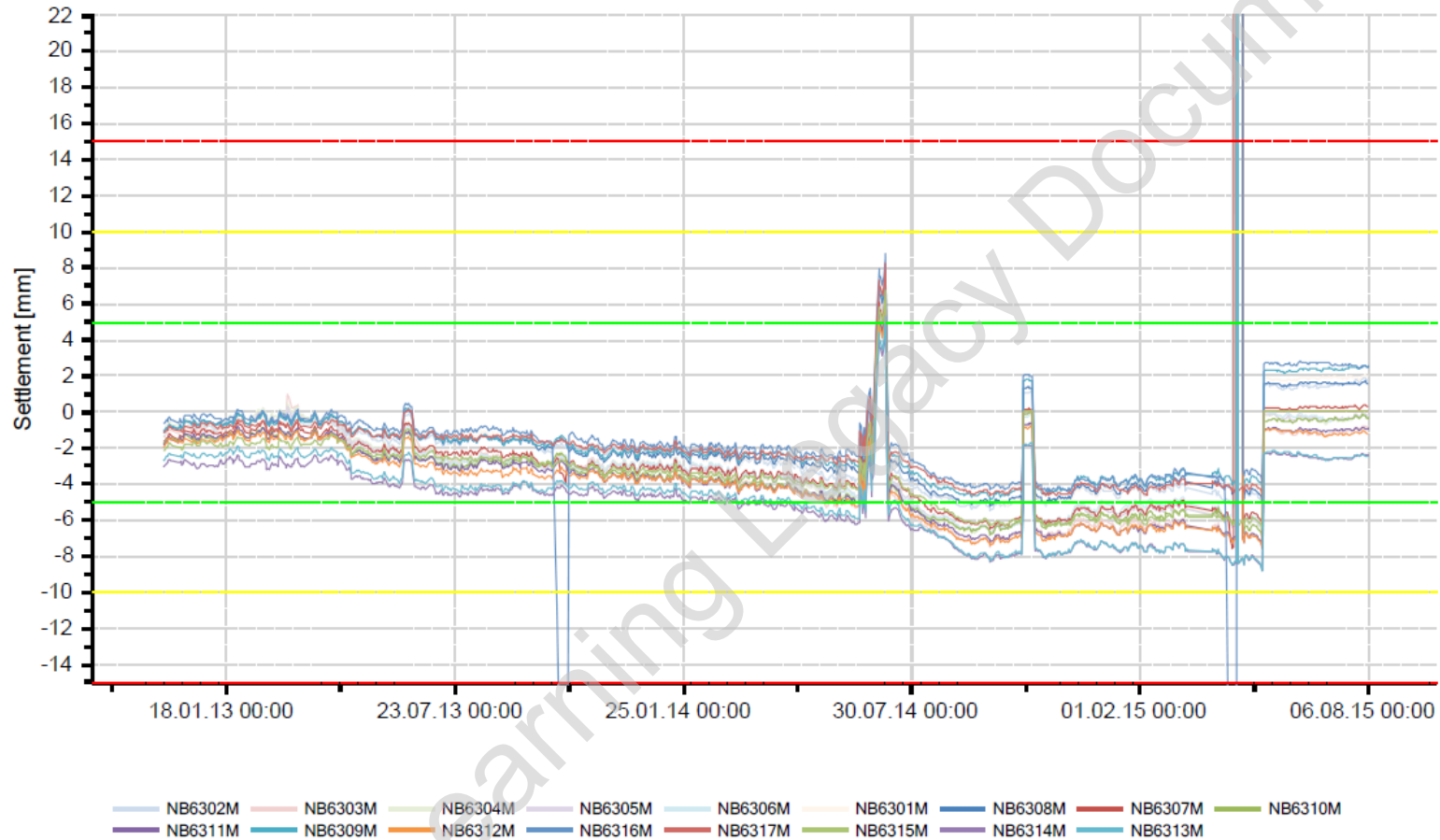


VD4



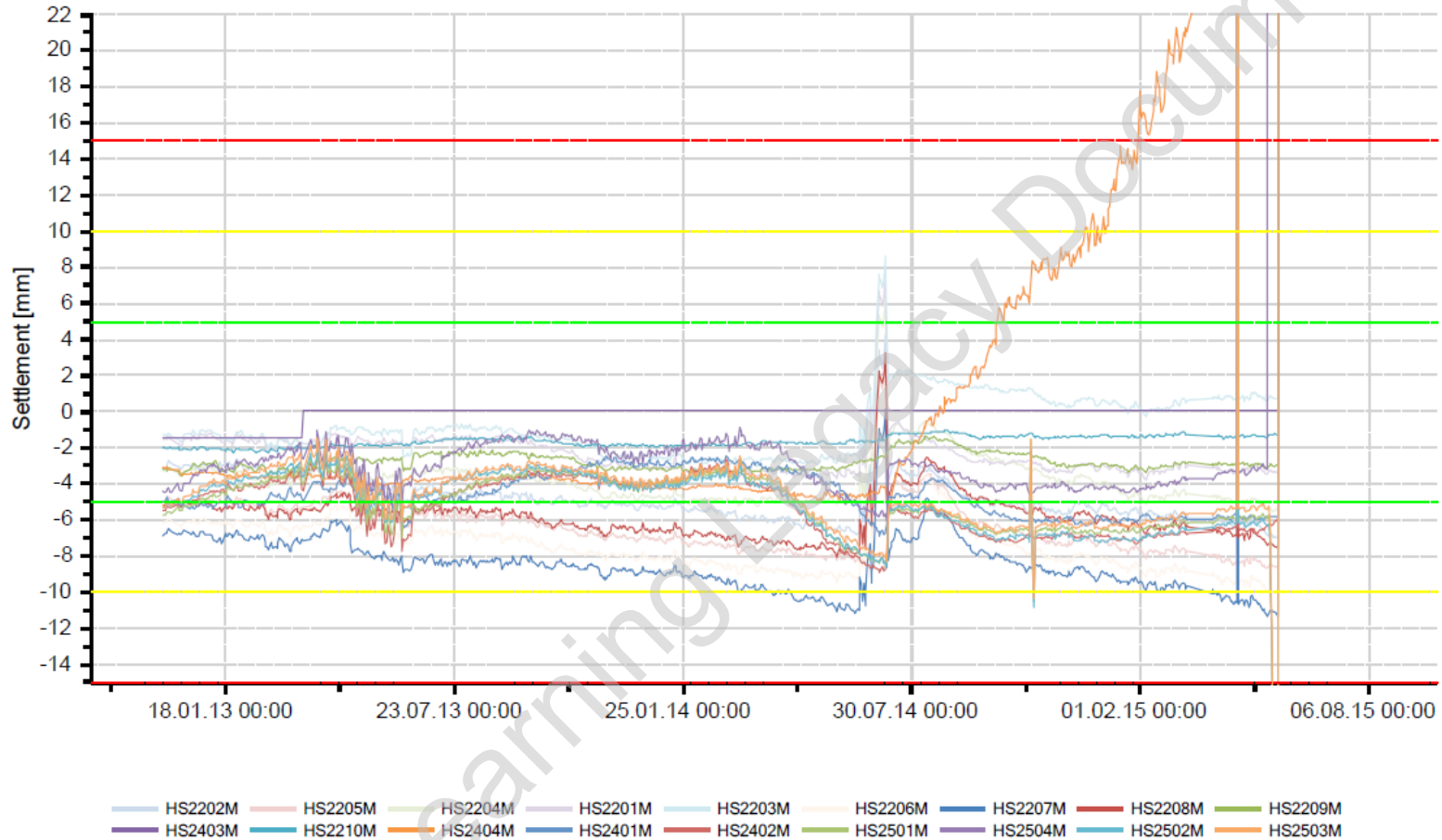
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Date of Measurement: 10.10.2015 09:12

5-17 Brook Street



Project: Bond_Street
Reference Date: none
Date of Measurement: 10.10.2015 09:12

22-25 Hanover Square



Project: Bond_Street
Reference Date: none
Date of Measurement: 10.10.2015 09:12