C300/410

Western Tunnels & Caverns Project

Report

Grouting Summary & I &M Final Report - BOS GS2

CRL Document No. **C300-BFK-C4-RGN-CRT00_ST005-51179**

Contract MDL reference: C14.020

1. Contractor Document Submittal History

Revision	Date	Prepared by	Checked by	Approved by	Reason for Issue
3.0	11 Nov 2015	[redacted]	[redacted]	[redacted]	For acceptance
		[redacted]	[redacted]	[redacted]	

2a. Stakeholder Review Required? YES ☐ NO ☒

Stakeholder submission required: LU ☐ RfL ☐ NR ☐ LO ☐ DLR ☐ Other: _____

Purpose of submission: For no objection ☐ For information ☐

This document has been reviewed by the following individual for coordination, compliance, integration and acceptance and is acceptable for transmission to the above stakeholder for the above stated purpose.

Sign: _____ Name: _____ Role: _____ Date: _____

Sign: _____ Name: _____ Role: _____ Date: _____

2b. Review by Stakeholder (if required):

Stakeholder Organisation	Job Title	Name	Signature	Date	Acceptance
					☐
					☐

3. Acceptance by *Crossrail:*

Crossrail Review and Acceptance Decal

This decal is to be used for submitted documents requiring acceptance by Crossrail.

☒	Code 1:	Accepted. Work May Proceed
☐	Code 2.	Not Accepted. Revise and resubmit. Work may proceed subject to incorporation of changes indicated
☐	Code 3.	Not Accepted. Revise and resubmit. Work may not proceed
☐	[illegible]	Received for information only. Receipt is confirmed

Reviewed/Acce[redacted] by: (signature) Print Name: [redacted] Position: [redacted] Date: 19/2/16

Acceptance b[redacted] he designer/s[redacted] contractual o[redacted]s not constitute Crossrail approval of design, details, calculations, analyses, test methods or materials developed or selected by the designer/supplier.

Contents

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 2 and associated automatic monitoring 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 Specification for the Control of Ground Movement Clause 3.2.5.1 and 3.2.5.2.

All BFK excavation (tunnelling) works within the plan extent of the compensation grouting arrays from Bond Street Station Grout Shaft 2 were completed by mid July 2014, over 11 months ago. Grout jacking episodes were implemented within one month after completion of tunnelling. It is understood that excavation of the Eastern Ticket Hall (ETH) is ongoing and is not expected to be completed until the fourth quarter of 2015.

This report aims to summarise the relevant construction, compensation grouting and monitoring information for Grout Shaft 2 at Bond Street Station and provide justification for the decommissioning of the shaft and associated automatic monitoring.

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.

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.

2. CONSTRUCTION WORKS PROGRESS

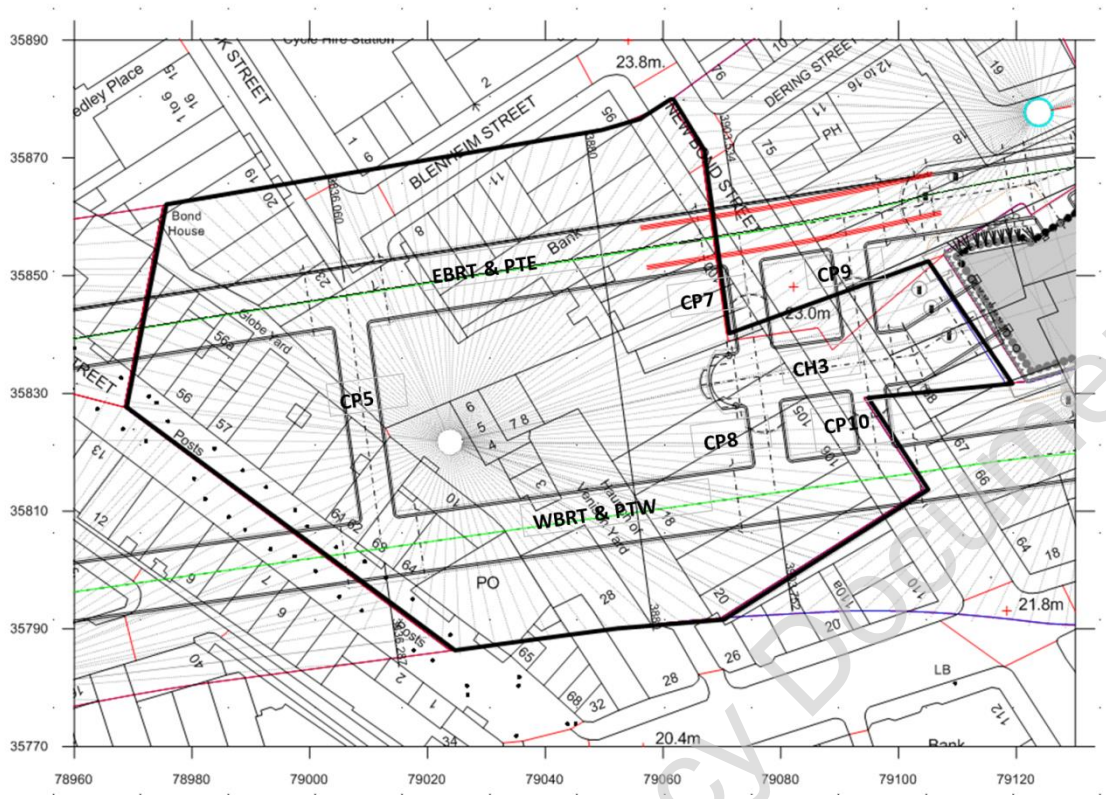
2.1. Tunnels

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 2 at Bond Street Station. Tunnel excavation commenced with the Westbound TBM in March 2013 and was completed with the excavation of CP9 stub from the PTE in July 2014. To facilitate comparison of monitoring data with construction activities 7 periods (A to G) have been assigned. Tunnelling was completed in 5 of these periods (B, C, D, 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 tunnelling works in BOS GS2 area.

	TUNNEL	ABB.	START DATE	NOTES	END DATE
Period B	Westbound Running Tunnel	WBRT	25/03/2013	from Ring nos: 1901 to 2300	06/04/2013
Period C	East Bound Running Tunnel	EBRT	05/06/2013	from Ring nos: 1901 to 2300	14/06/2013
	Lower Concourse Tunnel 3	CH3	29/05/2013	End CH: 49.94	15/07/2013
Period D	Cross Passage 8	CP8	28/07/2013	Excavated up to CH: 9.71	31/07/2013
	Cross Passage 10	CP10	31/07/2013	Excavated up to CH: 9.71	03/08/2013
	Cross Passage 7	CP7	03/08/2013	Excavated up to CH: 11.46	08/08/2013
	Cross Passage 9	CP9	09/08/2013	Excavated up to CH: 11.46	13/08/2013
Period E	Platform Tunnel Westbound (Enlargement)	PTW (West)	10/11/2013	Xmas shut down @ CH: 73.85: 10/12/13 to 05/01/14 Sequence Change @ CH: 137.75 25/01/14 Break @ CH 264.75: 28/03/14 - 16/04/14	09/02/2014
	Cross Passage 8 (Stub)	CP8 (out of PTW)	30/01/2014	Excavated up to CH: 11.62	02/02/2014
	Cross Passage 10 (Stub)	CP10 (out of PTW)	02/02/2014	Excavated up to CH: 11.62	04/02/2014
Period F	Cross Passage 9 (Stub)	CP9 (out of PTE)	08/07/2014	Excavated up to CH: 11.46	10/07/2014
	Cross Passage 5	CP5	21/04/2014	Excavated up to CH: 33.10	01/05/2014
	Platform Tunnel Eastbound Enlargement (west)	PTE (west)	10/05/2014	Changed Excavation Sequence @ CH: 68.00: 17/05/2014 Breaks for CPs: 18/06/2014 - 10/07/2014 @ CH: 164.48 30/07/2014 - 06/08/2014 @ CH: 189.48 Drive to westernmost end CH: 219.66	12/06/2014
	Cross Passage 5 (stub)	CP5 (out of PTE)	22/06/2014	9nos advances excavated	25/06/2014
	Cross Passage 7 (Stub)	CP7 (out of PTE)	05/07/2014	Excavated up to CH: 11.46	08/07/2014

Figure 2.1. Tunnels within extent of grout array from Grout Shaft 2



2.2. Other construction works

Works by BFK prior to the commencement of tunnelling in GS2 area included:

- Drilling for installation of TaMs
- Pre-treatment grouting
- Pre-TBM grout jacking
- AP3A (GS5 area)
- LCE1 & LCE2 (part – GS3 area)

Works by Others prior to the start of tunnelling included:

- Sinking of Grout Shaft 2
- Demolition for MPS
- Piling for MPS
- Excavation of the North west and Masterplan shafts
- Bonham's Underpinning and Excavation works

Works by Others during tunnelling with the potential to generate ground movements 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)
- Bonham's re-development

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 2015)
- Excavation of ETH to Level -5 (programmed to complete late 2015)

2.3. Compensation Grouting

The volume of grout injected from GS2 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 40m^3 injected prior to tunnelling, concurrent grouting approximately 430m^3 and grout jacking almost 190m^3. Concurrent grouting was undertaken with all tunnels except the Cross Passages 7 to 10, WBRT and EBRT. 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. CP7 to CP10 are short length tunnels and the extent of the exclusion zones over the tunnel face, 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 GS2 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 GS2 area.

Periods	Start Date	End Dates	Main Works
A	22/09/2011	24/03/2013	Bonhams Excavation works, MPS, GS2 Shaft Sinking GS2 Drilling and Pre-treatment grouting, [AP3A, LCE1/2 Pilot to Ch. 28.0; LCE1/2 enlargement to Ch. 7.4]
B	25/03/2013	29/05/2013	WBRT, Grout Jacking [LCE1/2 Pilot to Ch. 33.0; LCE1/2 enlargement to Ch. 33.0]
C	30/05/2013	15/07/2013	EBRT, CH3, Concurrent grouting and Grout Jacking (post WBRT grouting)
D	16/07/2013	10/11/2013	CP8, CP10, CP7, CP9, Grout Jacking
E	11/11/2013	09/02/2014	PTW(west), CP8(out of PTW), CP10 (out of PTW), Concurrent grouting, Grout Jacking
F	10/02/2014	10/07/2014	CP9(out of PTE), CP7(out of PTE), CP5, CP5(stub), PTE(west), Concurrent Grouting, Grout Jacking
G	11/07/2014	26/06/2015	ETH Excavation below level -2, Grout Jacking

Figure 2.2 Volume of grout injected from GS2 by grouting type.

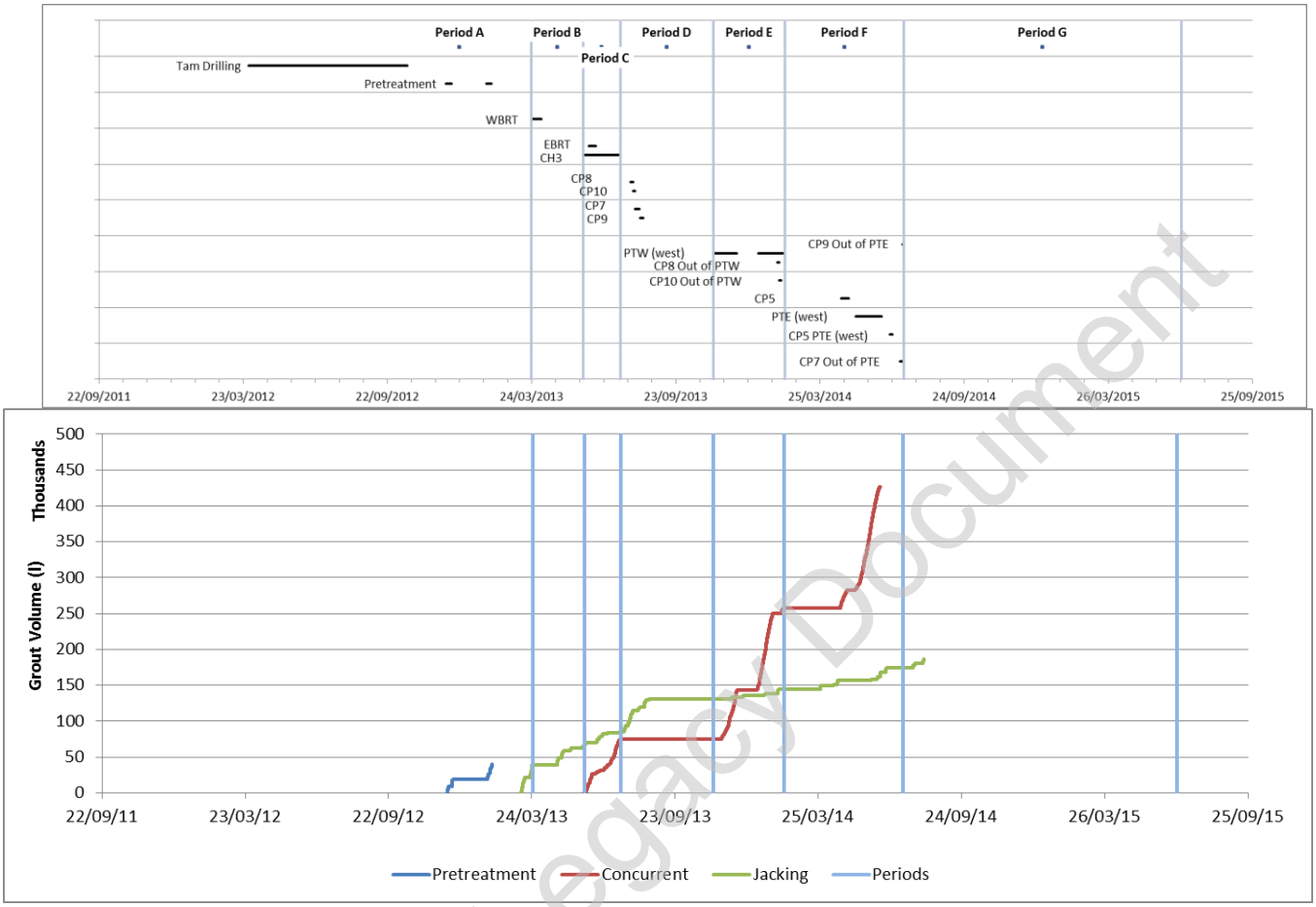


Figure 2.3 Distribution of grout injected from GS2: Pretreatment grouting. Grout Intensity (l/m^2).

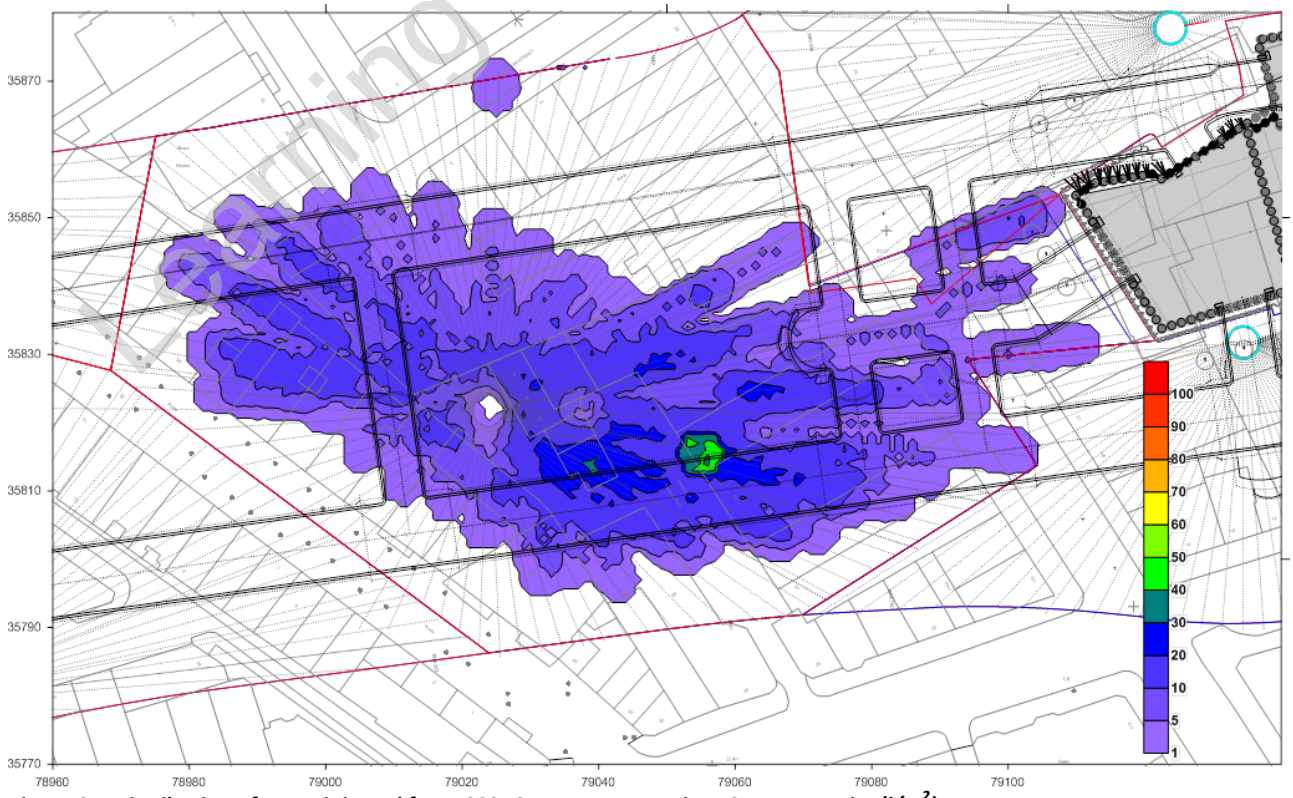


Figure 2.4 Distribution of grout injected from GS2: Concurrent grouting. Grout Intensity (l/m^2).

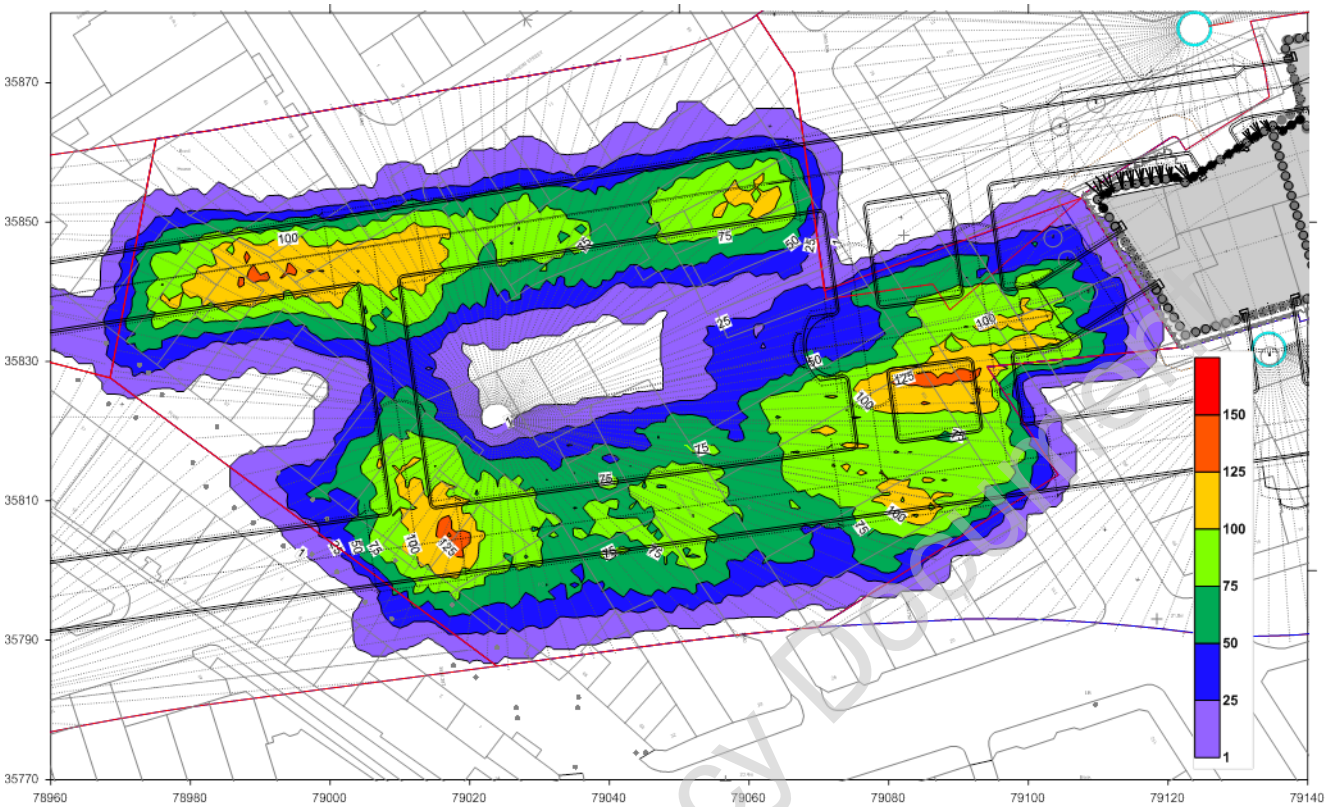


Figure 2.5 Distribution of grout injected from GS2: Jack grouting. Grout Intensity (l/m^2).

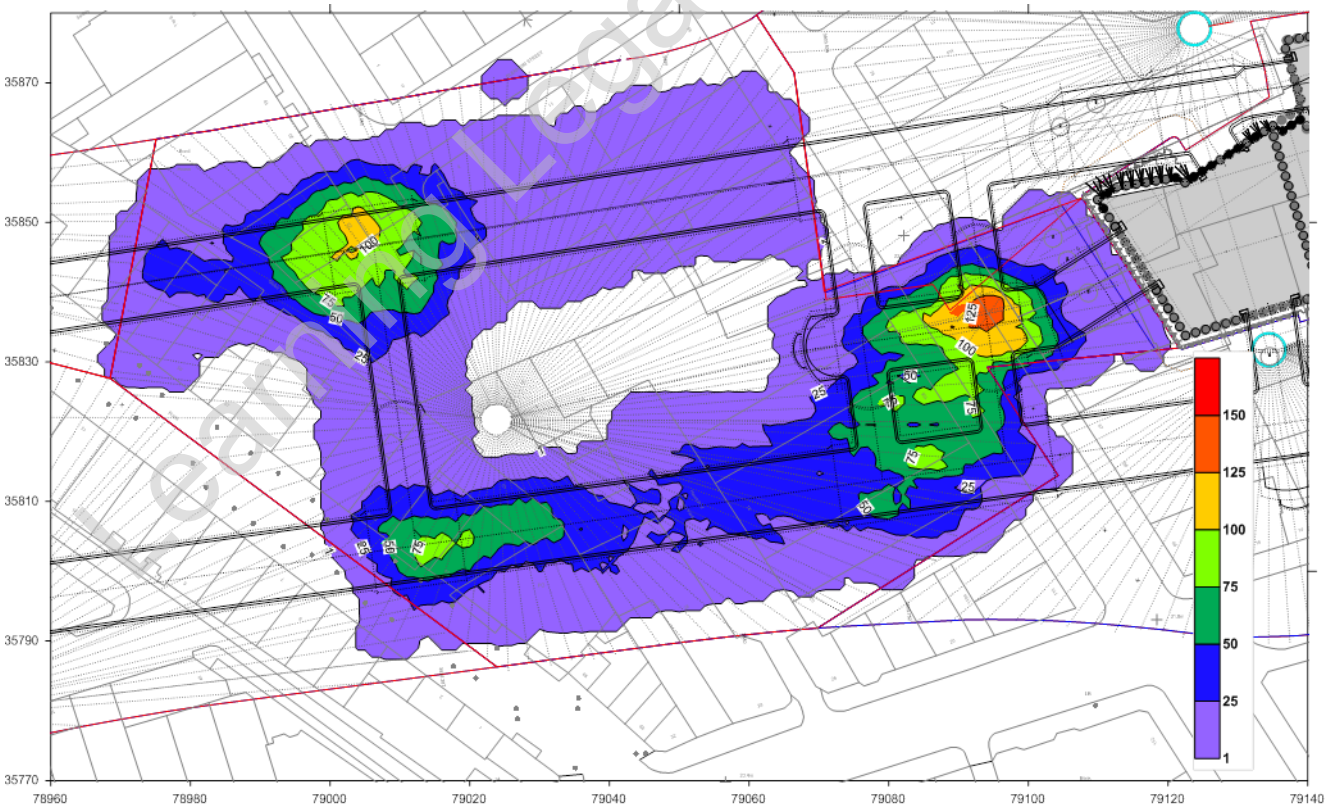
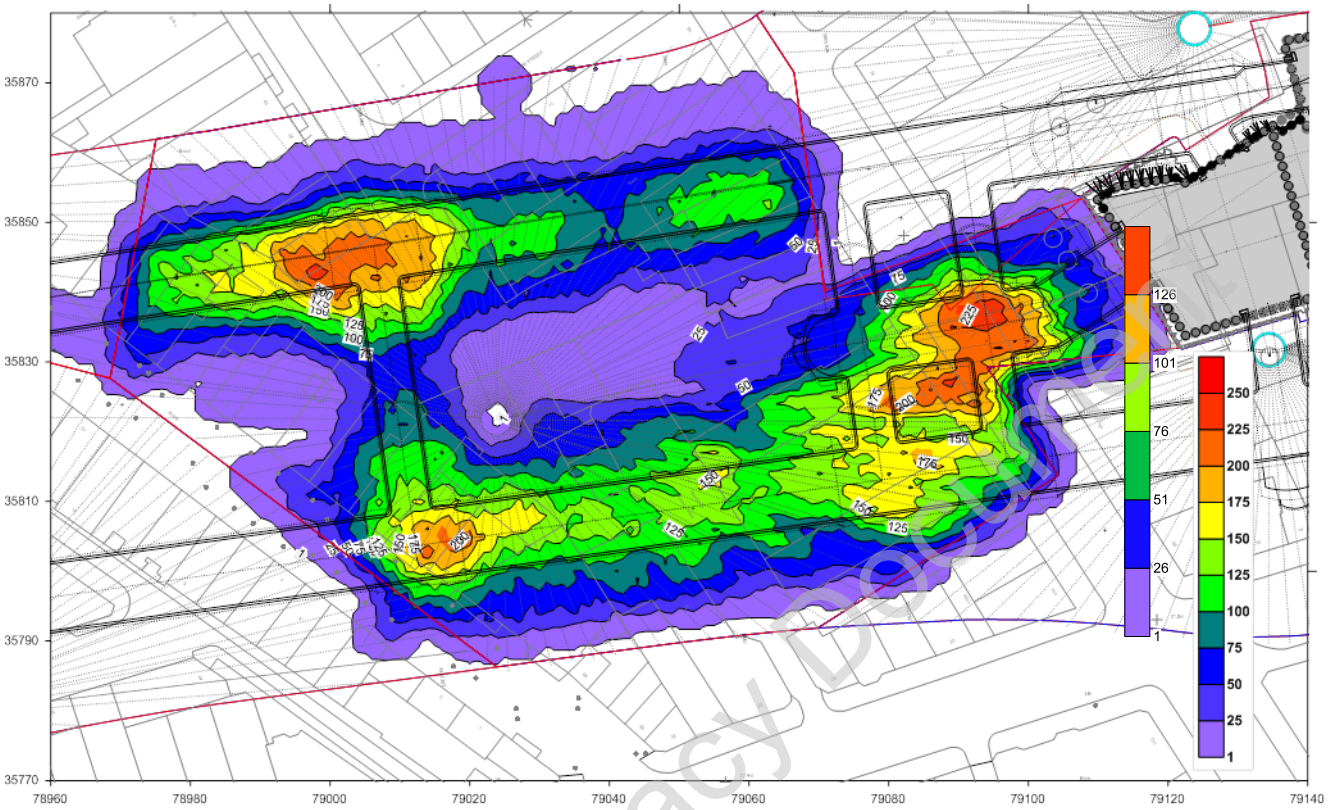


Figure 2.6 Distribution of grout injected from GS2: All grouting. Grout Intensity (l/m^2).



3. COMPARISON OF OBSERVED AND PREDICTED SETTLEMENT

3.1. SETTLEMENT OVERVIEW

Contours of total predicted short term settlement (supplied on C122) are shown in Figure 3.1.1. The measured settlement to May 2015, including consolidation settlement during the period of construction and for a period of 11 months after tunnelling was complete in the GS2 area, is shown in Figure 3.1.2.

The following points are noted:

- Settlements are generally less than or similar to 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 settlements at the east end of the GS2 area are less than predicted (70mm maximum contour cf. 120mm): the difference is most marked adjacent to the west wall of the Masterplan shaft where the maximum settlement is 50mm;
    - Over the platform tunnels the recorded magnitude of settlement is similar to that predicted (40 to 50mm) whereas between the tunnels the observed settlement is greater than predicted (minimum 30mm contour cf. 20mm);
    - the extent of the zone of settlement on the southern boundary of GS2 is greater than predicted with 20mm settlement recorded at the 10mm predicted contour and 5mm at the 1mm predicted contour;
    - the settlement on the northern boundary of GS2 is greater than predicted with 15 to 20mm settlement recorded at the 10mm predicted contour, however within the limits of the data, the 1mm contour appears at a similar location.

Figure 3.1.1 Predicted settlement contour (mm) (supplied by C122)

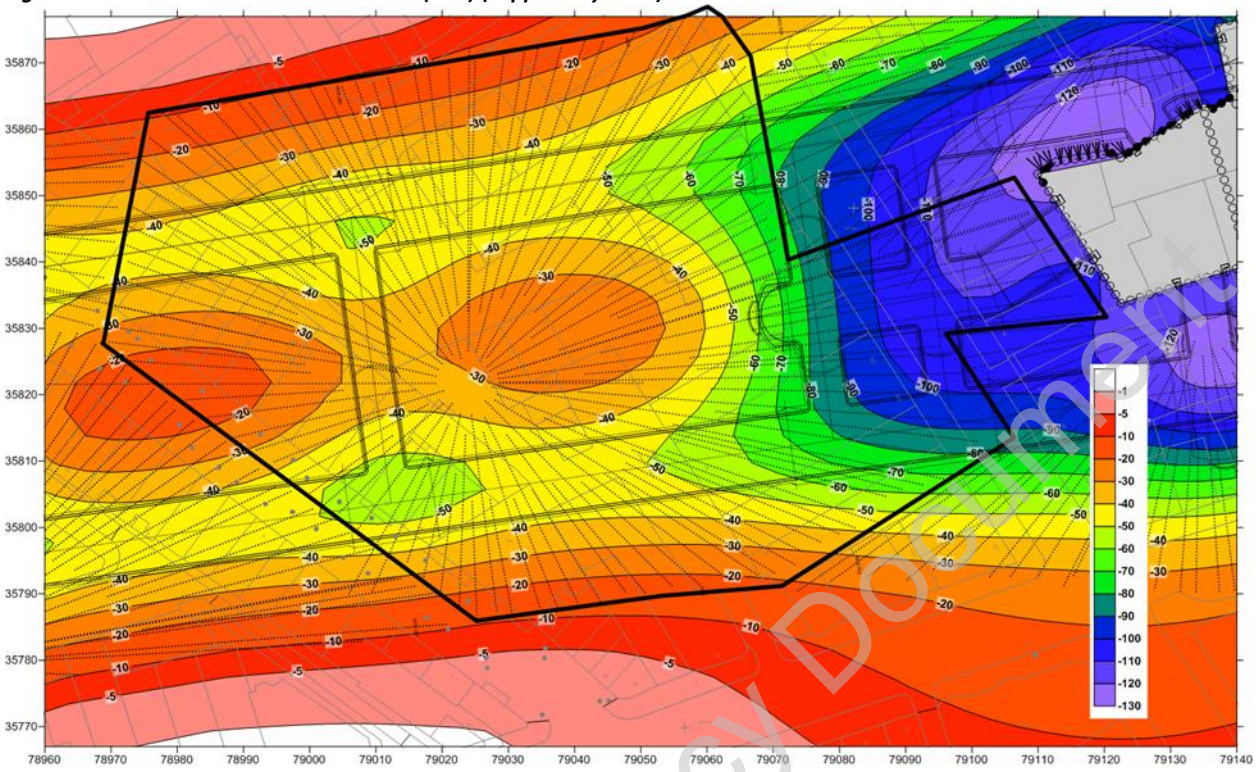
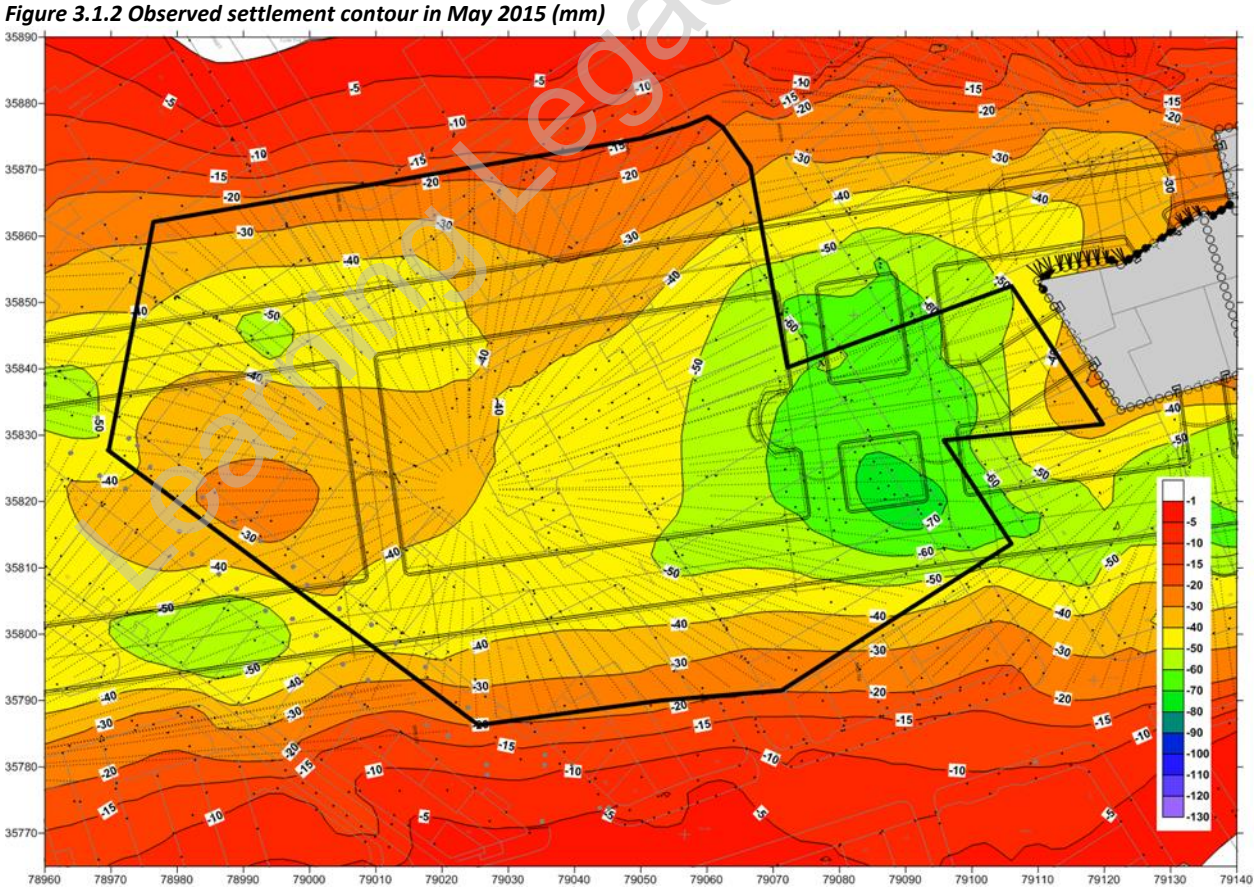


Figure 3.1.2 Observed settlement contour in May 2015 (mm)



In order to compare the predicted and actual movements at various stages of construction the overall monitoring period from September 2011 to date (June 2015) has been divided into a number of periods, based largely on tunnel excavation. The dates of each period and the associated construction activities 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 GS2 area.

Periods	Start Date	End Dates	Main Works
A	22/09/2011	24/03/2013	Bonhams Excavation works, MPS, GS2 Shaft Sinking GS2 Drilling and Pre-treatment. [AP3A, LCE1/2 Pilot to Ch. 28.0; LCE1/2 enlargement to Ch. 7.4]
B	25/03/2013	29/05/2013	WBRT [LCE1/2 Pilot to Ch. 33.0; LCE1/2 enlargement to Ch. 33.0]
C	30/05/2013	15/07/2013	EBRT, CH3
D	16/07/2013	10/11/2013	CP8, CP10, CP7, CP9
E	11/11/2013	09/02/2014	PTW(west), CP8(out of PTW), CP10 (out of PTW)
F	10/02/2014	10/07/2014	CP9(out of PTE), CP7(out of PTE), CP5, CP5(stub), PTE(west)
G	11/07/2014	26/06/2015	ETH Excavation

3.2. Period A – Prior to tunnelling in GS2 area: 22/09/11 – 24/013/13

Period A includes all of the preparatory work prior to the commencement of tunnelling at the Eastern Ticket Hall site, including demolition, piling and excavation of the Masterplan and North-West Shafts, as well as significant 3rd party works (Bonhams). BFK works comprised the drilling and pre-treatment of TaMs from GS5. BFK SCL works had also commenced from the MasterPlan shaft as detailed in Table 3.1

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 North-west shaft contribution is probably minor but contours are not available for the Masterplan shaft alone.

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 entirely completed in Period A and, consequently, the contours of grout intensity shown in Figure 3.2.3 are identical to those in Figure 2.3. Grout jacking ahead of the TBM drives was also undertaken as shown in Figure 3.2.4.

A maximum settlement of over 15mm was produced by the preparatory works with more generally 5mm to 10mm over almost the majority of the footprint of the grouting arrays. It is notable that the greatest settlement is adjacent to the MasterPlan west wall. The observed settlement was much lower than the predicted value of ~50mm. The effect of the SCL works in the GS3 and GS5 areas is evident in the contour, however there is negligible impact in the GS2 area.

The contours of grout intensity show that during pretreatment efforts was concentrated in the area of maximum settlement to the west of New Bond Street: over the majority of the area less than 20l/m^2 was required to complete pre-treatment (uplift 3 – 5mm). It is noted that grout injections were undertaken during drilling due to the magnitude of observed settlement. These injections were undertaken without sophisticated recording of the data: consequently the

volumes injected are not included in the contour and as a result the actual intensity is somewhat higher than indicated in Figure 3.2.3.

Grout jacking targeted at generating approximately 50% of the expected volume loss settlement from the WB TBM drive was commenced in Period A. Figure 3.2.4 shows the contours of grout intensity are generally between 5 and 10 l/m^2.

Figure 3.2.1. Period A: Total predicted settlement from ETH MasterPlan and North west shafts (mm) (supplied by C122)

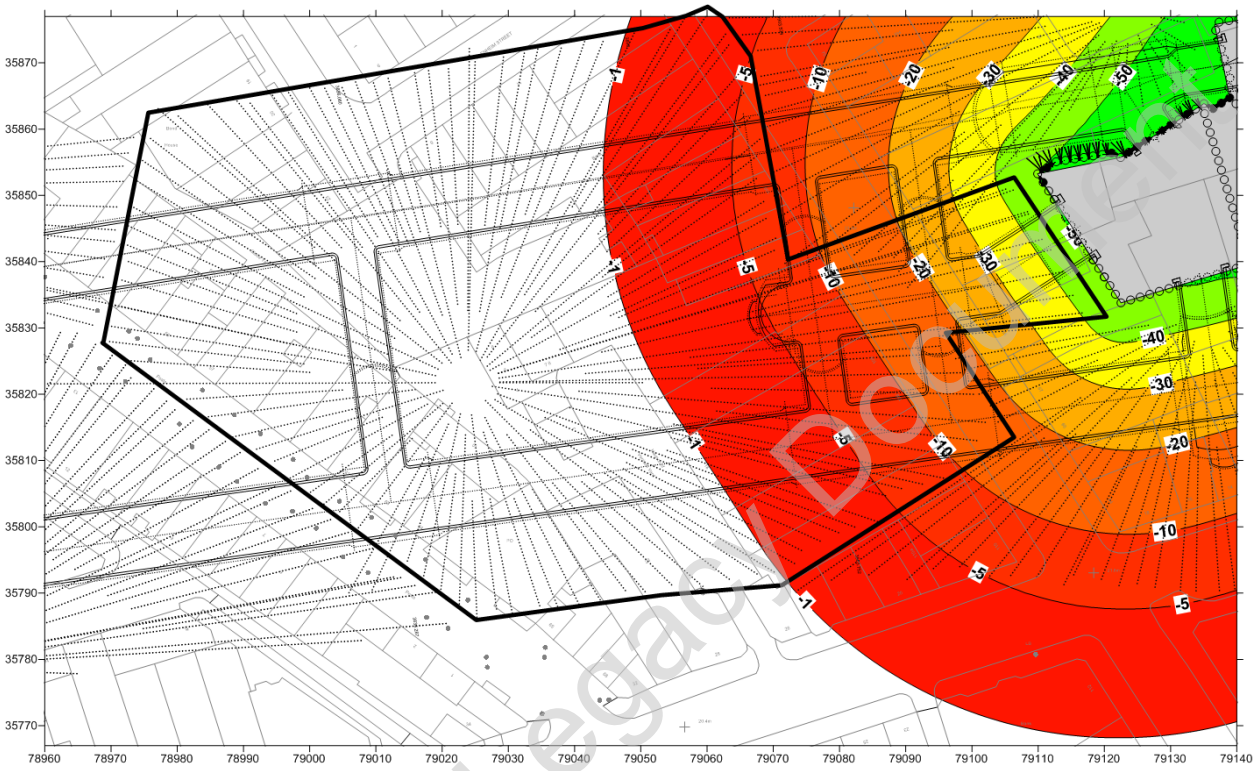


Figure 3.2.2. Period A: Total measured settlement (mm)

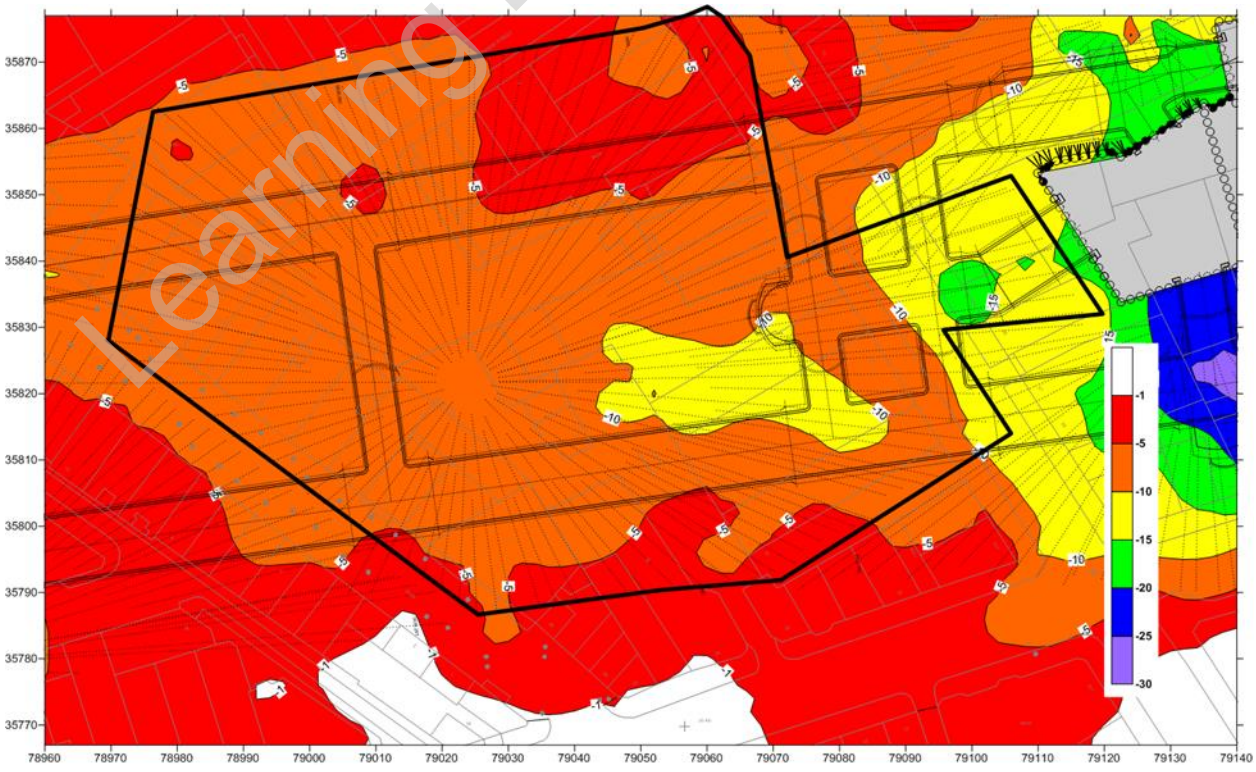


Figure 3.2.3 Distribution of grout injected from GS2: Pretreatment grouting. Grout Intensity (l/m^2).

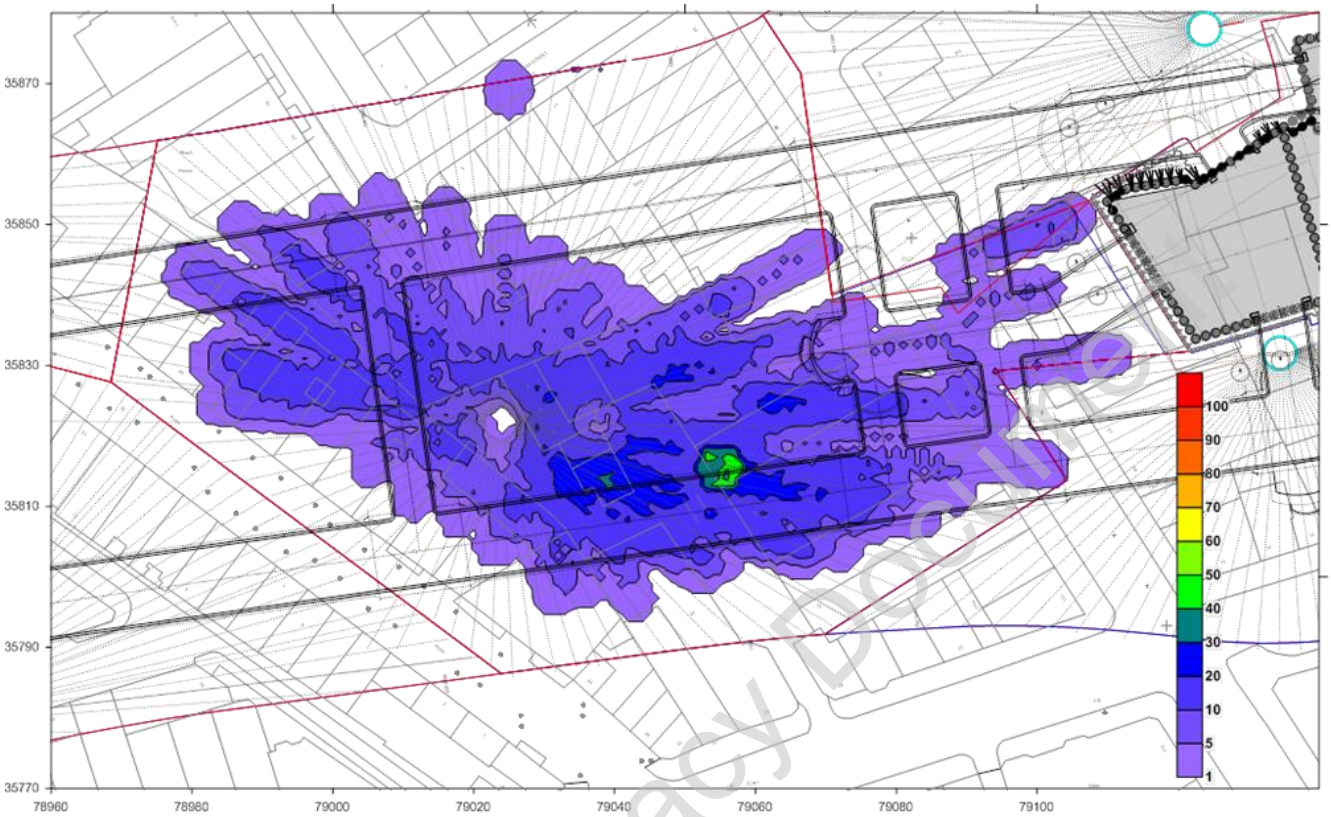
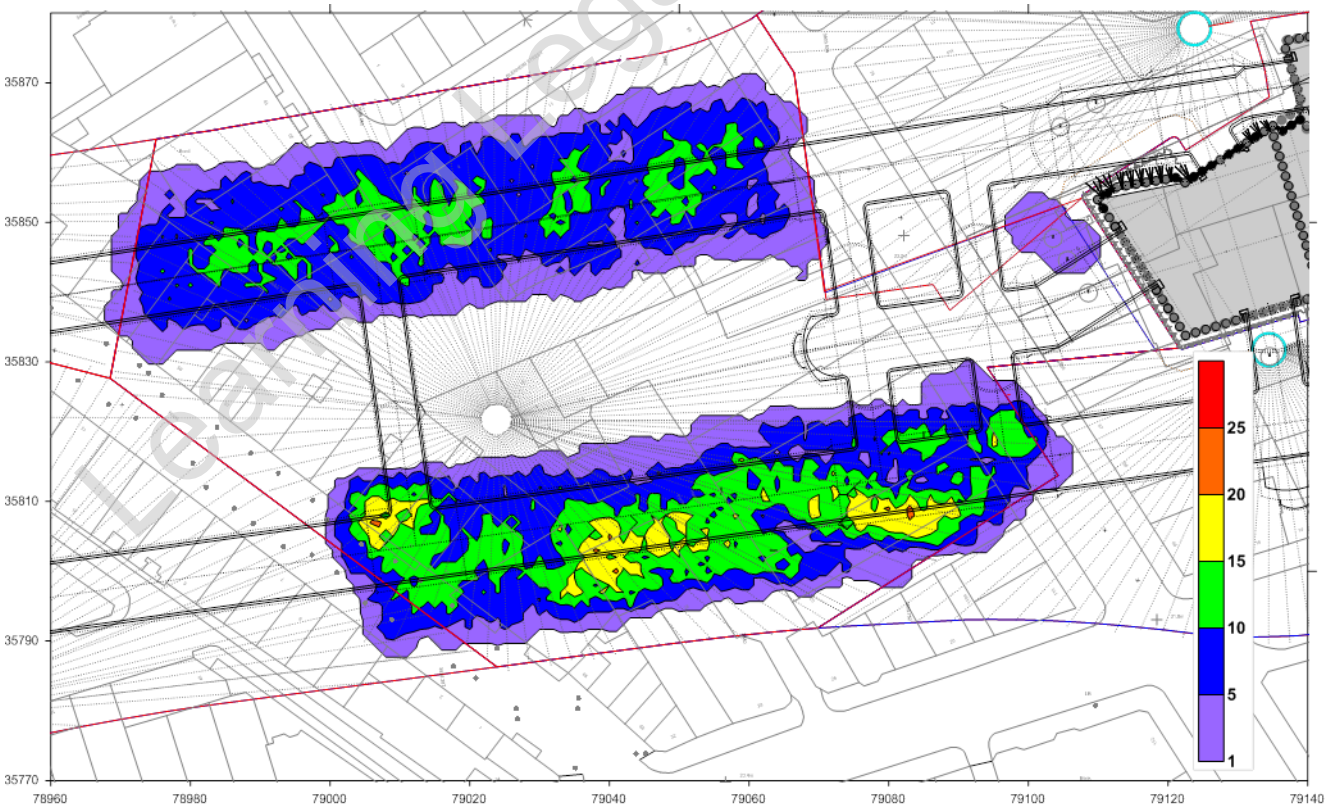


Figure 3.2.4 Distribution of grout injected from GS2: Pre-TBM Grouting Jacking. Grout Intensity (l/m^2).



3.3. Period B – WBRT: 25/03/13 – 29/05/13

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

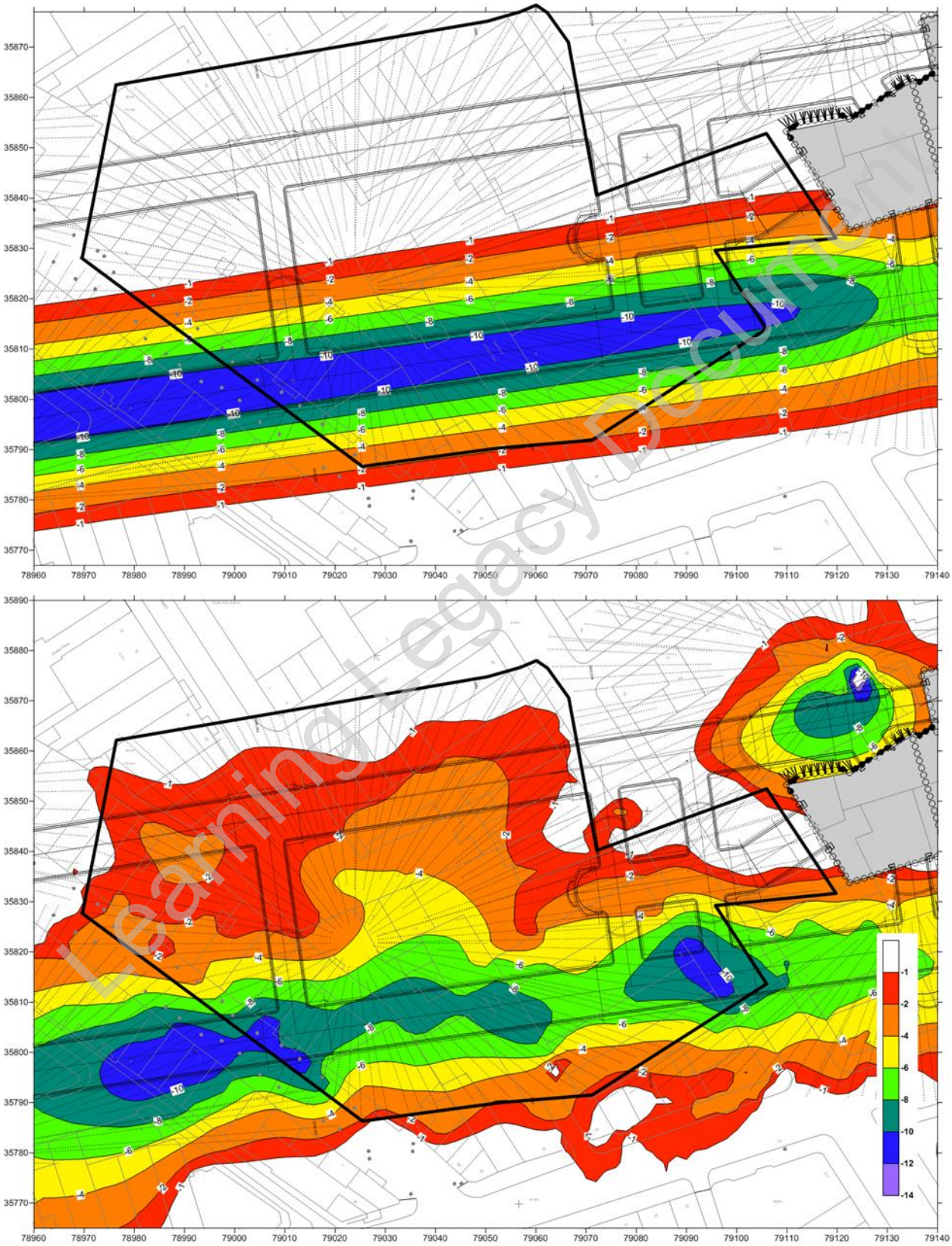


Figure 3.3.2 Period B: Total measured settlement (mm).

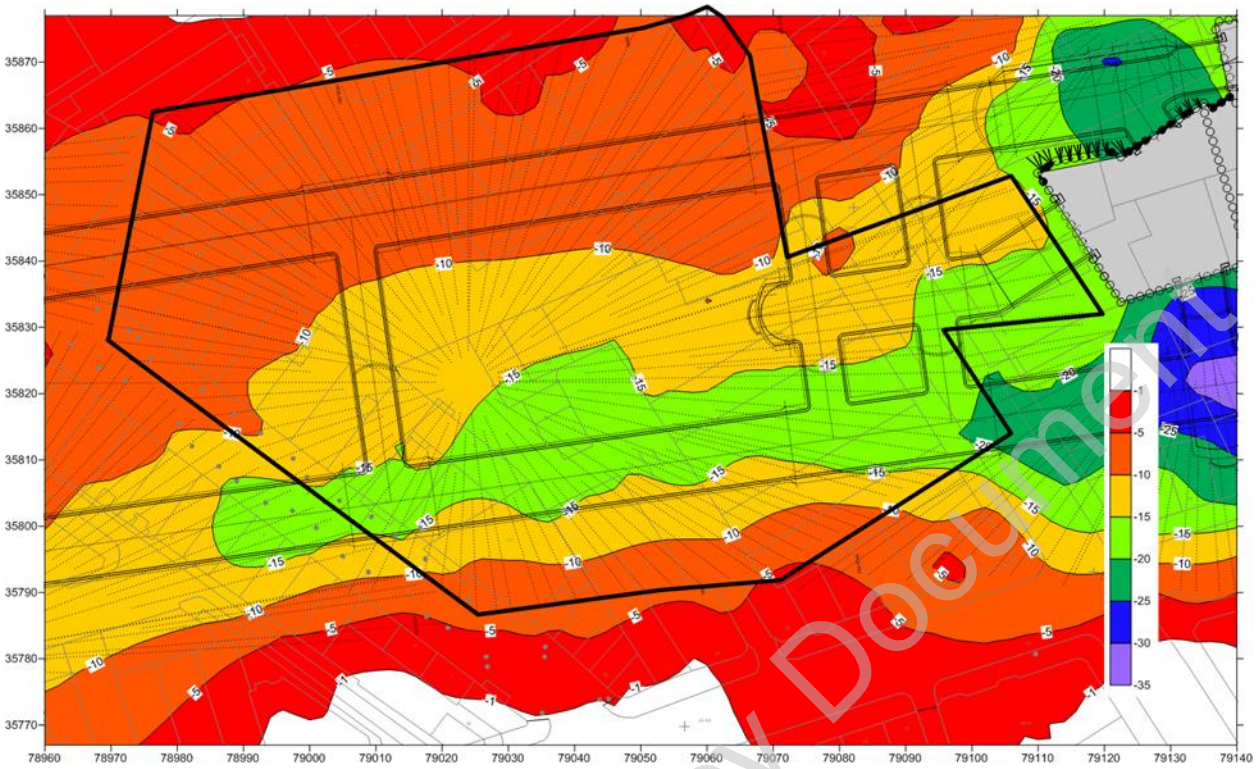


Figure 3.3.3 Period B: Distribution of grout injected from GS2: Jack grouting. Grout Intensity (l/m^2).

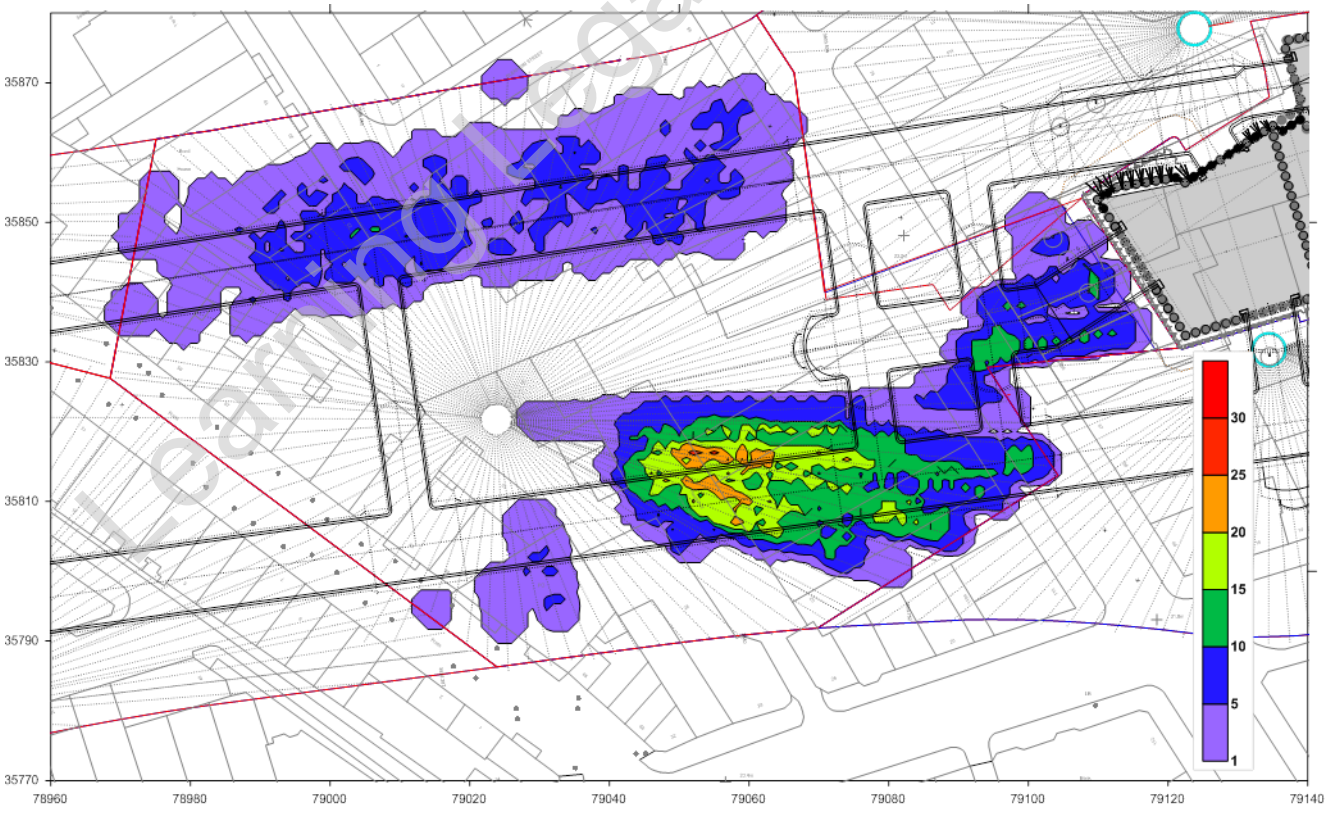


Figure 3.3.1(a) shows that just over 10mm volume loss settlement was anticipated for the WBRT drive.

Figure 3.3.1(b) shows that maximum recorded settlement was just over 10mm at the western and eastern boundaries of the GS2 arrays. Over the remainder of the zone the settlement was about 8mm maximum. It is notable that the maximum settlement at the eastern end is on the facades on the west side of New Bond Street. There is an asymmetry in the measured contours with greater settlements to the north of the WBRT than to the south. This is attributed to long term movements following installation of the TaMs for GS2.

Figure 3.3.1(b) also shows the effect of the SCL works within the GS3 area (LCE 1/2) which had a negligible effect within the GS2 area.

At the end of Period B the cumulative movements (Figure 3.3.2) show a maximum of ~20mm over the WBRT decreasing to ~5mm at the north and south boundaries of the GS2 area.

No concurrent grouting was undertaken with the WBRT. Instead pre- and post- jacking was undertaken and the distribution of grout injected in shown in Figure 3.3.3. Grout pre-jacking was also undertaken in Period B for the EBRT and the commencement of CH3 adjacent to the ETH in the area where the exclusion zone restricts the ability to control movements at the break out of the tunnel.

The majority of the grouting above the WBRT in Period B was focussed on the area between New Bond Street and Haunch of Venison Yard with a maximum intensity of ~25 l/m^2. Comparison of Figures 3.3.1 and 3.3.3 confirms that additional grout jacking was successful in reducing the magnitude of settlement. Further grout jacking associated with the WBRT was undertaken in Period C (see Section 3.4).

3.4. Period C - EBRT, CH3: 30/05/13 – 15/07/13

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

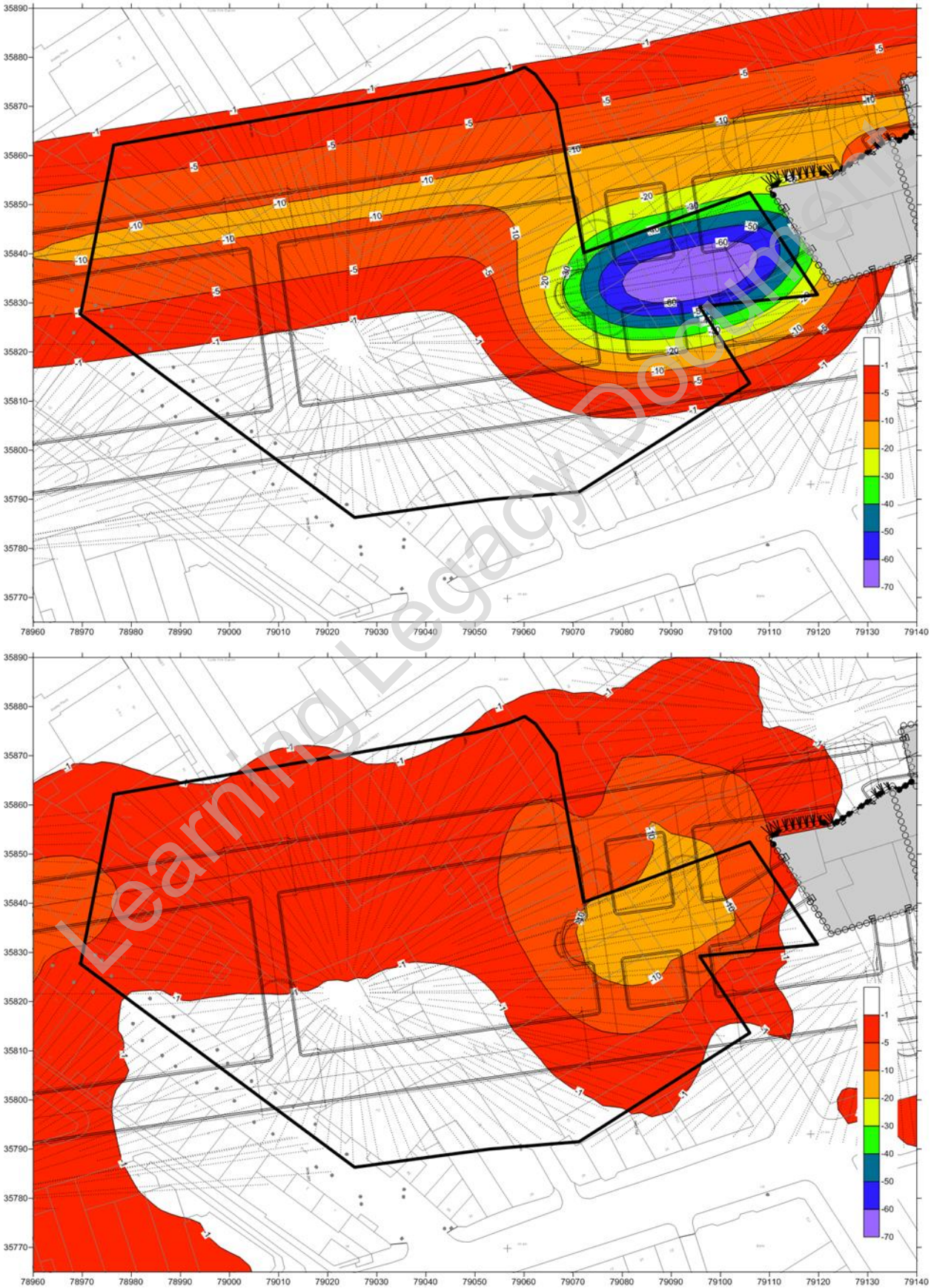


Figure 3.4.2 Period C: Total measured settlement (mm).

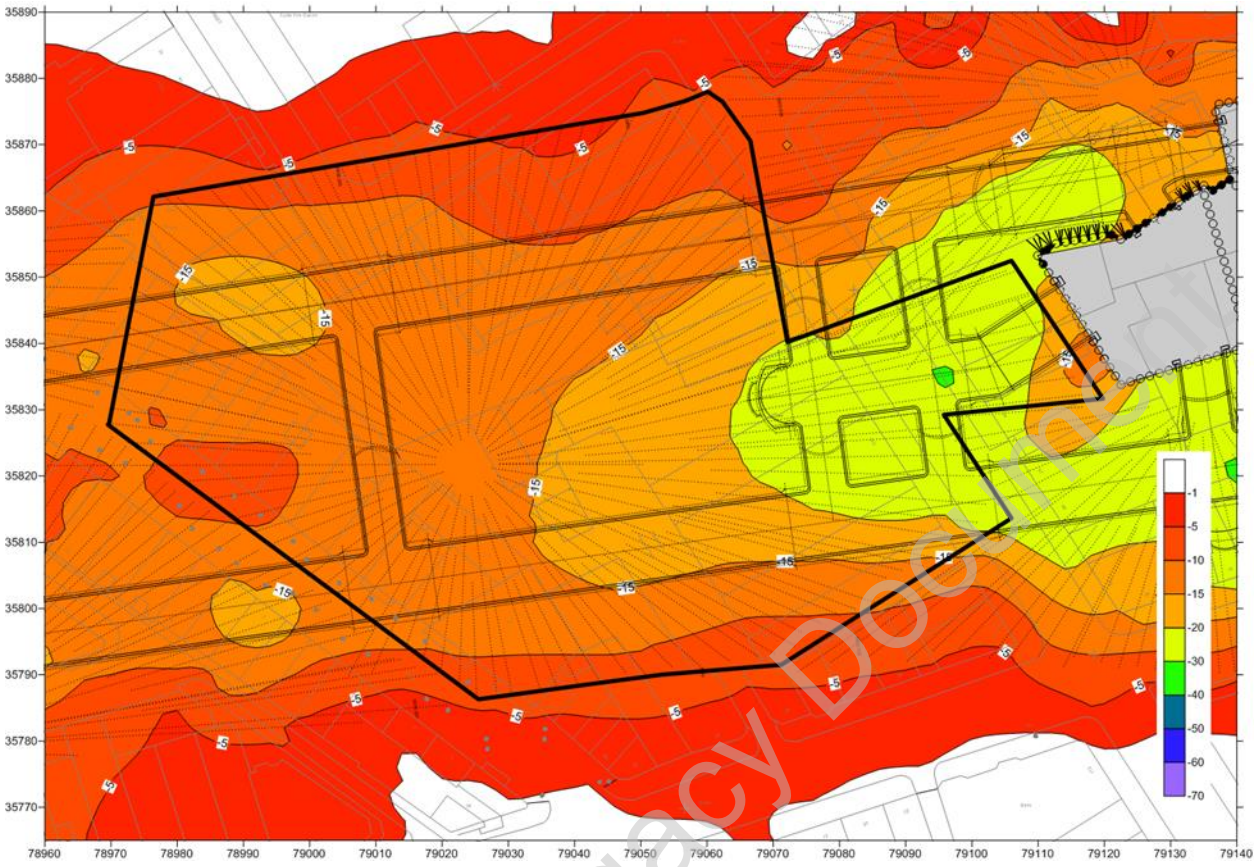


Figure 3.4.3 Period C: Distribution of grout injected from GS2: Concurrent grouting. Grout Intensity (l/m^2).

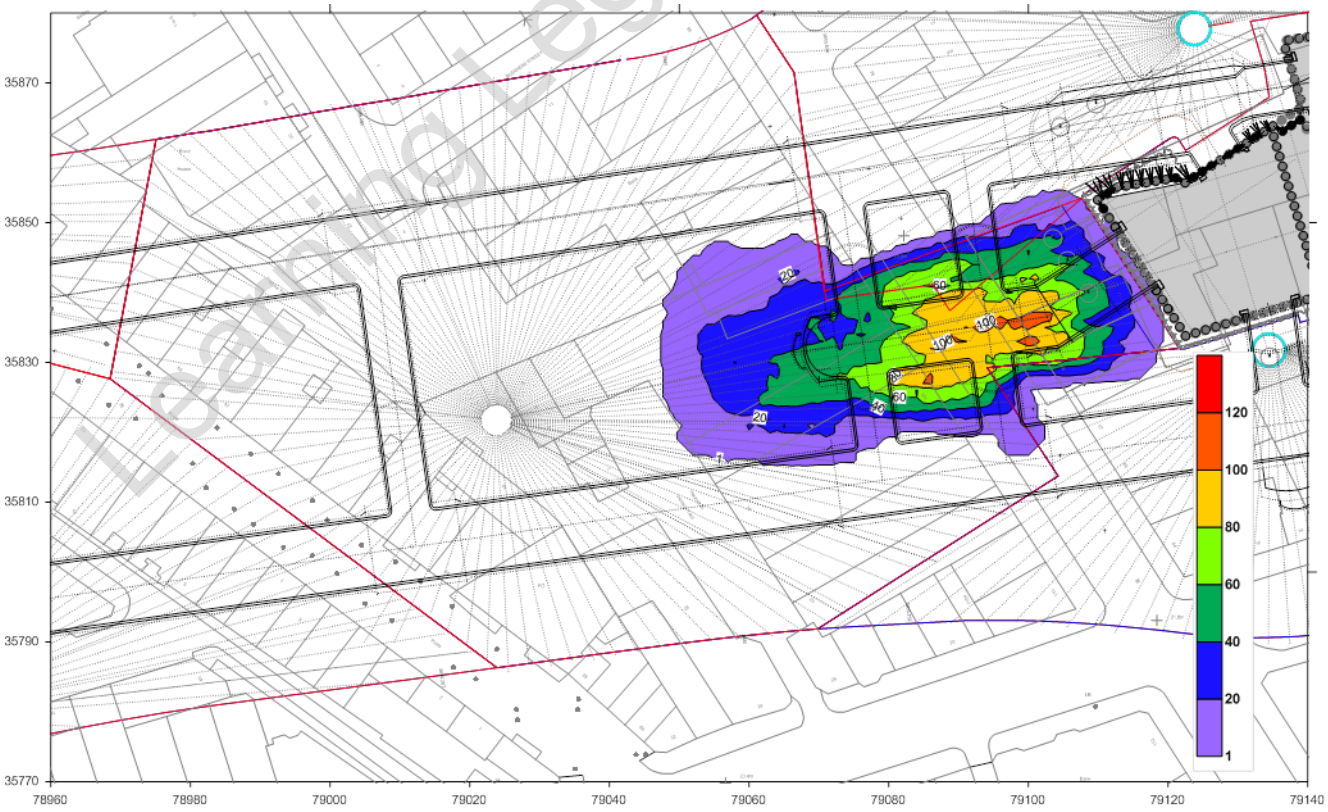


Figure 3.4.4 Period C: Distribution of grout injected from GS2: Grout jacking. Grout Intensity (l/m^2).

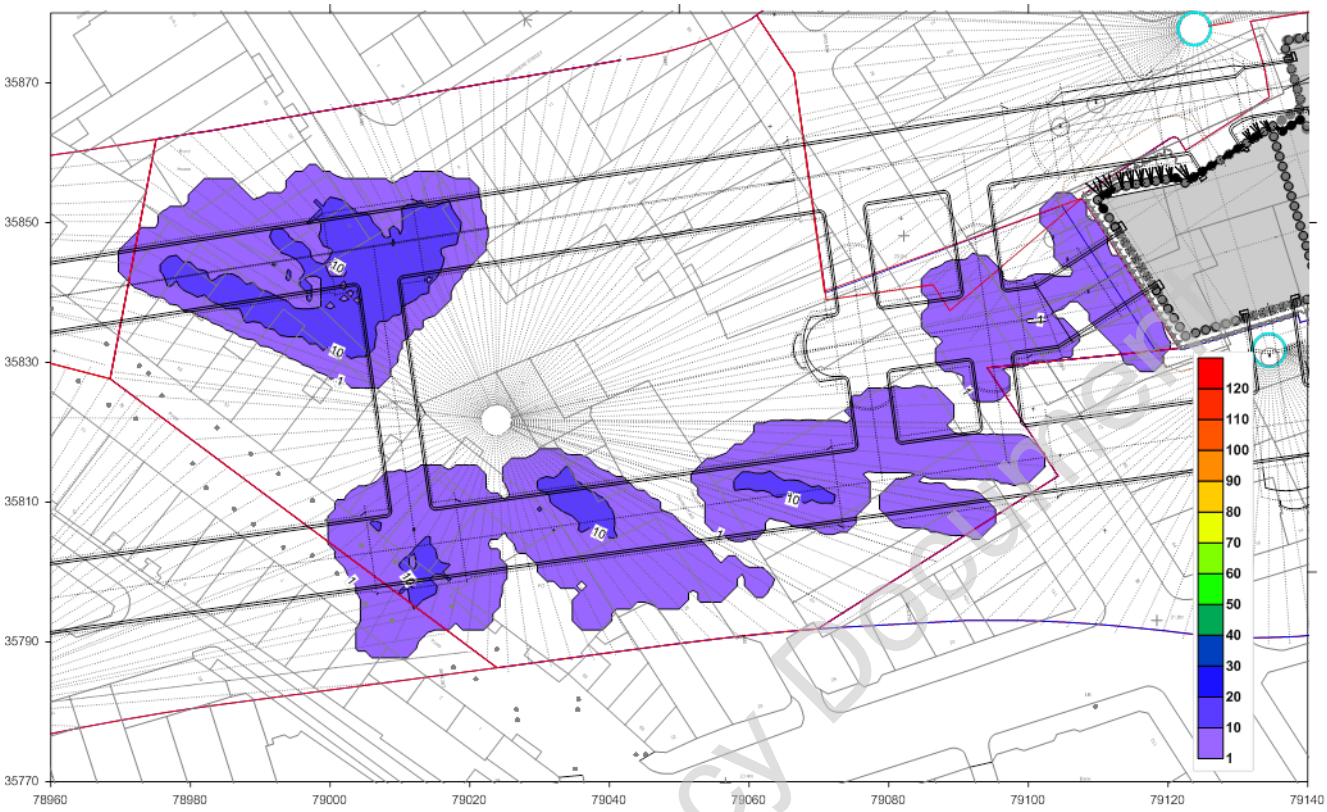


Figure 3.4.1(a) shows that over 60mm volume loss settlement was anticipated for CH3 and about 10mm for the EBRT.

Figure 3.4.1(b) shows the recorded settlement with a maximum of 12mm over CH3. The movements over the EBRT within the GS2 area were a maximum of 5mm in Period C. At the end of Period C the cumulative movements (Figure 3.4.2) show that the maximum settlement over CH3 had reached 30mm locally. Over CH3 settlement was generally over 20mm reducing to the west with about 5mm settlement at the northern and southern boundaries of the GS2 arrays.

Figure 3.4.3 shows the concurrent grouting undertaken for CH3 from GS2. A limited amount of grouting was undertaken from GS5. The grout intensity reached 100 l/m^2 where both front and rear injections were made. The reduced intensity to the west of CP7 / CP8 and adjacent to the ETH is a result of the exclusion zones specified in the SCoGM.

Comparison of Figures 3.4.2 and 3.4.4 confirms that additional grout jacking was undertaken in the area of maximum total settlement over the WBRT, the EBRT and CH3. Additional grout jacking was also undertaken in Period D (see Section 3.5).

3.5. Period D - CP8, CP10, CP7 & CP9: 16/07/13 – 10/11/13

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

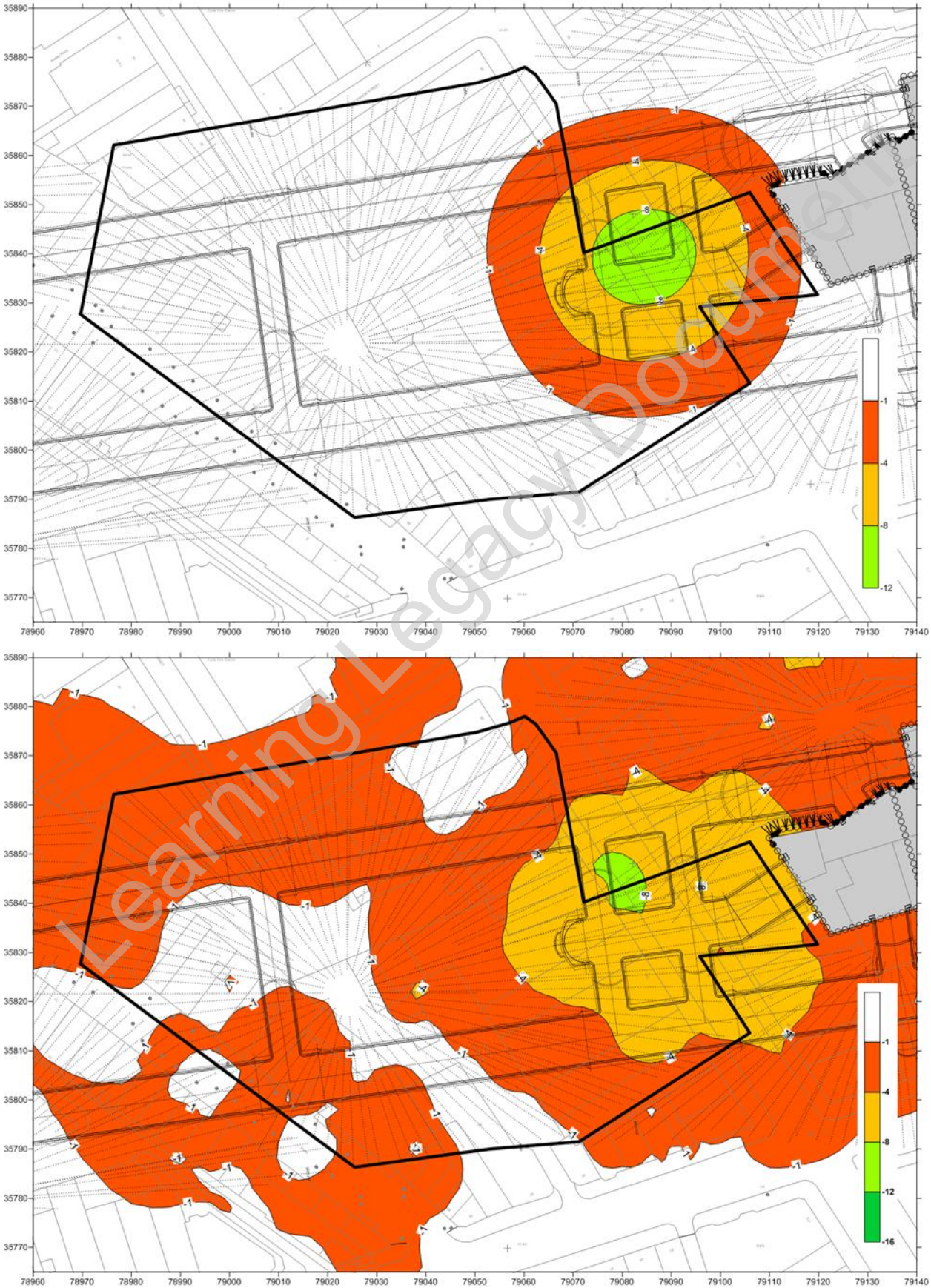


Figure 3.5.2 Period D: Total measured settlement (mm).

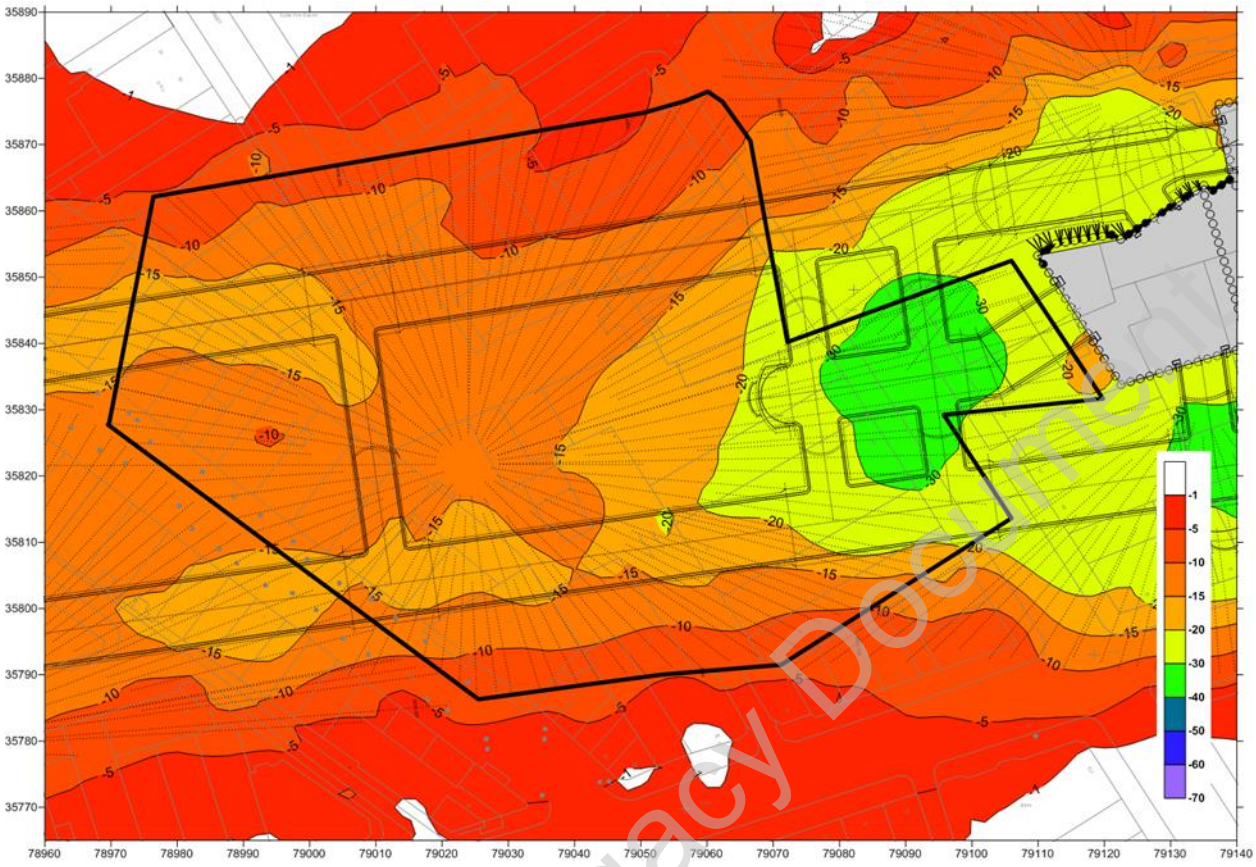
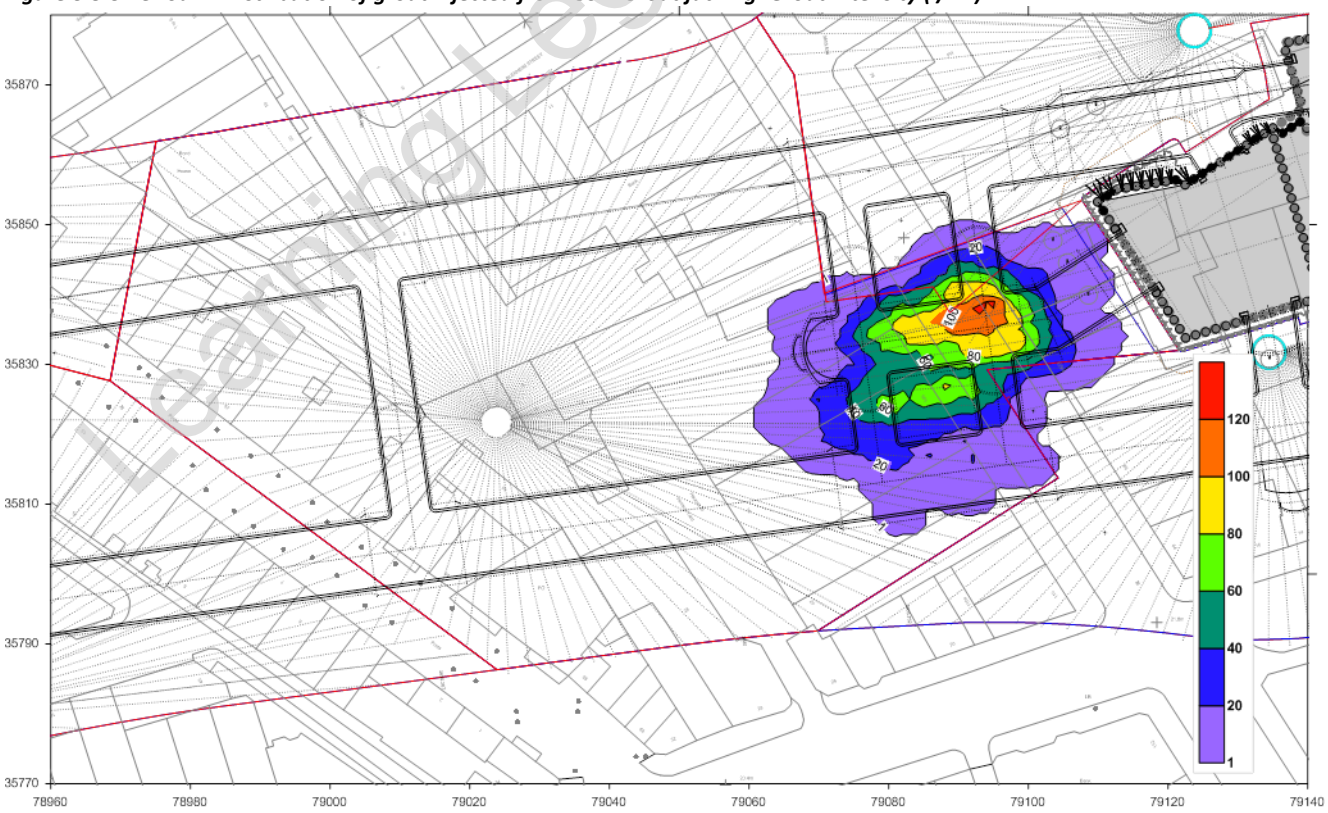


Figure 3.5.3 Period D: Distribution of grout injected from GS2: Grout jacking. Grout Intensity (l/m^2).



The four cross passages (CP7, CP8, CP9 and CP10) were constructed out of CH3 in Period D up to a couple of metres from the respective future platform tunnel junctions. The maximum volume loss settlement for all four CPs is ~10mm, as shown in Figure 3.5.1(a). The maximum observed settlement was locally ~8mm and about 4mm over the whole of the

volume loss zone of influence (Figure 3.5.1(b)). No concurrent grouting was undertaken with these tunnels due to their short length and the extent of the exclusion zone specified in the SCoGM. Grout jacking was targeted based on the pre-existing settlements as well as the anticipated volume loss movements to control slopes and distortions.

Figure 3.5.2 shows that the area with over 30mm settlement over CH3 had increased significantly and that settlement continued to increase gradually throughout the area.

The contour of grout intensity in Figure 3.5.3 shows that a large amount of grouting was undertaken centred directly over CH3 but biased to the south to account for existing movements. A maximum intensity of 120 l/m2 was injected. It is noted that the tunnelling and the grouting were in the early part of Period D (to 21/08/13) and that the majority of the recorded movement occurred after this date during the 2 ½ months to the end of Period D (10/11/13).

3.6. Period E - PTW (west), CP8 (out of PTW), CP10 (out of PTW): 11/11/13 – 09/02/14

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

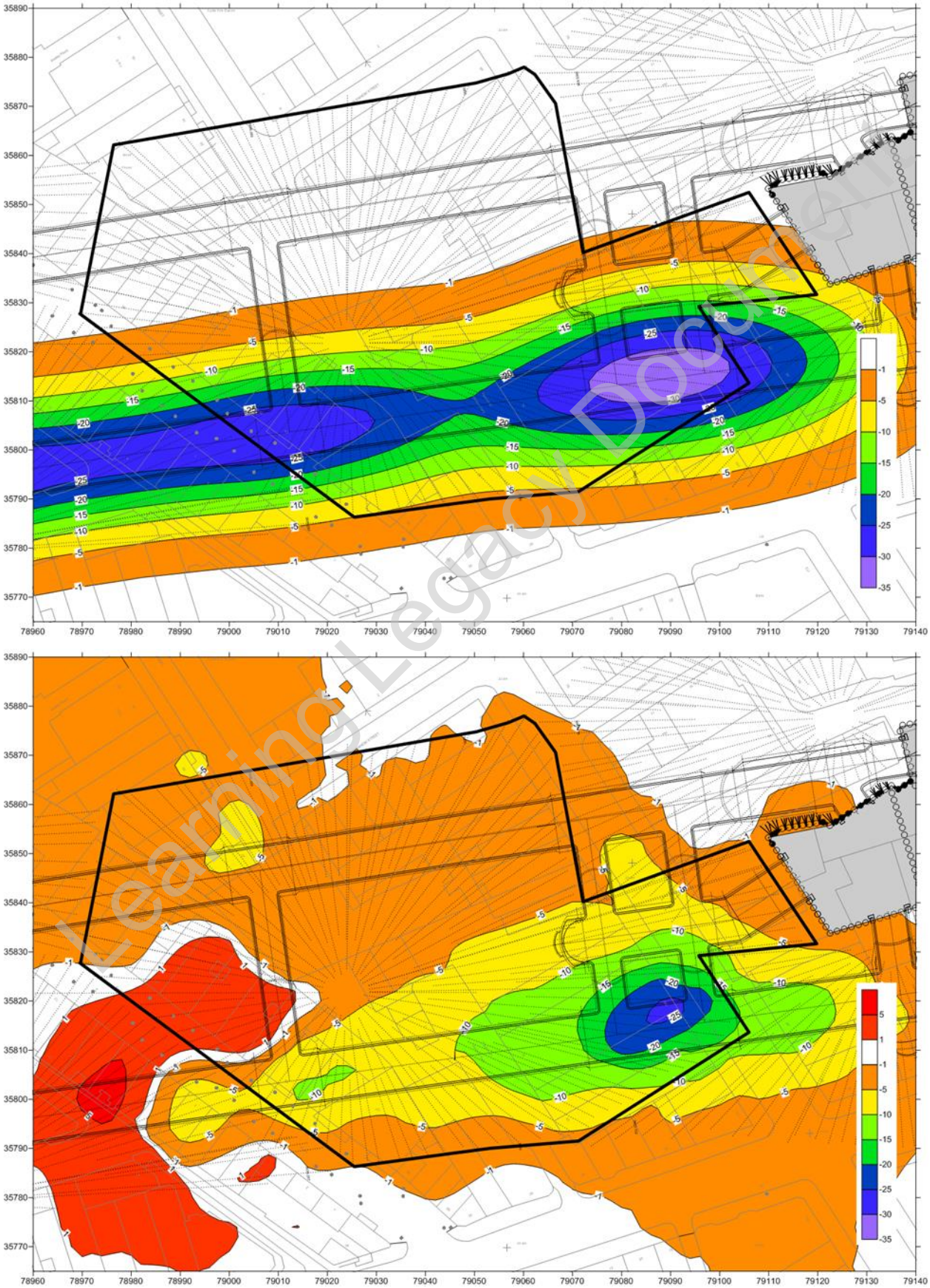


Figure 3.6.2 Period E: Total Measured Settlement (mm)

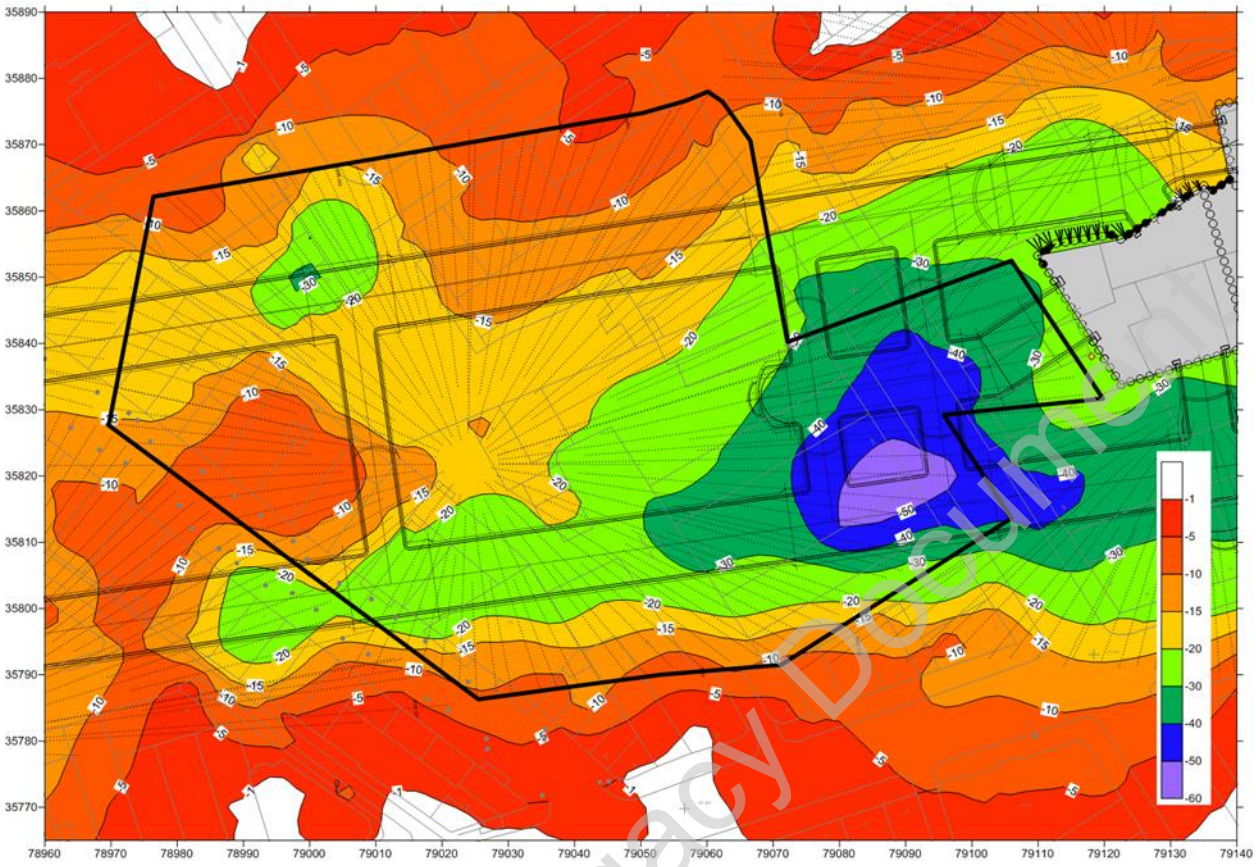


Figure 3.6.3 Period E: Distribution of grout injected from GS2: Concurrent grouting. Grout Intensity (l/m^2).

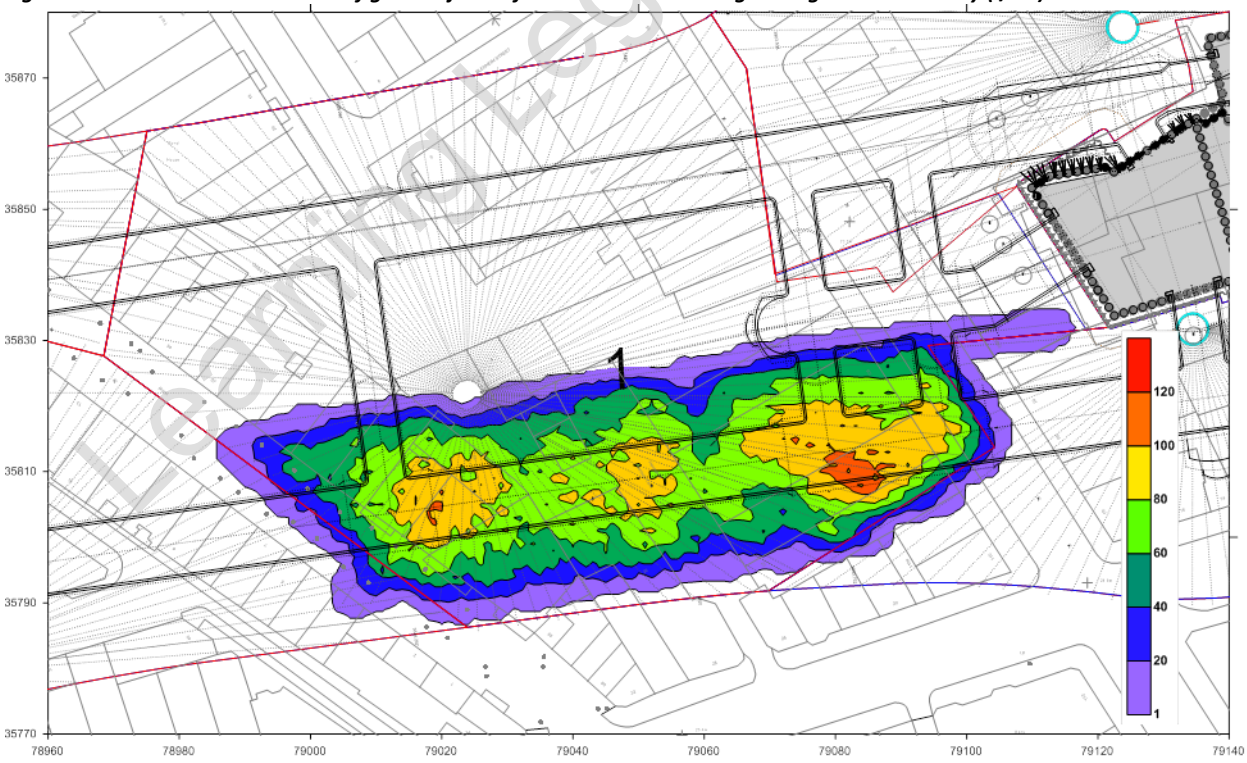
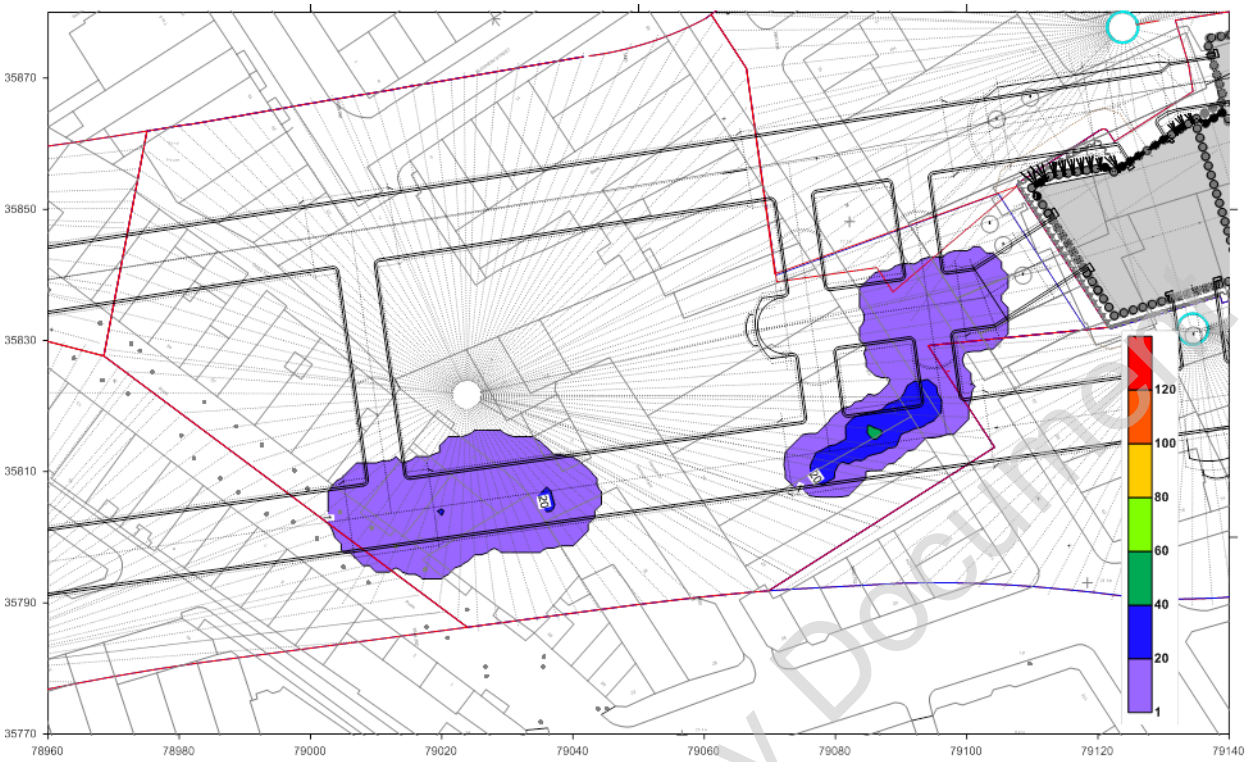


Figure 3.6.4 Period E: Distribution of grout injected from GS5: Grout jacking (l/m^2).



The main activity in Period E is the PTW. The stub tunnels completing 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 for 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 just over 25mm locally on the west side of New Bond Street. 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 is discussed further below and in Section 4.2. The settlements decrease significantly to the east with less than 10mm at the eastern extent of the GS2 arrays. Further east, within the GS1 arrays, heave caused by the front injections for the PTW is evident.

The incremental change in settlement in Period E is clearly evident in the total settlement contour in Figure 3.6.2 with the settlement above the PTW varying from 50mm on New Bond Street to ~20mm on South Molton Street.

The contours of concurrent grouting intensity shows relatively uniform distribution centred on the PTW with a peak intensity of 100 l/m^2. The variation in intensity over the centreline of the tunnel is a result of the management of the grout volumes to allow more settlement where this would be beneficial in controlling slopes or to limit heave from the front injection to the specified limit of 5mm.

During the PTW drive damage was noted within 105-106 New Bond Street, most notably to the floor finishes. Additional internal survey points were installed. It was concluded that the grouting was lifting the floor instead of the building structure and in particular the southern party wall. Targeted jack grouting directly below the party wall was carried out as shown in Figure 3.6.4 and although some uplift was achieved, the floor lifted more than the wall. Since the damage had already occurred, it was agreed by all parties that no further grouting should be undertaken (see Section 4.2).

3.7. Period F - CP9 and, CP7 (out of PTE), CP5, PTW(west): 10/02/14 – 10/07/14

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

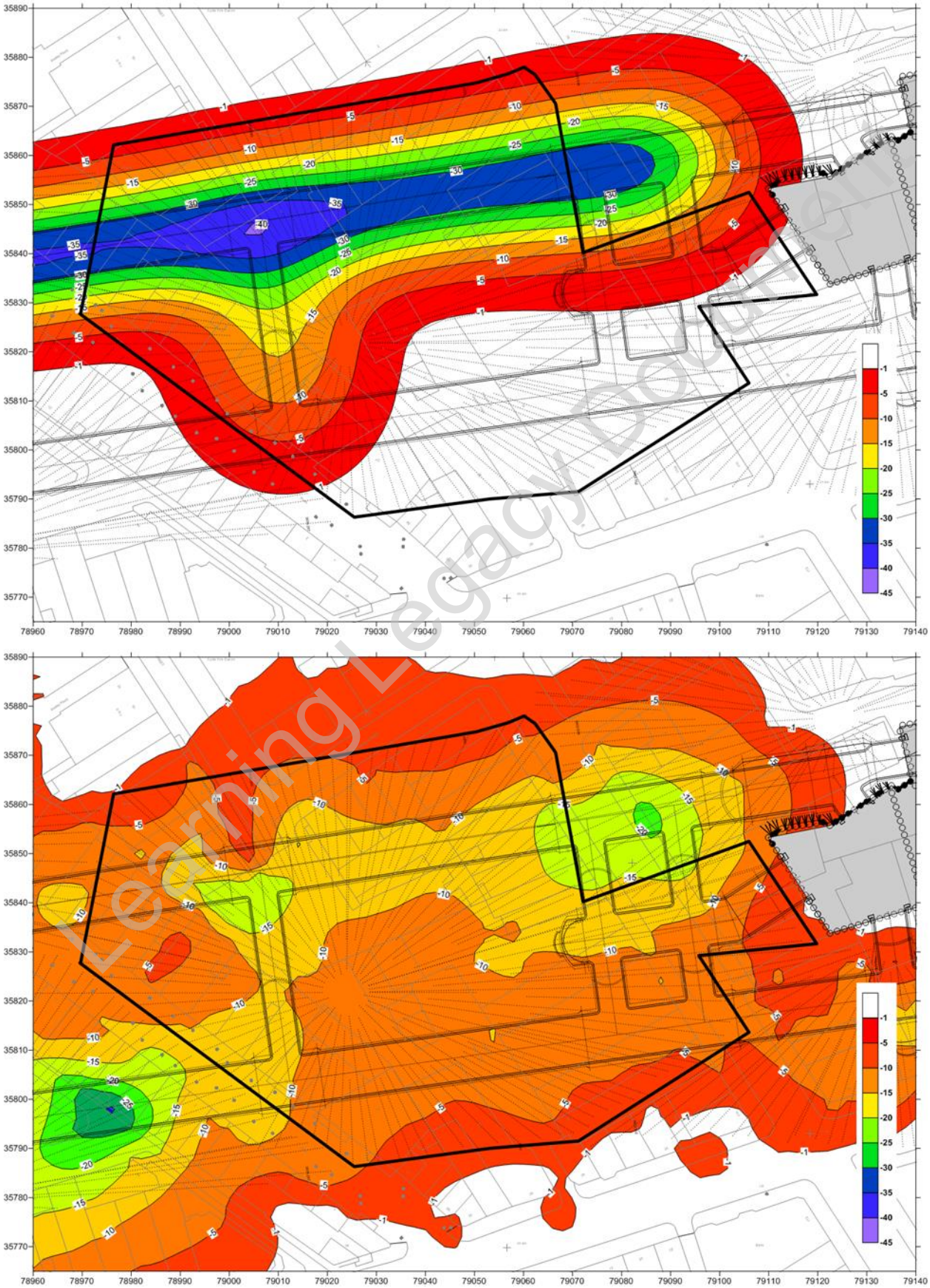


Figure 3.7.2 Period F: Total measured settlement (mm)

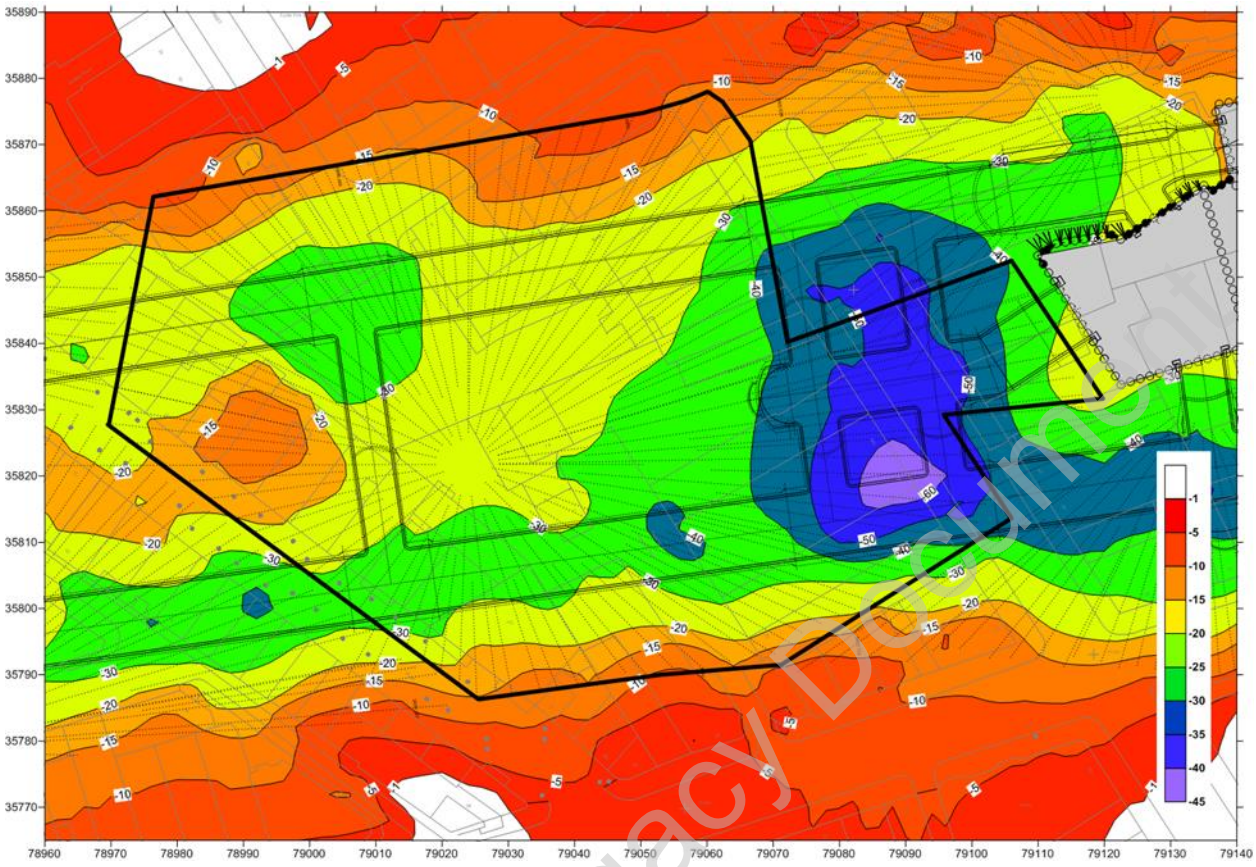


Figure 3.7.3 Period F: Distribution of grout injected from GS2: Concurrent grouting. Grout Intensity (l/m^2).

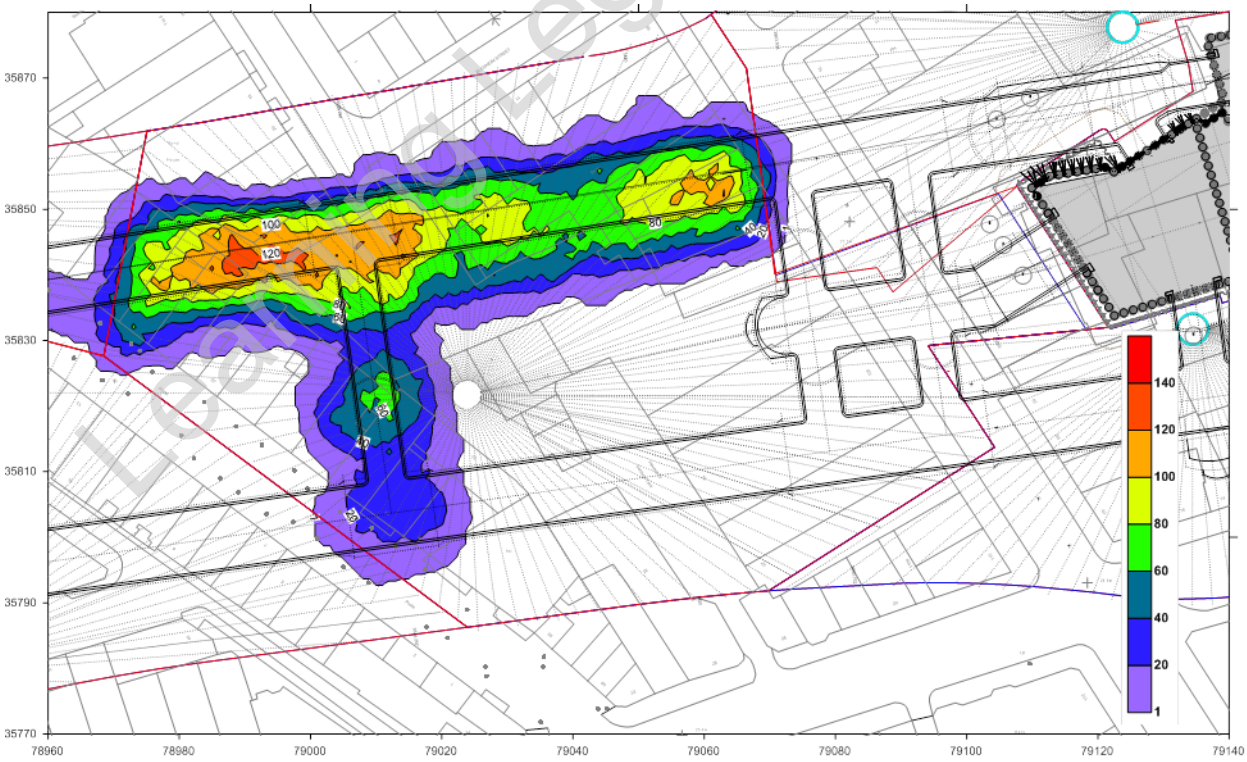
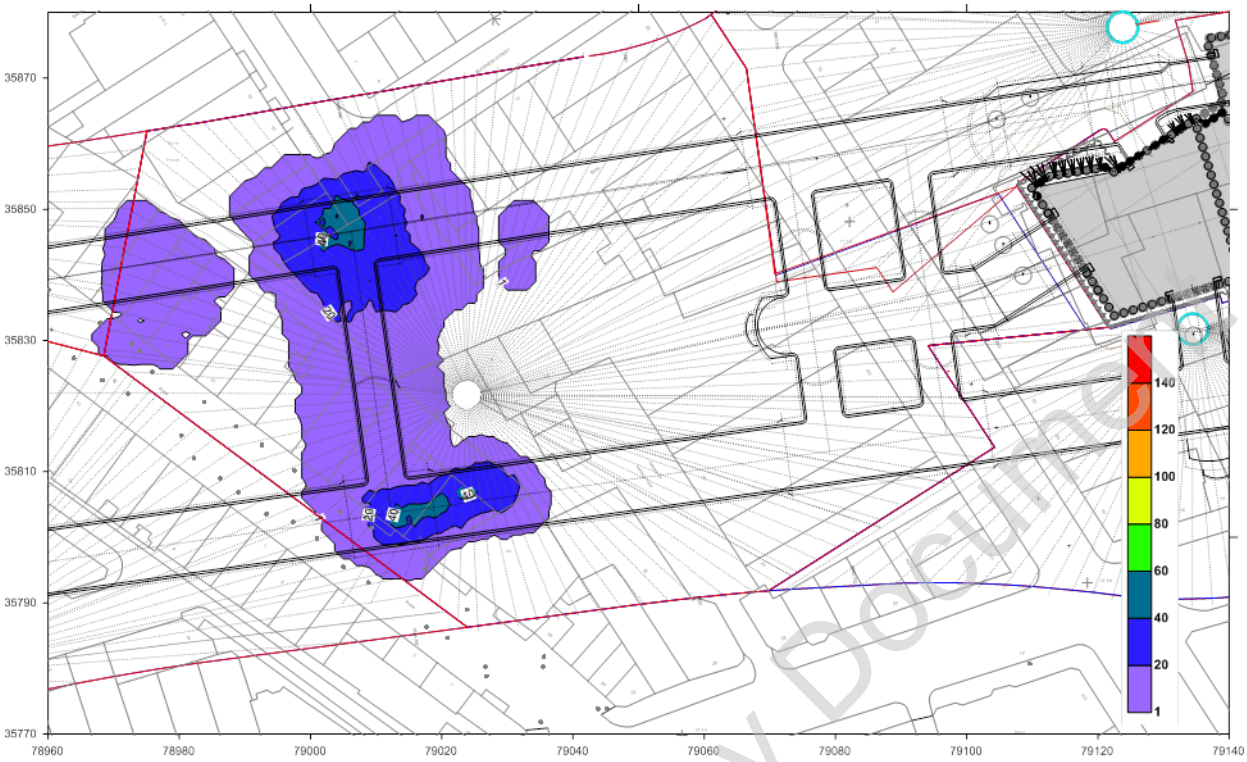


Figure 3.7.4 Period F: Distribution of grout injected from GS2: Grout jacking. Grout Intensity (l/m^2).



PTE and CP5 were constructed in Period F along with the connections of CP7 and CP9 to PTE. The volume loss for the PTE 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 40mm at the junction of PTE and CP5. Excavation of the ETH by others continued during Period F but no allowance for this is included in the contour.

The actual settlements are shown in Figure 3.7.1(b) and show 10 to 15mm over PTE within the extent of GS2 arrays, with the higher values associated with the junctions to the CPs. Settlement due to PTW is evident within the GS1 area to the west GS2 arrays. It is notable that a 5mm increase in settlement is shown over virtually the whole extent of the GS2 area.

The maximum total settlement increased to over 60mm along New Bond Street over PTW whereas in the west of the GS2 area the maximum settlement above the tunnel is between 30 and 40mm. Settlement above PTE is generally less than 30mm except at the junctions with the CPs.

The concurrent grouting for PTE and CP5 is illustrated in Figure 3.7.2 and shows a maximum intensity of over 120 l/m^2. Variation in intensity is indicative of the management of grout volumes to try to reduce any increase in slopes and to avoid producing more than the specified limit on uplift of 5mm. Grout jacking was undertaken in Period F as shown in Figure 3.7.3, which targeted the CP5 area and in particular the junctions with both PTW and PTE. A maximum intensity of 40 l/m^2 was injected.

3.8. Period G - No tunnelling (ETH below level -2): 11/07/14 – 26/06/15

All BFK tunnel excavation works were completed before the start of Period G and consequently no volume loss settlement has been generated during this period.

As noted in Sections 3.6 and 3.7 the ETH excavation (by Others) 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 late 2015. The contour plot shown in Figure 3.8.1 has been supplied by CRL (C122) as the estimated 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: Contour of settlement for ETH excavation excluding MasterPlan & North (mm). (supplied by C122)-

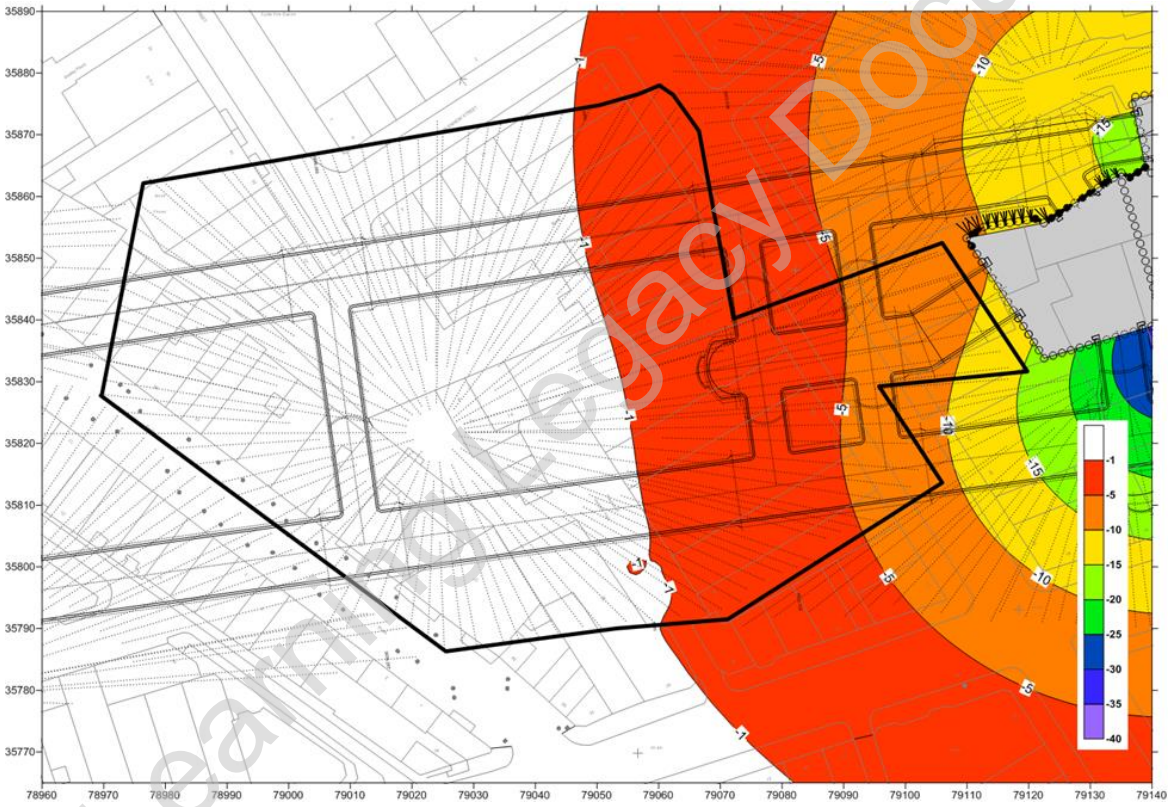
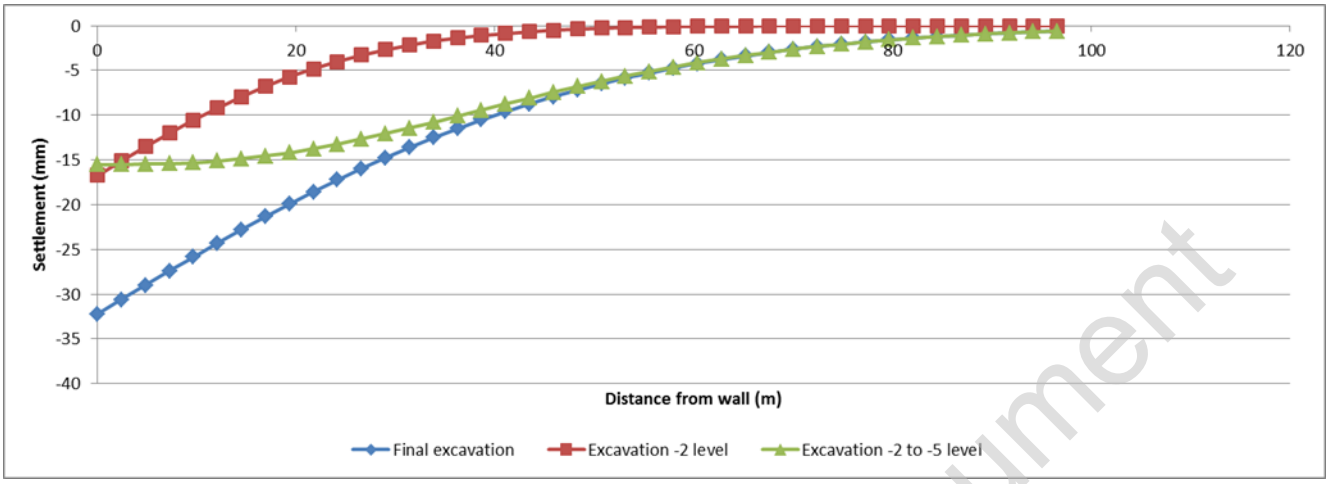


Figure 3.8.2 Period G: Estimate of settlement for ETH excavation post tunnelling



Waterproofing and secondary lining work within the tunnels has been completed within the GS2 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 March 2015.

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

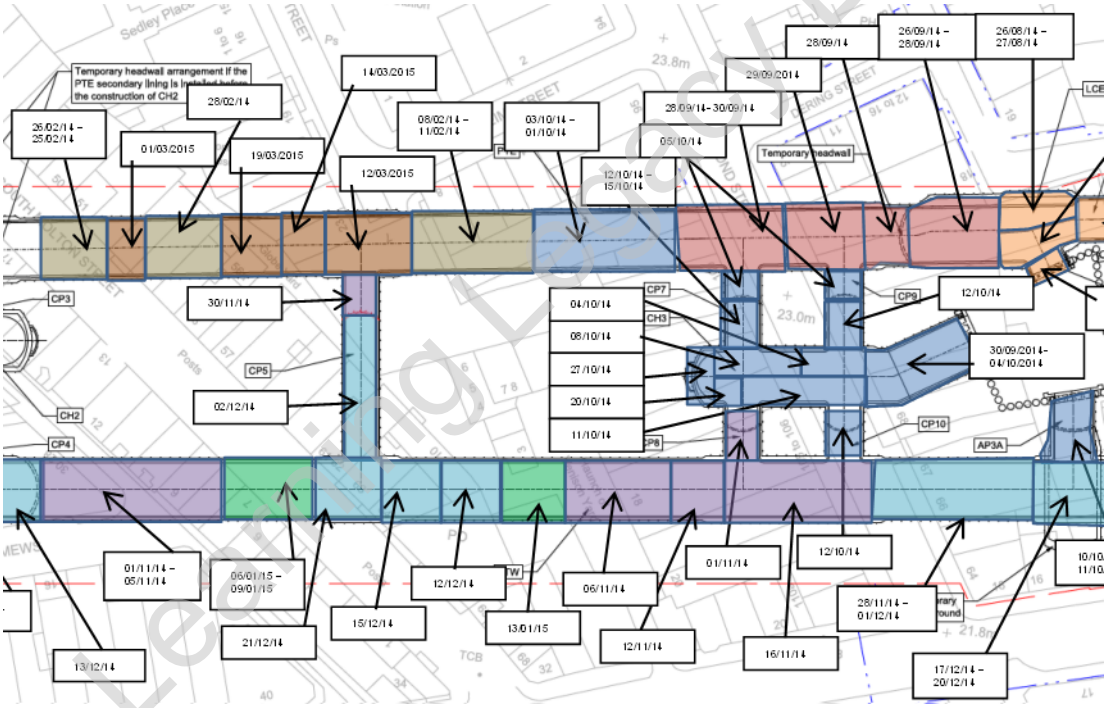


Figure 3.8.4(a) shows an increase of settlement of up to 15mm during the 11 months since the completion of tunnelling from a combination of consolidation settlement and the on-going excavation work within the ETH. The maximum movement is located above the west end of PTE where the effect of the excavation progressing within the GS4 area is evident.

The total settlement at the end of Period G is shown on Figure 3.8.4(b) (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 PTE / CP5 junction where the maximum rate of settlement was observed at the beginning of Period G. The effect of the grouting in reducing the movements in Period G to less than 10mm in this area is evident on Figure 3.8.4(a).

Figure 3.8.4 Period G: (a) Observed settlement in Period G (mm); (b) Total settlement (mm)

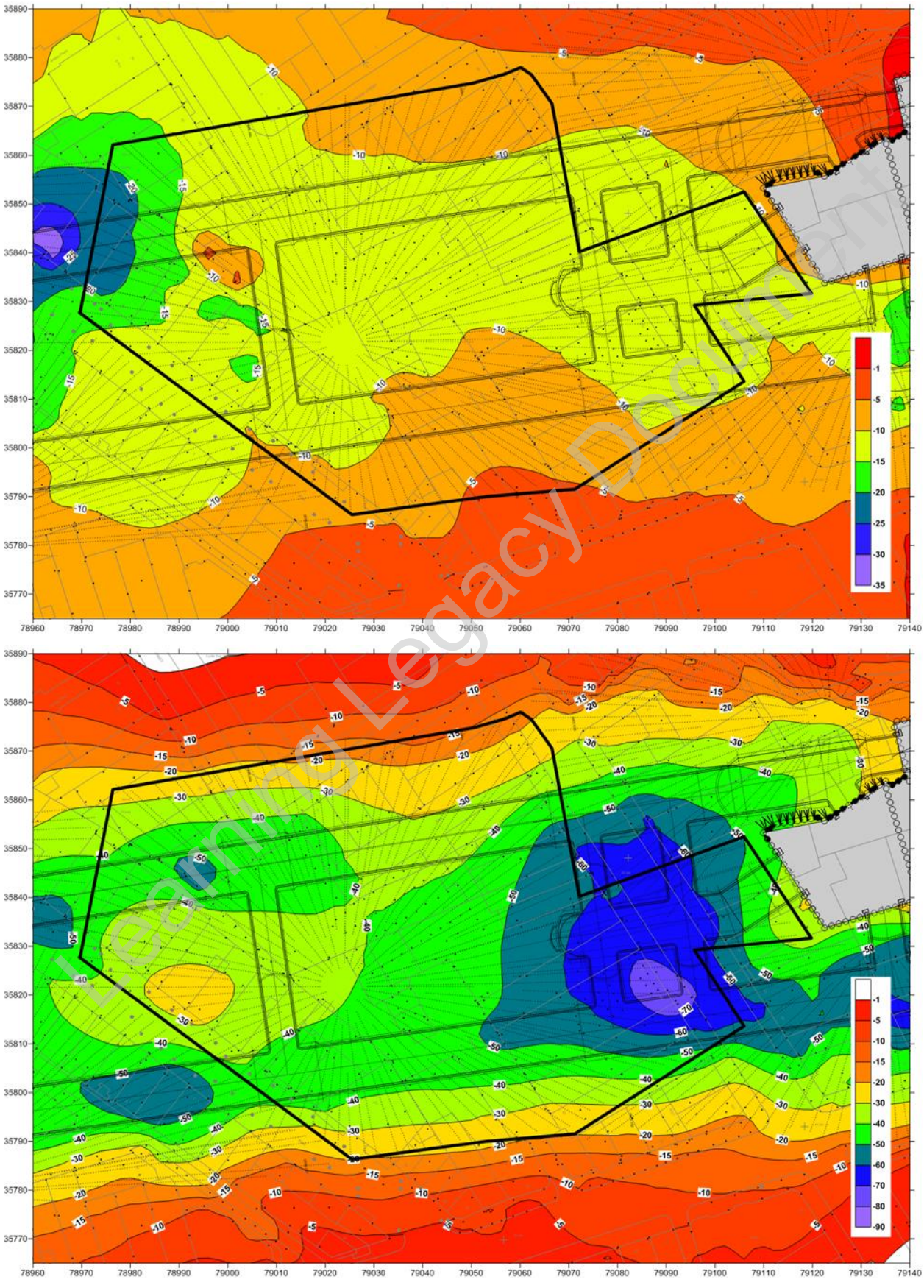
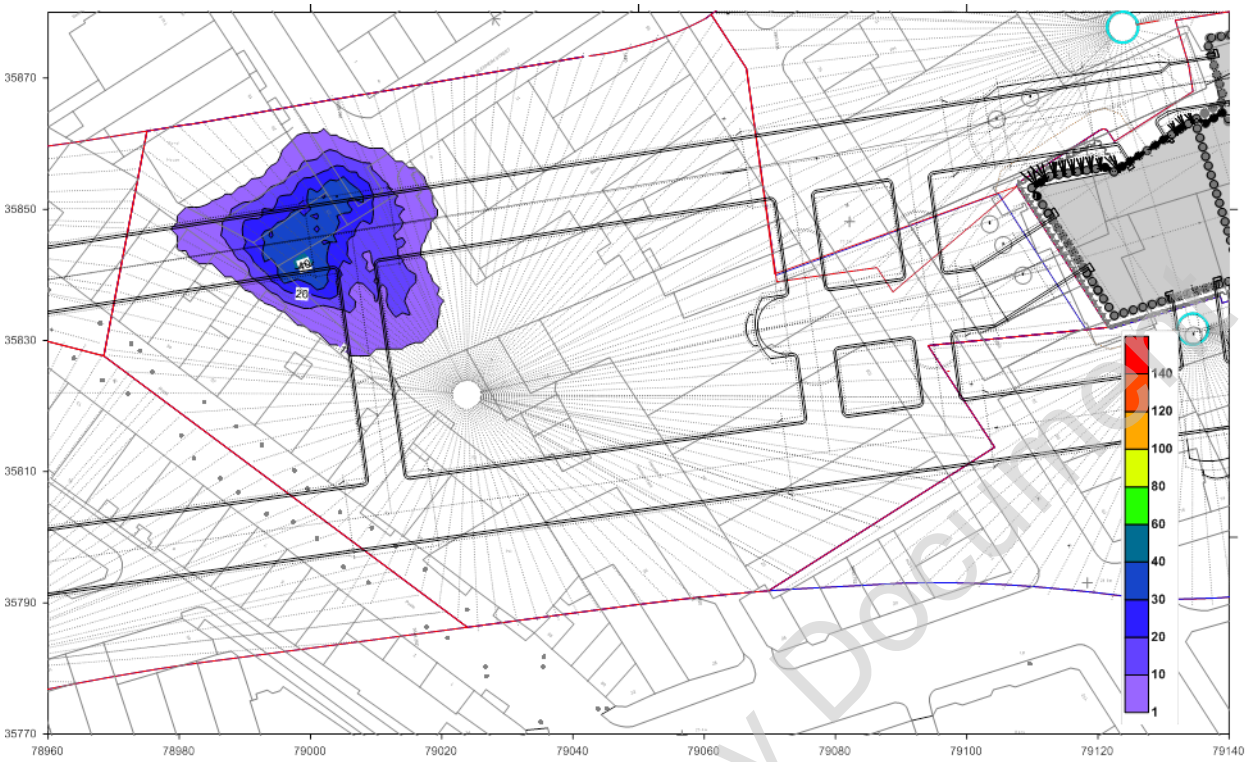


Figure 3.8.5 Period G: Distribution of grout injected from GS2: Grout jacking. Grout Intensity (l/m^2).



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 as follows:

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

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

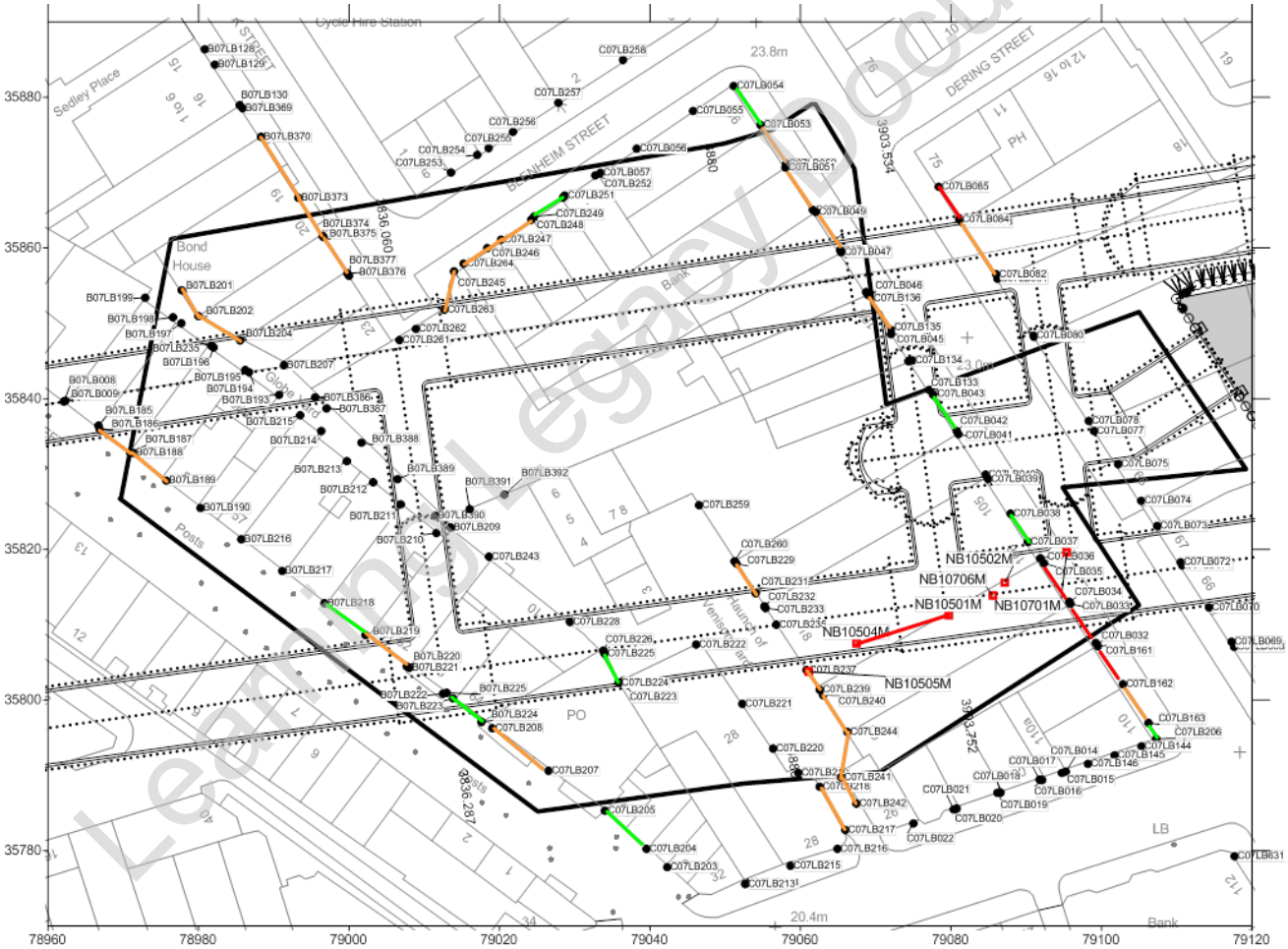


Table 4.1 Details of trigger breaches on BRE & HLC

BRE / HLC point nos.	Maximum Level	Comment	Date exceeded	Maximum (mm/m)	Current (mm/m)
New Bond Street - West					
C07LB038 - C07LB037	Amber	Borderline latest Green	23/12/2013	1.23	0.91
C07LB043 - C07LB042	Amber	Borderline latest Green	09/07/2013	1.62	0.95
C07LB049 - C07LB048	Amber	Stable ± 0.1 over 12 months	25/05/2014	1.60	1.53
C07LB136 - C07LB135	Amber	Stable ± 0.1 over 12 months	08/01/2014	1.77	1.23
C07LB054 - C07LB053	Green	Stable	19/05/2015	0.84	0.84
C07LB053 - C07LB052	Amber	Stable	19/02/2015	1.10	1.10
C07LB051 - C07LB050	Amber	Stable ± 0.1 over 12 months	26/06/2014	1.41	1.41
C07LB035 - C07LB034	Red	Stable ± 0.1 over 12 months	02/12/2013	2.85	2.85
C07LB033 - C07LB032	Red	Latest reading high: Mean ~2.0 ± 0.1 over 14 months	08/05/2014	2.20	2.20
C07LB161 - C07LB162	Red	Latest reading high: Mean ~1.9 ± 0.1 over 11 months	19/02/2015	2.10	2.10
C07LB162 - C07LB163	Amber	Increasing at reducing rate	17/06/2014	1.31	1.31
C07LB163 - C07LB206	Amber	Only 2 outliers >1.0: Green	29/07/2014	1.10	0.93
Brook Street - North					
No Breaches					
Haunch Of Venison Yard - East					
C07LB242 -C07LB241	Amber	Reduced rate	23/02/2015	1.11	1.04
C07LB241 -C07LB244	Amber	Stable ± 0.1 over 12 months	04/01/2014	1.58	1.41
C07LB239 -C07LB237	Amber	Reduced rate	09/01/2014	1.95	1.63
C07LB244 -C07LB240	Amber	Latest reading high: slight increase at a reduced rate	09/01/2014	1.74	1.74
C07LB231 -C07LB229	Amber	Stable ± 0.1 over 12 months	01/02/2014	1.23	1.13
Haunch Of Venison Yard - West					
C07LB217-C07LB218	Amber	Latest reading high: slight increase at a reduced rate	14/02/2014	1.11	1.11
C07LB224-C07LB225	Green	Stable	12/04/2014	1.02	0.88
Globe Yard -West					
No Breaches					
Globe Yard - East					
B07LB198-B07LB197	Amber	borderline Green. Stable	20/06/2014	1.32	1.32
B07LB201-B07LB202	Amber	Stable ± 0.1 over 12 months	23/01/2014	1.71	1.59
B07LB202-B07LB204	Amber	borderline Green. Stable	20/05/2015	1.09	1.09
South Molton East					
C07LB204 - C07LB205	Green	Gradual increase - stabilising	19/02/2015	0.93	0.91
C07LB207 - C07LB208	Amber	Point destroyed - stable	21/01/2014	1.67	1.67
B07LB223 - B07LB224	Green	Gradual increase - stabilising	24/01/2014	1.28	0.93
B07LB219 - B07LB220	Amber	Stable	22/01/2014	1.95	1.52
B07LB218 - B07LB219	Green	Borderline Green latest non-breach	19/02/2015	0.84	0.75
B07LB188 - B07LB189	Amber	Stabilising - but latest reading high	09/07/2014	1.51	1.51
B07LB186 - B07LB187	Amber	Stabilising - but latest reading high	09/07/2014	1.40	1.40
Woodstock Street - West					
B07LB370-B07LB373	Amber	Stable ± 0.1 over 12 months	08/10/2014	1.29	1.29
B07LB373-B07LB374	Amber	Stable ± 0.1 over 12 months	02/06/2014	1.78	1.72
B07LB375-B07LB376	Amber	Stable ± 0.1 over 12 months	24/06/2014	1.46	1.46
Blenheim Street - South					
C07LB263-C07LB245	Amber	Borderline Green. Stable	26/06/2014	1.29	1.29
C07LB264-C07LB246	Amber	Stable ± 0.1 over 12 months	05/06/2014	1.47	1.39
C07LB246-C07LB247	Amber	Stable ± 0.1 over 12 months	18/06/2013	1.29	1.39
C07LB247-C07LB248	Amber	Stable ± 0.1 over 12 months	05/06/2014	1.34	1.34
C07LB249-C07LB250	Green	Stable ± 0.1 over 12 months	26/06/2014	0.86	0.86
Blenheim Street - North					
No Breaches					
105-106 New Bond Street - South party wall					
NB10501M - NB10504M	Red	Gradual increase - stabilising	02/12/2013	2.60	2.34

BRE monitoring data from the facades within the footprint of GS2 are presented in the following sections, namely New Bond Street west, Brook Street north, Haunch of Venison Yard east and west, Globe Yard east and west, South Molton Street east, Woodstock Street west and Blenheim Street South and North. HLC data is used where no BRE data is available; namely, the party wall of 105 – 106 New Bond Street. The locations of the HLC on party walls are shown on Figure 4.1. All HLC data presented is based on daily means.

The GS2 arrays extend below the east façade of New Bond Street but the buildings to the east of New Bond Street are primarily within the GS3 and GS5 area and the data for the north and south sections will be included in the relevant reports.

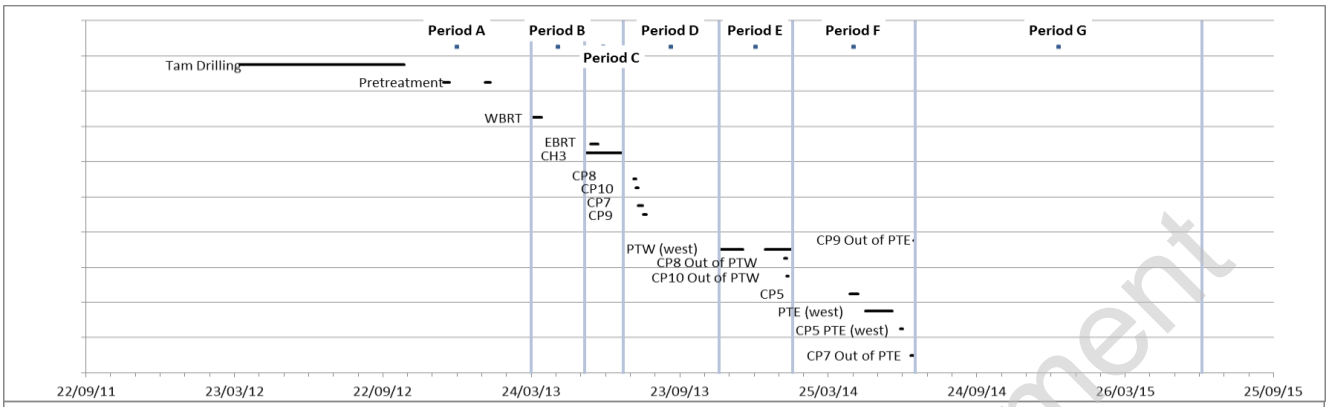
The settlements on the south of Brook Street are less than 10mm and data for these points is not presented.

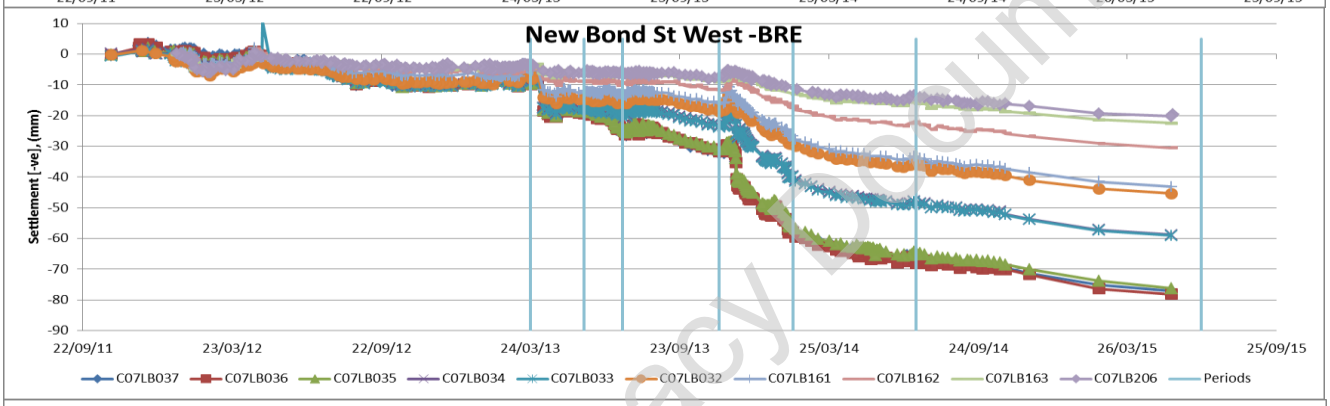
The plots presented for each façade comprise:

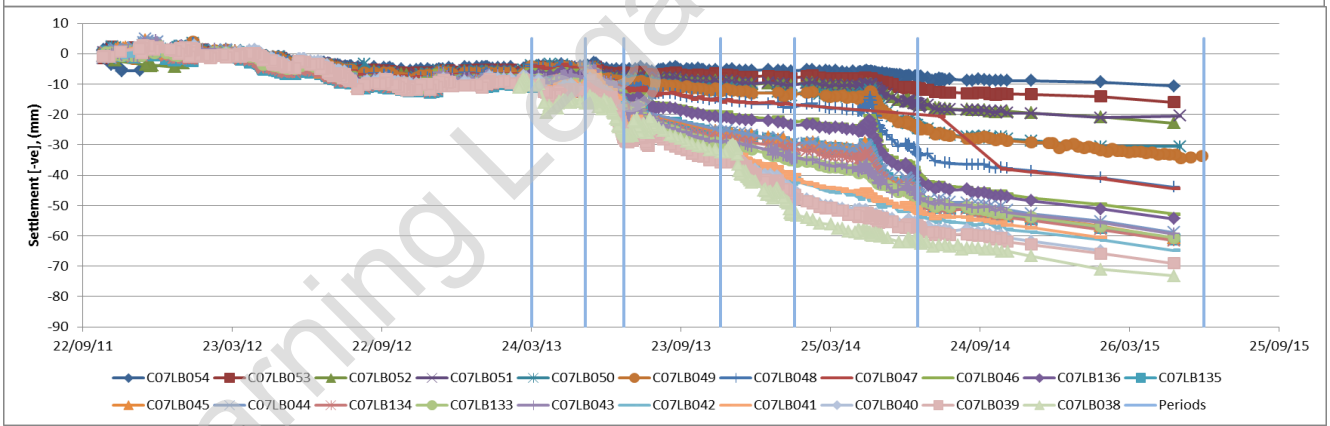
1. Summary of tunnel construction and associated construction periods.
2. Time settlement history (1 or 2 plots).
3. Settlement profile plots with a series as close as possible to the date of the end of each construction period.
4. Time slope history over the full construction period with the distances 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.
6. Deflection ratio plots are provided as necessary.

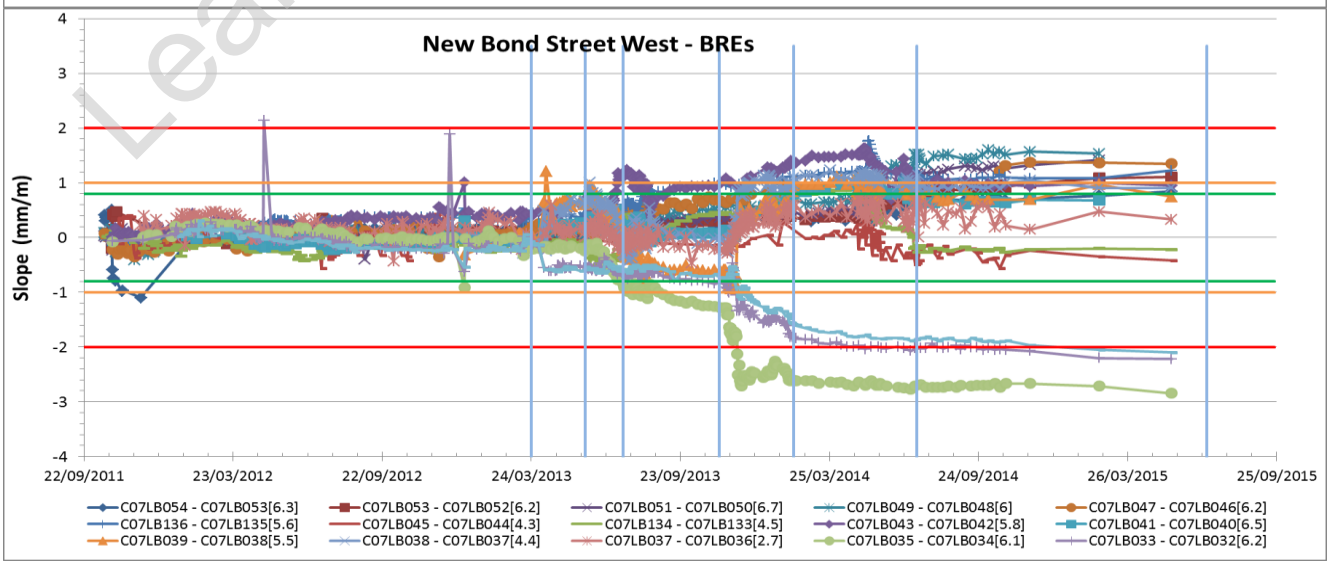
All available data is plotted in these figures. It is noted that where a point is blocked or destroyed these affects 2 slope calculations and 3 deflection ratio calculations.

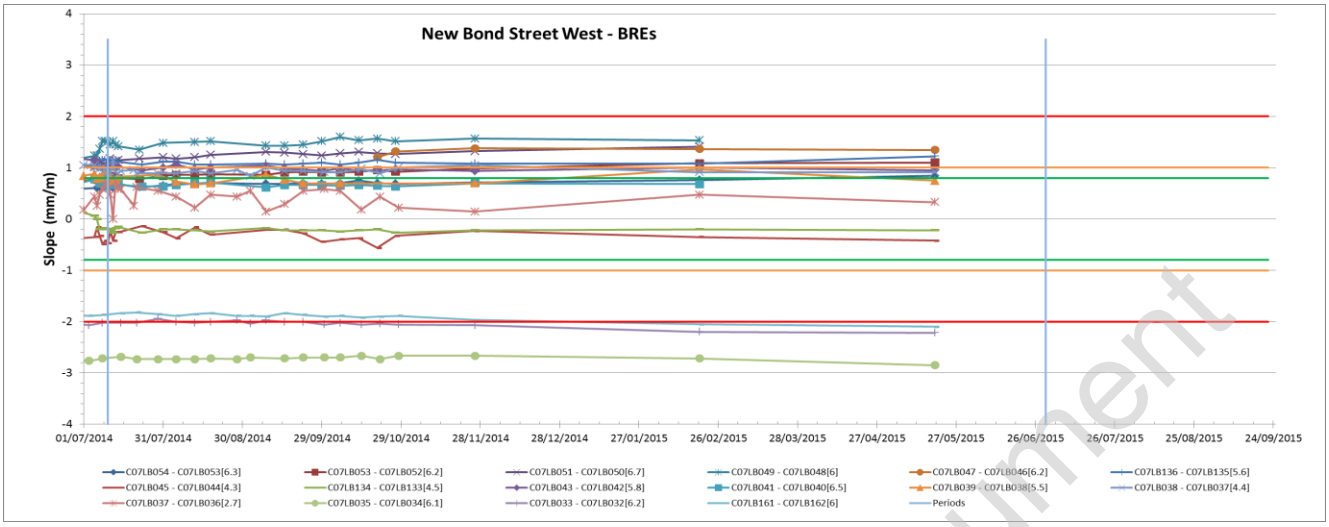
4.2. New Bond Street - West

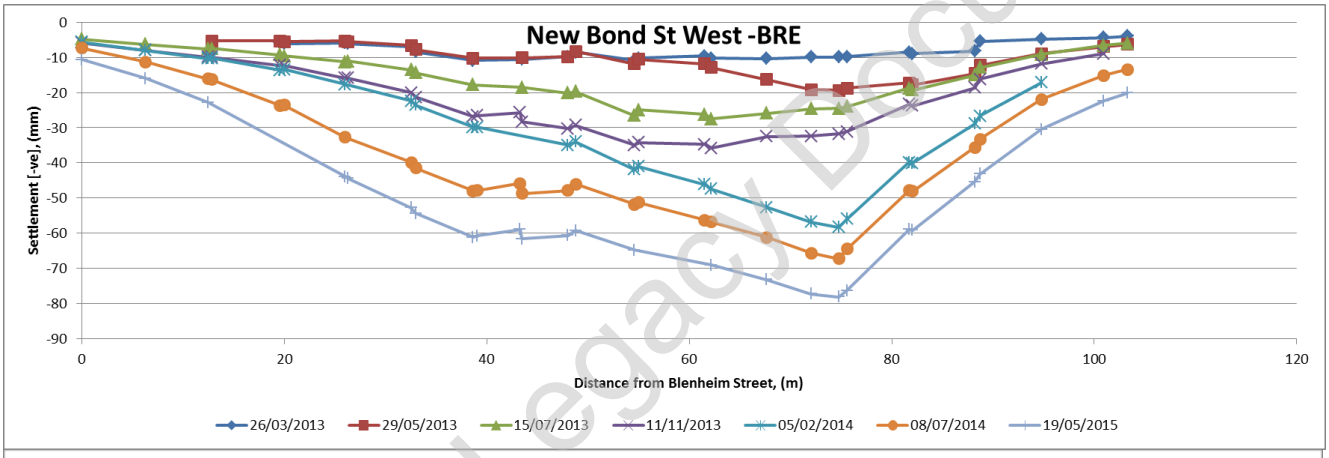


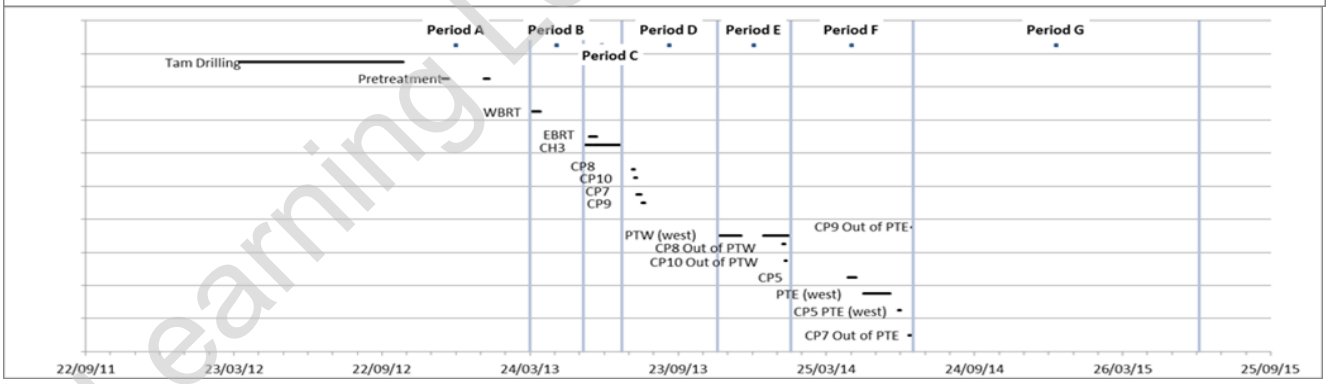


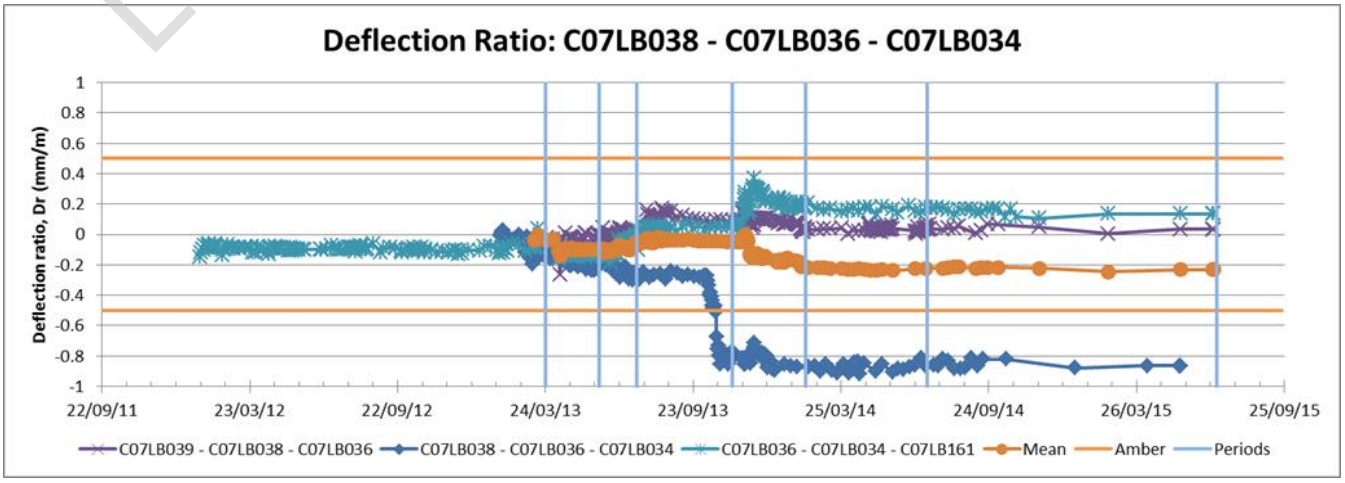








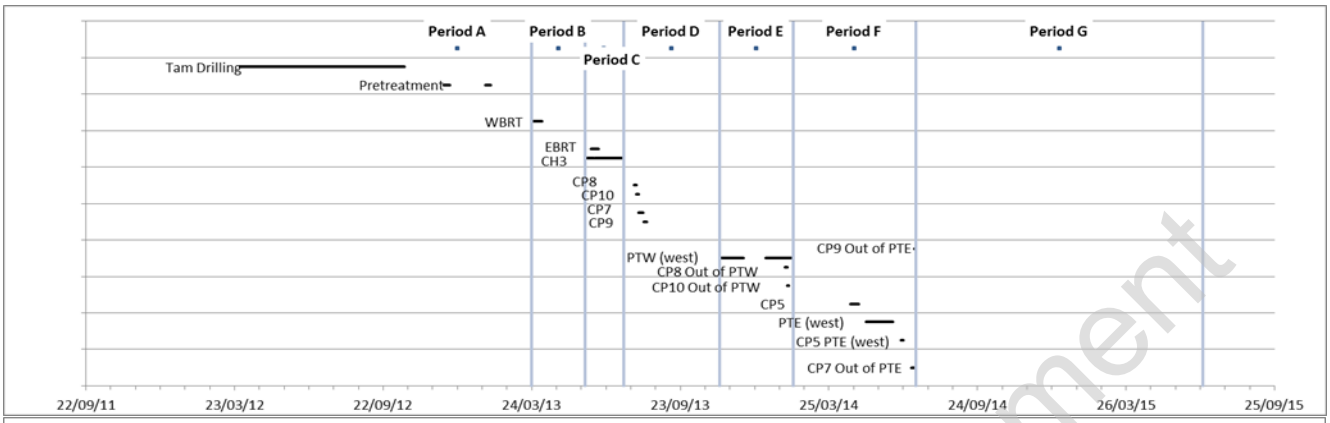


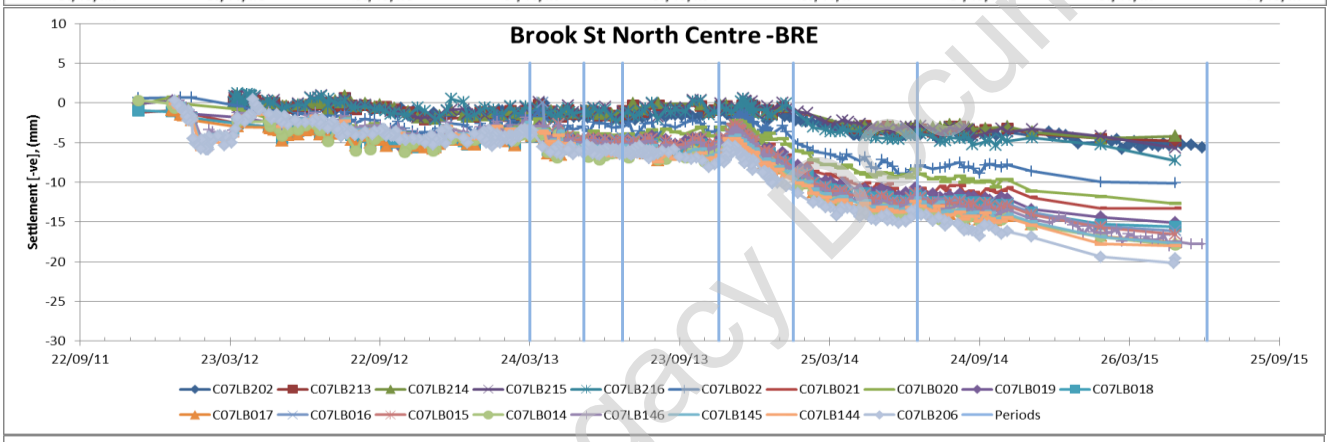


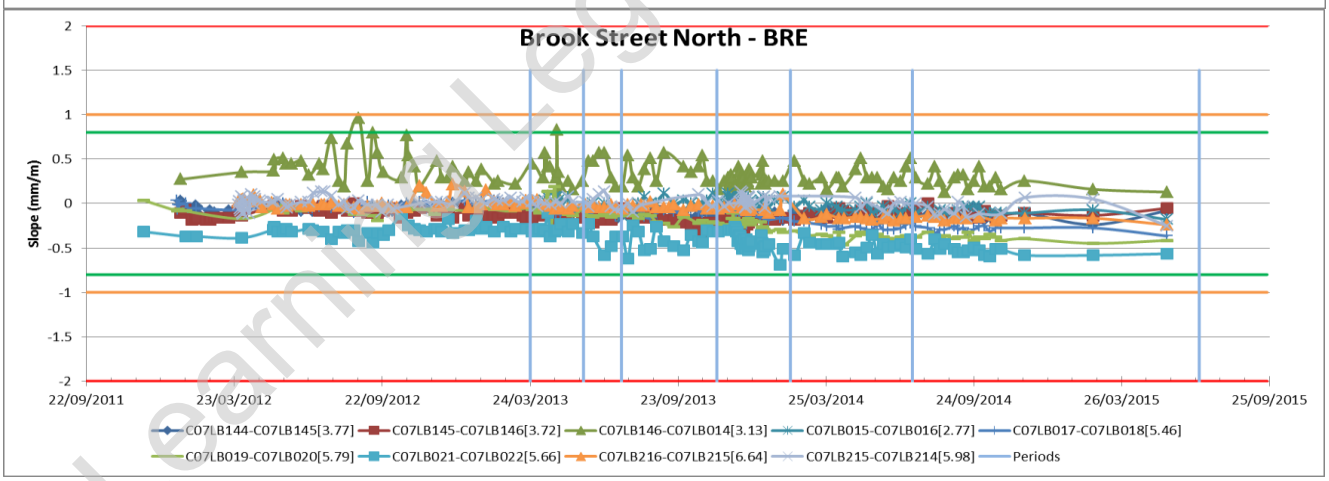
The following points are noted:

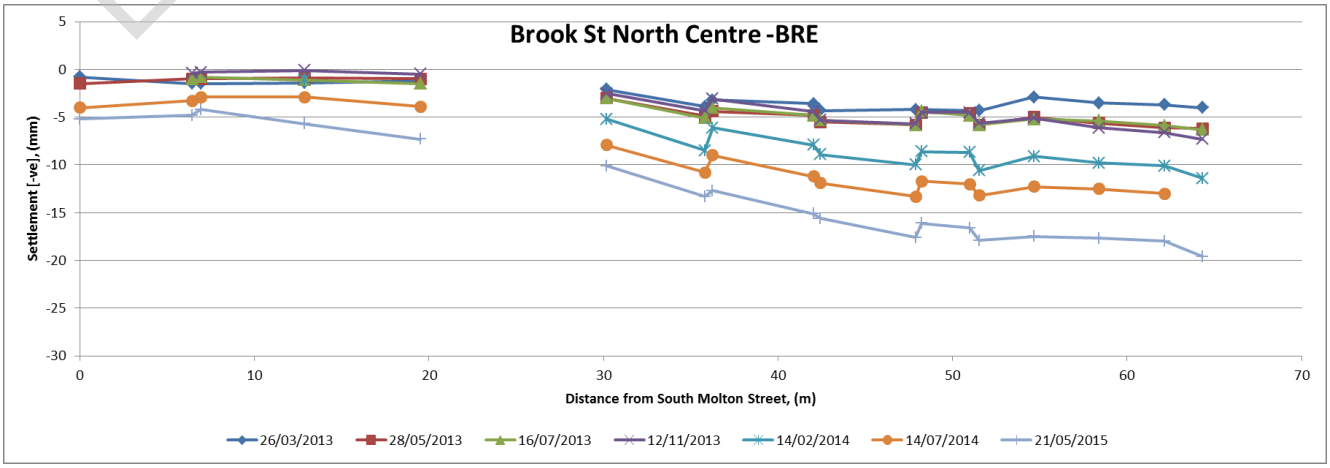
- The most southerly part of the New Bond Street west façade is within the GS5 array (from distance 90m): data from all points are presented.
- The New Bond Street west façade traverses the entire extent of the tunnels and consequently the key events vary with location. The most notable event was however the construction of PTW in Period E (see Section 3.6).
- At the end of Period A, prior to tunnelling, the maximum settlement was ~10mm but there was only minor variation over the full length of the façade.
- In Period B, the WBRT generated a further 10mm settlement with a trough extending from distance 60m to 103m at Brook Street (nos. 104 to 110 New Bond Street).
- The construction of the EBRT and CH3 increased the settlement over the full extent of the façade but generated an approximately symmetrical trough with a maximum settlement of under 30mm. Slopes were generally maintained below the Amber trigger level, although the first occurrence was just prior to the end of Period C (09/07/13 C07LB043 - C07LB042 at distance 51m).
- In Period D the only works were the CP excavations: the increase in settlement was less than 10mm and this tended to widen the trough reducing some slopes but increasing others: at the end of Period D there was again only one amber slope trigger: at distance 78m (C07LB035 - C07LB034).
- The construction of PTW changed the form of the settlement profile substantially increasing the slopes and generating a red trigger at C07LB035 - C07LB034 and a number of amber triggers on adjacent points. The concurrent compensation grouting did not control the settlement at C07LB035 on the south party wall of 105-106 New Bond Street. It was discovered that the floor in the basement was being lifted in preference to the structure. Targeted grout jacking was undertaken but was not pursued.
- In Period F, the construction of PTE produced a much less marked effect than for PTW but increased slopes at the northern end of the façade sufficiently to generate two further amber triggers.
- Post construction, in Period G, settlement has continued to increase. As expected the movements are relatively uniform and hence the impact on slopes is minor. Nevertheless the change in slope has been sufficient to take two slopes from amber into red.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate albeit confirmed by few sets of readings. The only excavation within Period G is within the ETH (by Others)
- There is an “individual” deflection ratio in excess of the amber trigger at a distance of 75m which occurred in Period E due to the PTW as described above. The DR reached ~0.8mm/m and has subsequently increased slightly but in Period G has been stable within the range 0.8 to 0.9mm/m. If a “20m rolling average” deflection ratio is calculated In accordance with the method described in the C122 I&M Plan (Section 7.3), the value determined is less than the Amber trigger.

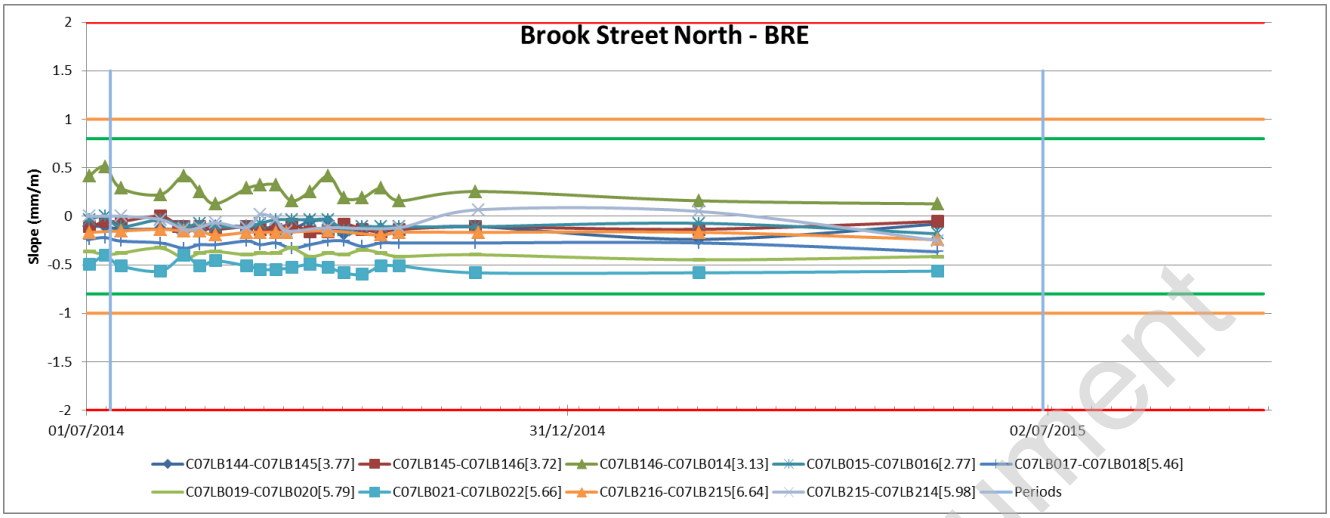
4.3. Brook Street - North







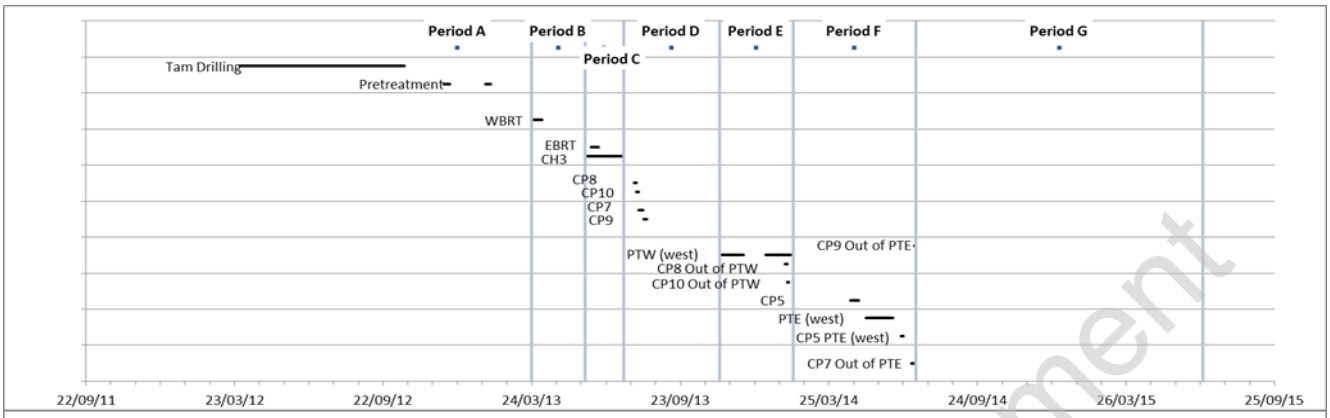


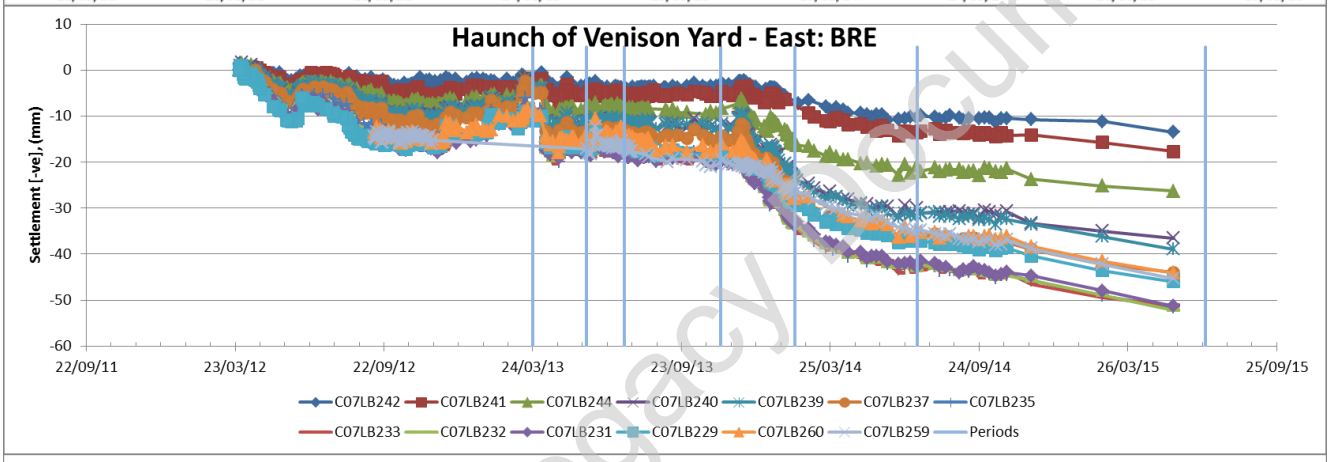


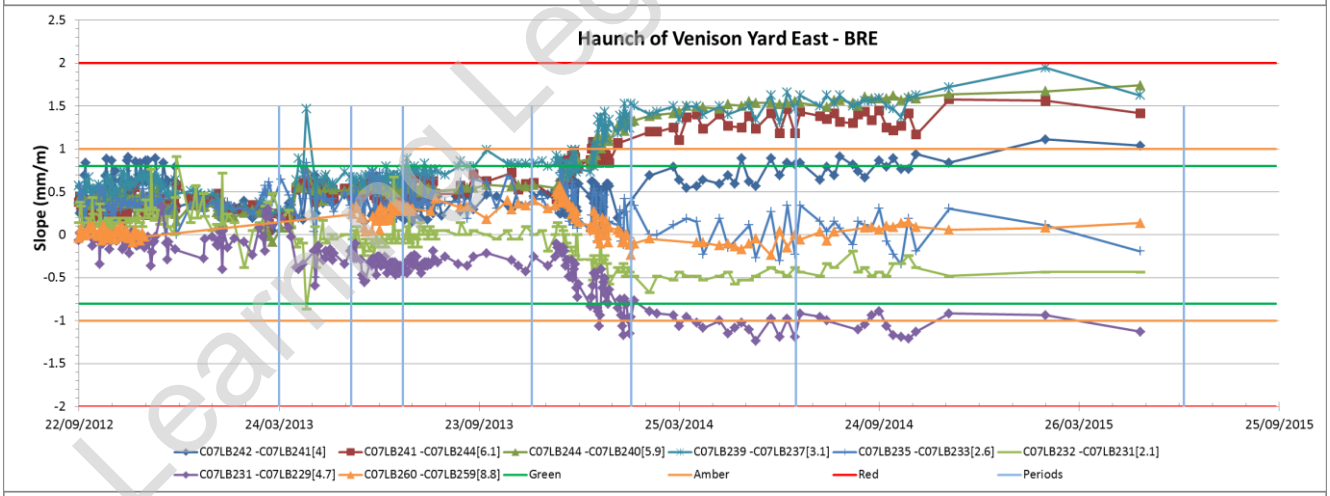
The following points are noted:

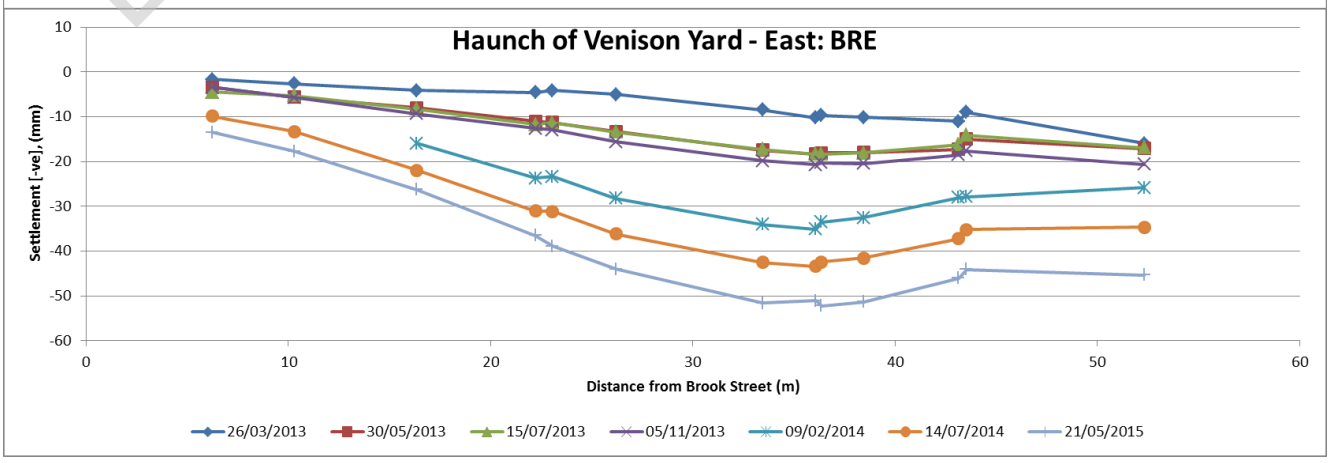
- The Brook Street north façade between South Molton Street and New Bond Street is outside the plan extent of the GS2 array: the eastern end is covered by GS5 arrays but the western end is outside the predicted 10mm contour (see Figure 3.1.1) and is therefore not within the grouting area.
- The key events are the WBRT in Period B and PTW in Period E. Settlement was less than 5mm prior to tunnelling and only increased by a few millimetres due to the WBRT and subsequent consolidation settlement. Settlement was less than 10mm prior to the PTW in Period E. Uplift is apparent from grouting during PTW and at the end of Period E settlement was only about 10mm.
- It is noted that at the end of these activities the settlement was about 10mm and that there has been 10mm consolidation settlement over a period of 16 months.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate albeit confirmed by few sets of readings. ETH excavation 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.
- No slope triggers have occurred and the slopes are essentially constant. By inspection, there are no deflection ratio triggers.

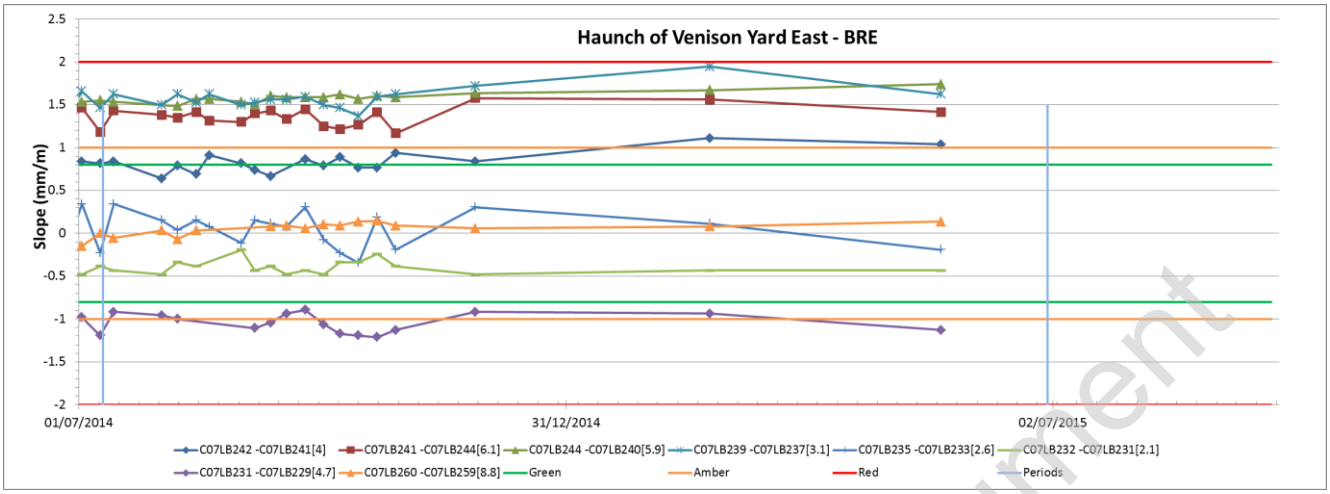
4.4. Haunch of Venison Yard - East







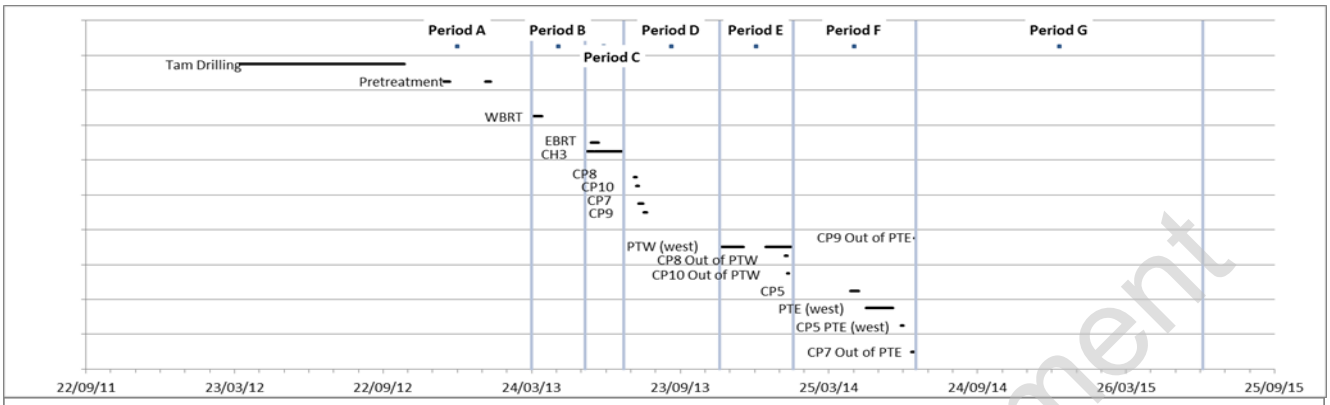


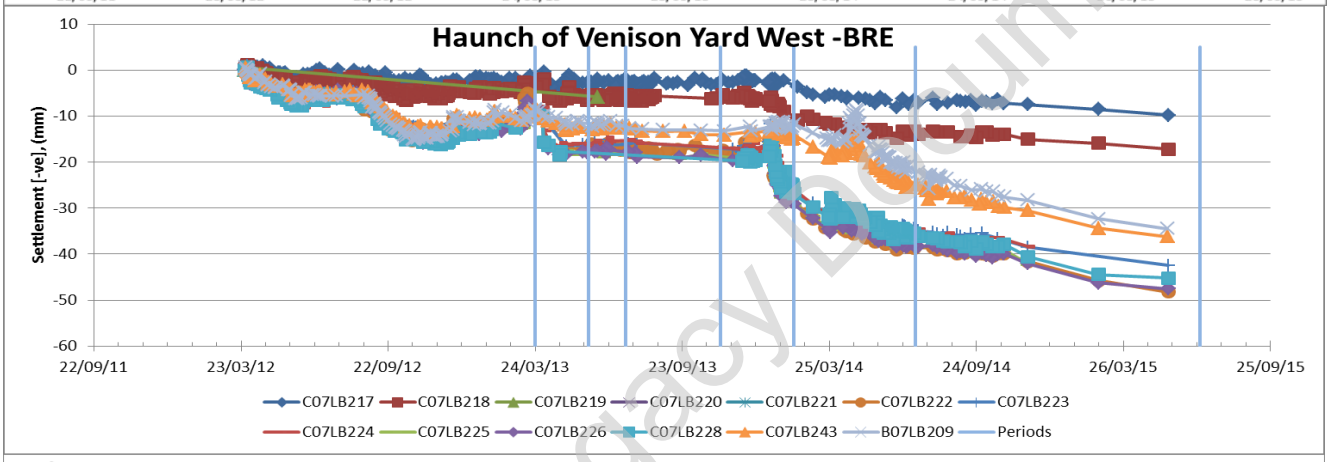


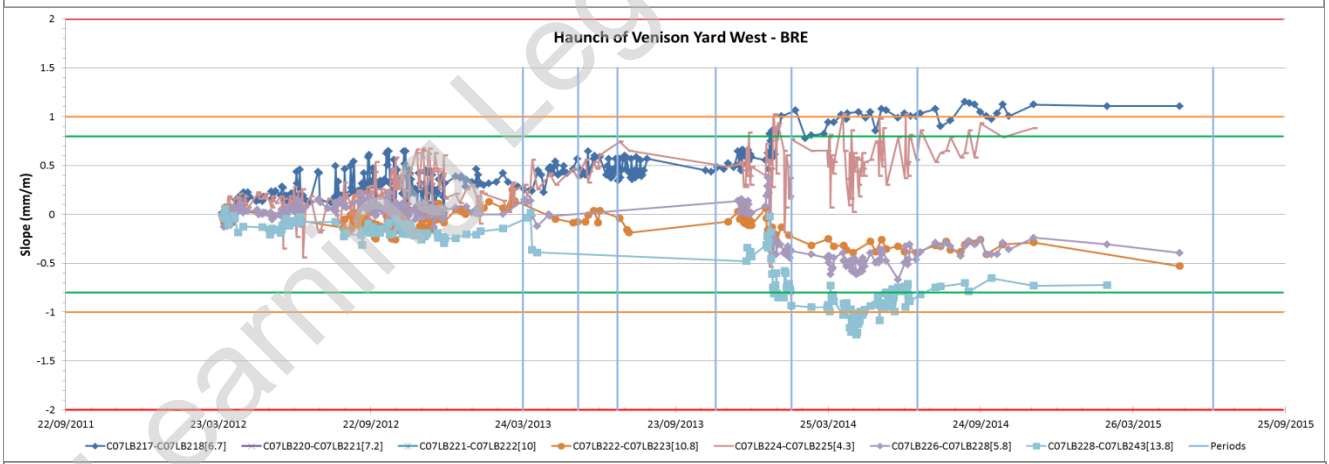
The following points are noted:

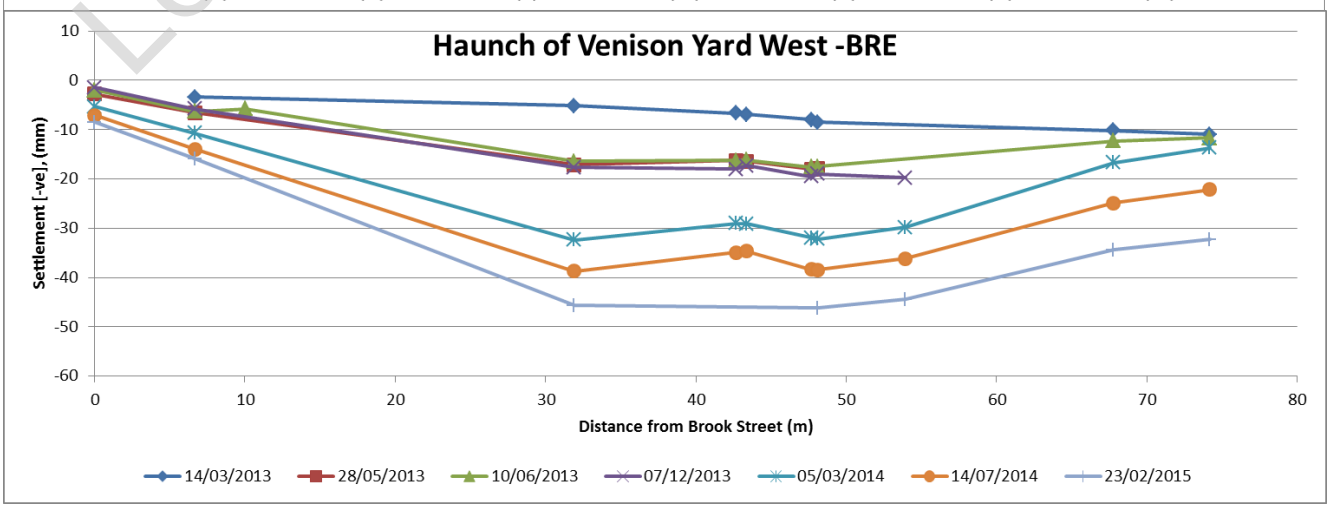
- The Haunch of Venison Yard east façade is within the plan extent of the GS2 array except at its southern end adjacent to Brook Street.
- The key events are the WBRT in Period B and PTW in Period E. Settlement reached 15mm prior to tunnelling but was reduced by pretreatment and pre-TBM jack grouting to about 10mm at the end of Period A. The WBRT and subsequent consolidation settlement increased the maximum settlement to about 20mm at the end of Period D. Uplift is apparent from grouting during PTW and at the end of Period E settlement had increased to 35mm including post construction consolidation.
- The settlement during Period E was sufficient to generate 3 amber triggers on points to the south of the tunnel (distances 10 to 26m).
- It is noted that at the end of these activities the settlement was about 35mm and that there has been 15mm consolidation settlement over a period of 16 months.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate albeit confirmed by few sets of readings. The only excavation works undertaken in Period G is continued excavation within the ETH (by Others).
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- Three amber slope triggers occurred during construction and a further two pairs of BRE are at or above the amber due to post construction movements. The slopes are essentially constant within the repeatability of the data. By inspection, there are no deflection ratio triggers.

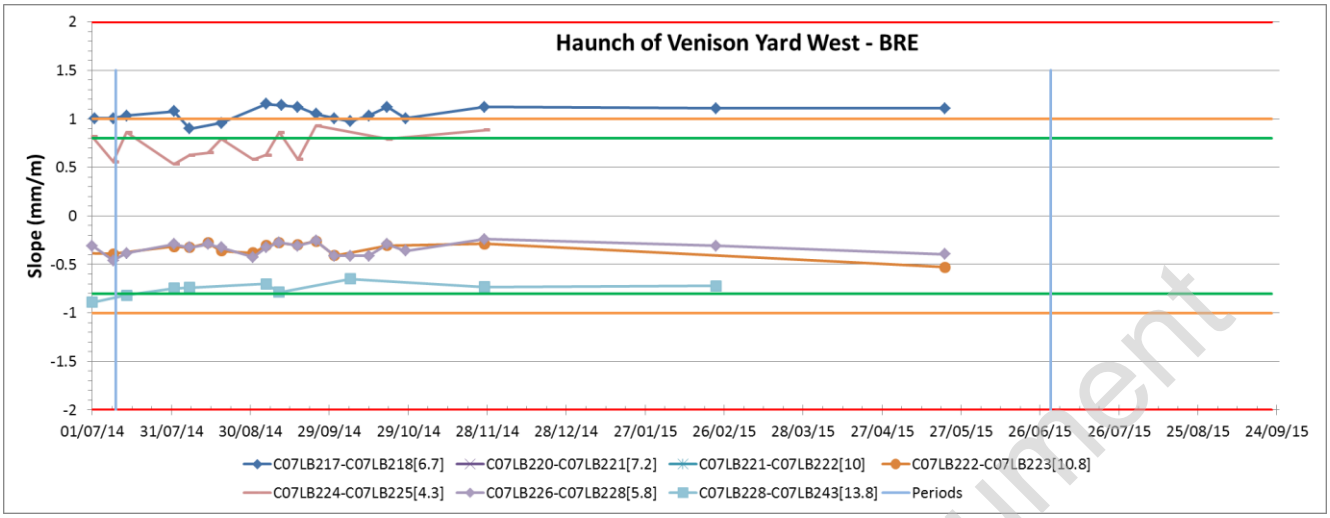
4.5. Haunch of Venison Yard - West







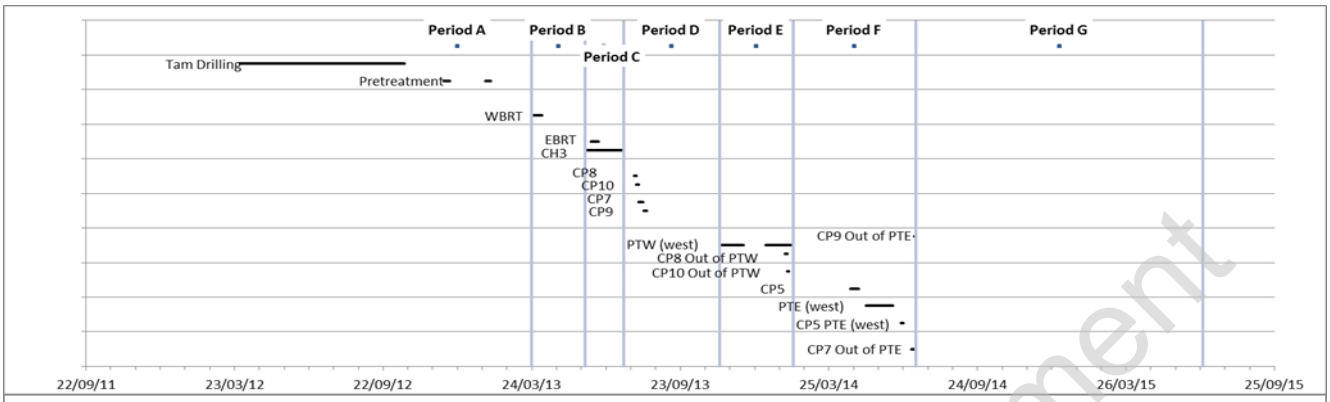


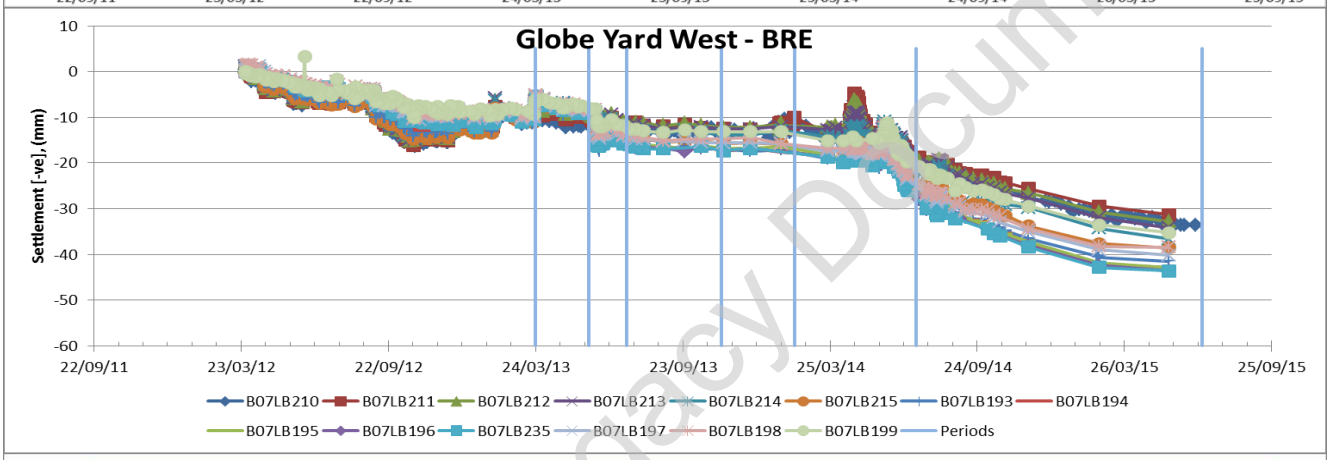


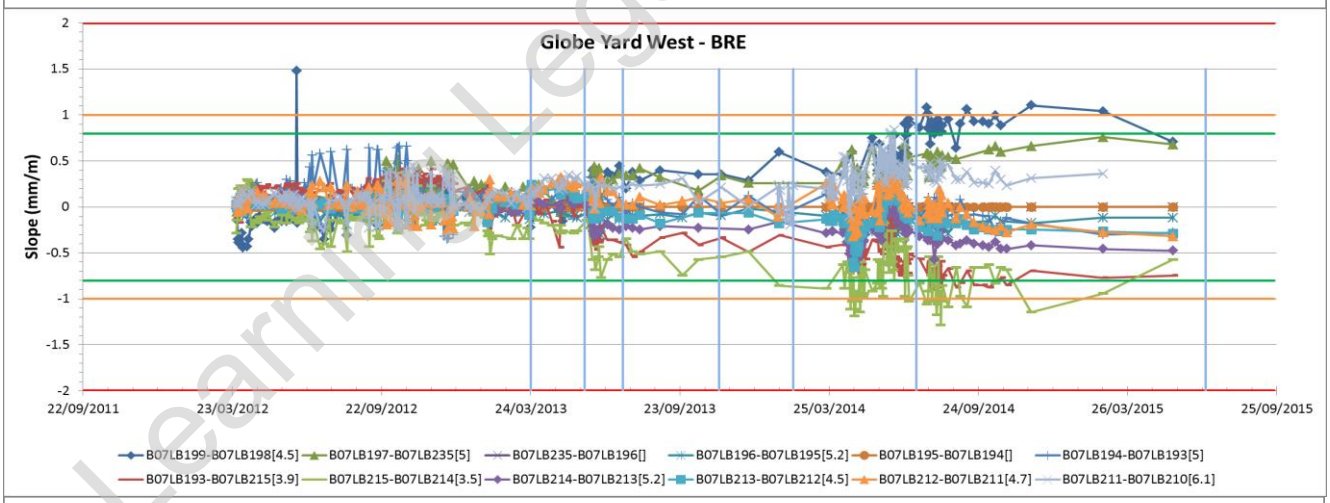
The following points are noted:

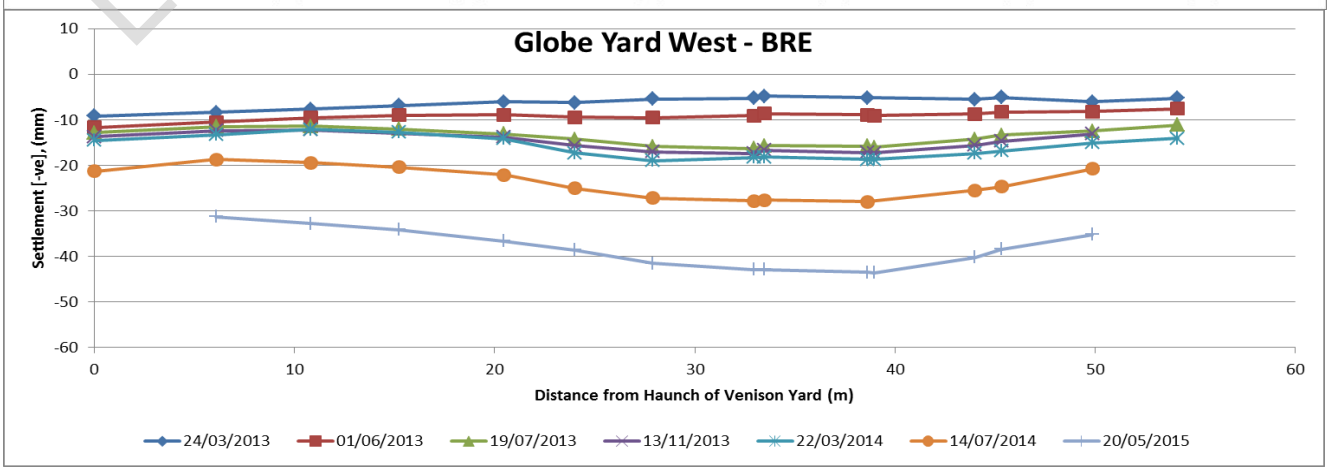
- The Haunch of Venison Yard west façade is within the plan extent of the GS2 array except at its southern end adjacent to Brook Street.
- The key events are the WBRT in Period B, PTW in Period E and CP5 in Period F. Settlement reached 15mm prior to tunnelling but was reduced by pretreatment and pre-TBM jack grouting to about 10mm at the end of Period A. The WBRT and subsequent consolidation settlement increased the maximum settlement to about 20mm at the end of Period D. Uplift is apparent from grouting during PTW and at the end of Period E settlement had increased to 30mm including some post construction consolidation.
- The settlement during Period E was sufficient to generate readings above the amber triggers in 2 locations on points to the south of the tunnel (distances 0 to 31m), albeit only one was confirmed by subsequent readings.
- It is noted that at the end of these activities the settlement was about 35mm and that there has been 20mm consolidation settlement over a period of 16 months. Concurrent and jack grouting in Period F associated with CP5 generated up to 5mm uplift.
- Following the grout jacking, the rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate albeit confirmed by few sets of readings. No excavation works have been undertaken by BFK in Period G.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- One amber slope trigger occurred during construction and a further pair of BRE (C07LB228-C07LB243) went above the amber due to post construction movements: this was addressed by grout jacking and only one amber slope trigger remains. The slopes are essentially constant within the repeatability of the data. By inspection, there are no deflection ratio triggers.

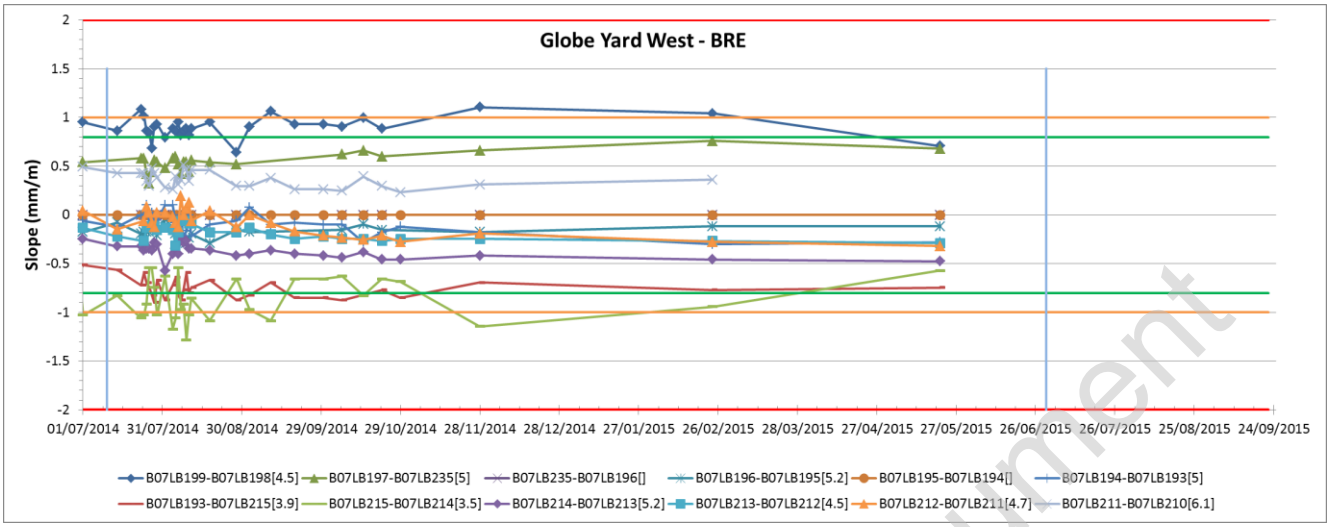
4.6. Globe Yard - West







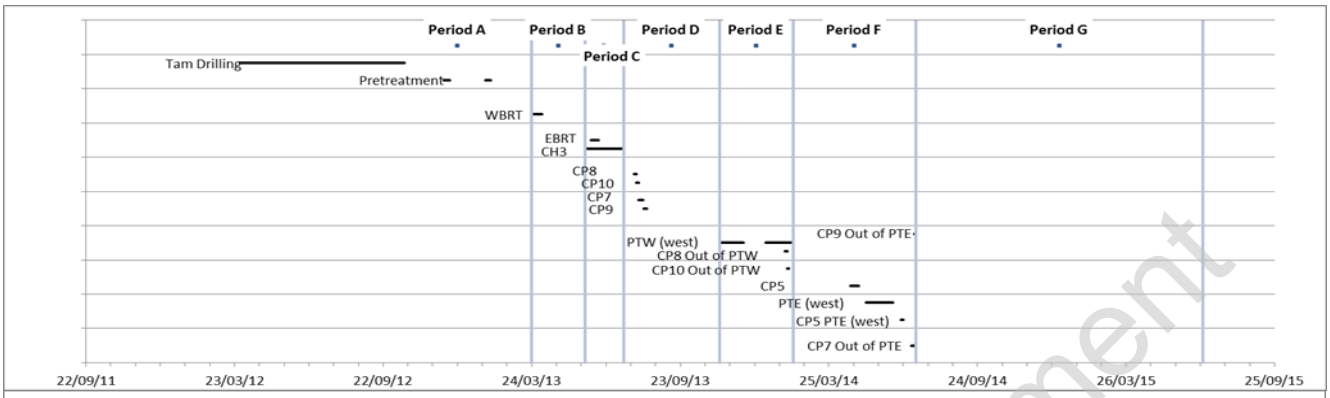


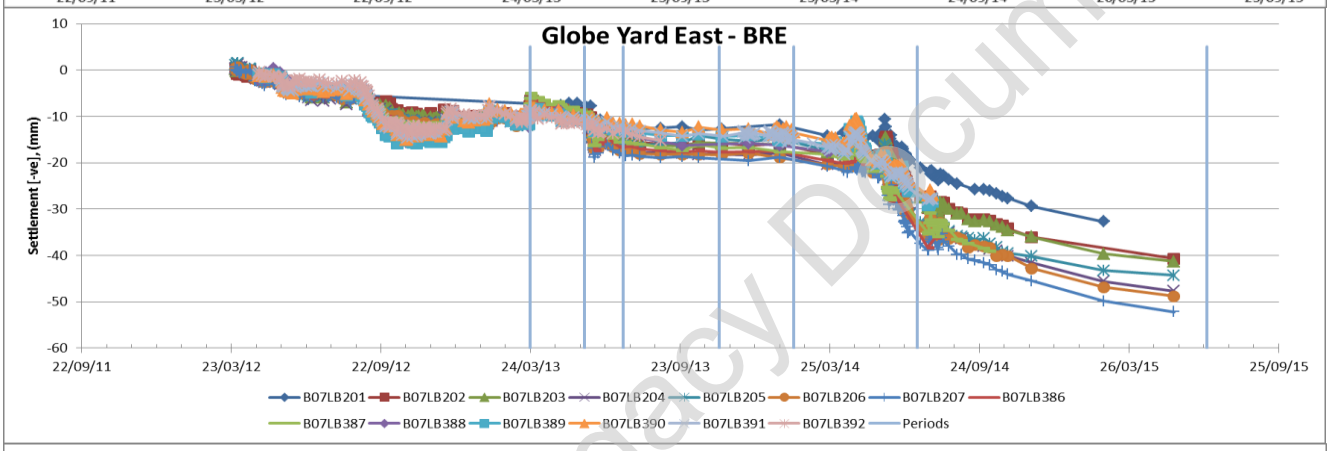


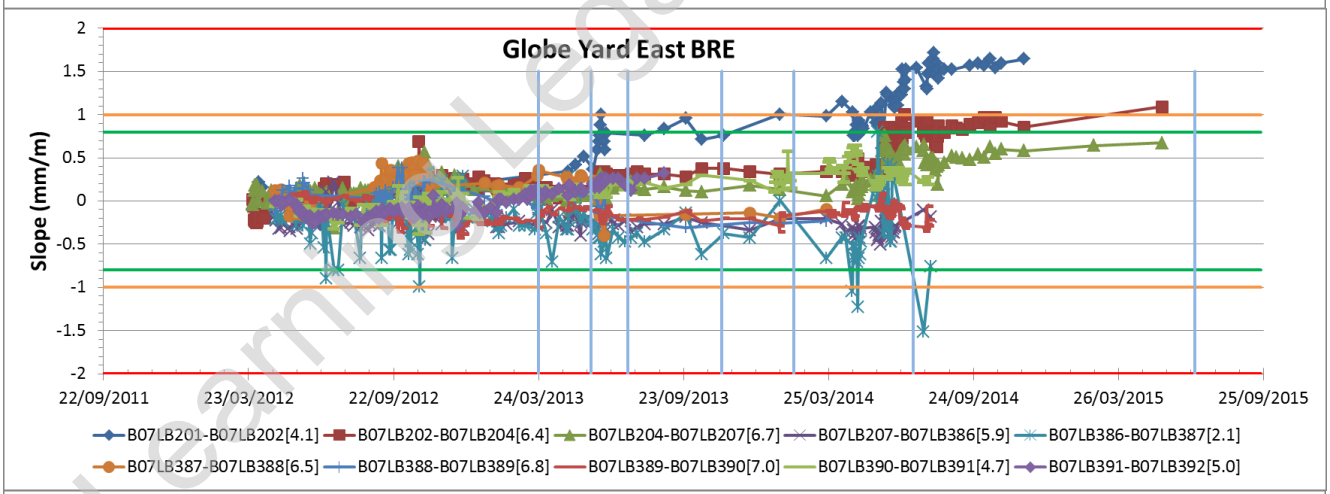
The following points are noted:

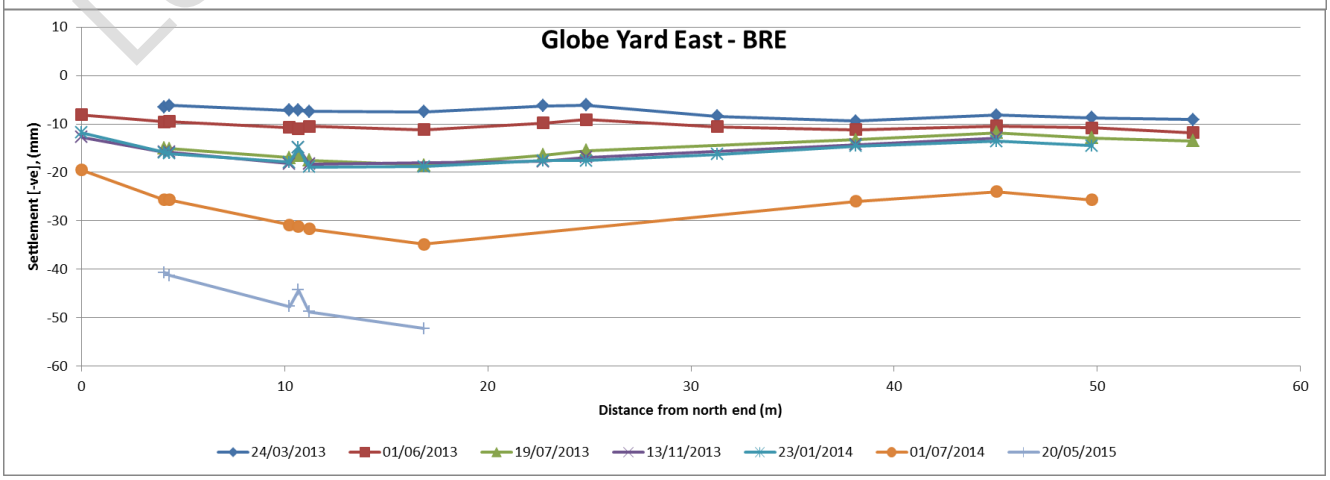
- The Globe Yard west façade is within the plan extent of the GS2 array.
- The key events are the EBRT in Period C and PTE / CP5 in Period F. Settlement reached 15mm prior to tunnelling but was reduced by pretreatment and pre-TBM jack grouting to about 10mm at the end of Period A. The EBRT and subsequent consolidation settlement increased the maximum settlement to about 18mm at the end of Period D. Uplift is apparent from grouting during PTE and CP5 at the end of Period F settlement had increased to 28mm including some post construction consolidation.
- The settlement during Period E was sufficient to generate occasional readings above the amber triggers in 2 locations however the majority of subsequent readings confirm that no triggers actually occurred.
- It is noted that at the end of these activities the settlement was about 28mm and that there has been 15mm consolidation settlement over a period of 11 months.
- The rate of post construction settlement has continuously reduced throughout Period G. No excavation works have been undertaken by BFK in Period G.
- The profile plot confirms that the consolidation settlement is relatively uniform over a wide area resulting in little change in slopes.
- Although occasional readings give slopes in excess of the amber trigger, the overall trend of the data confirms that no amber triggers have been exceeded. The slopes are essentially constant within the repeatability of the data. By inspection, there are no deflection ratio triggers.

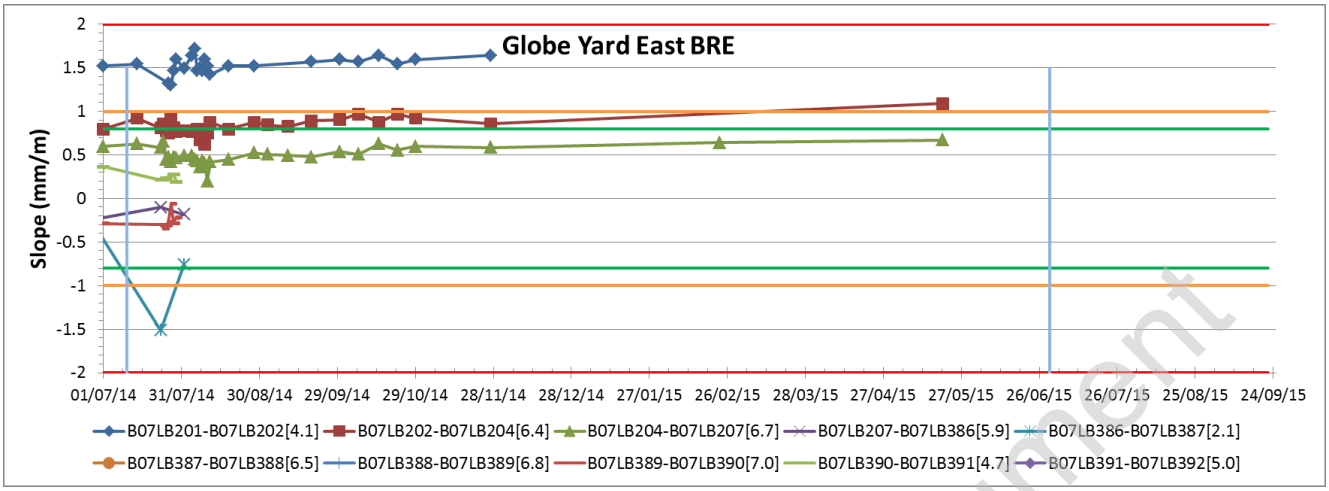
4.7. Globe Yard - East







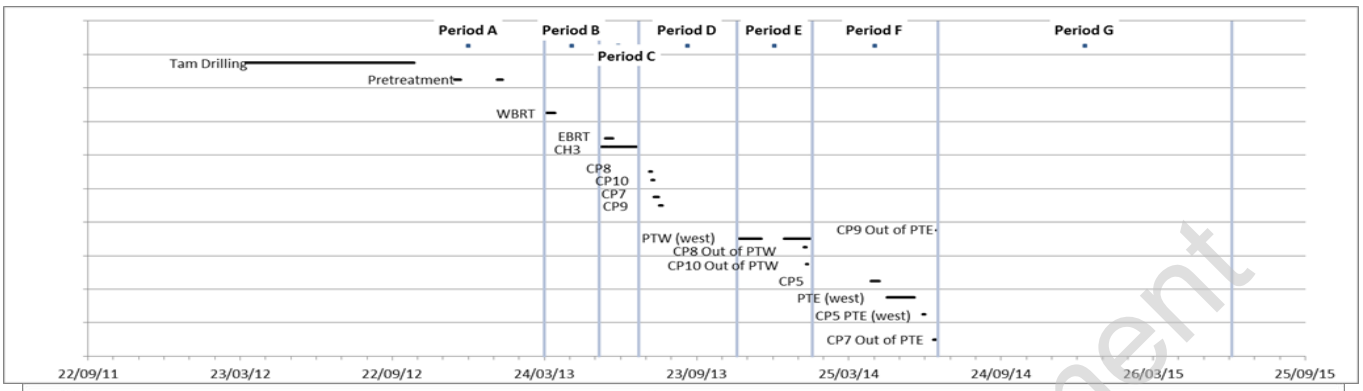


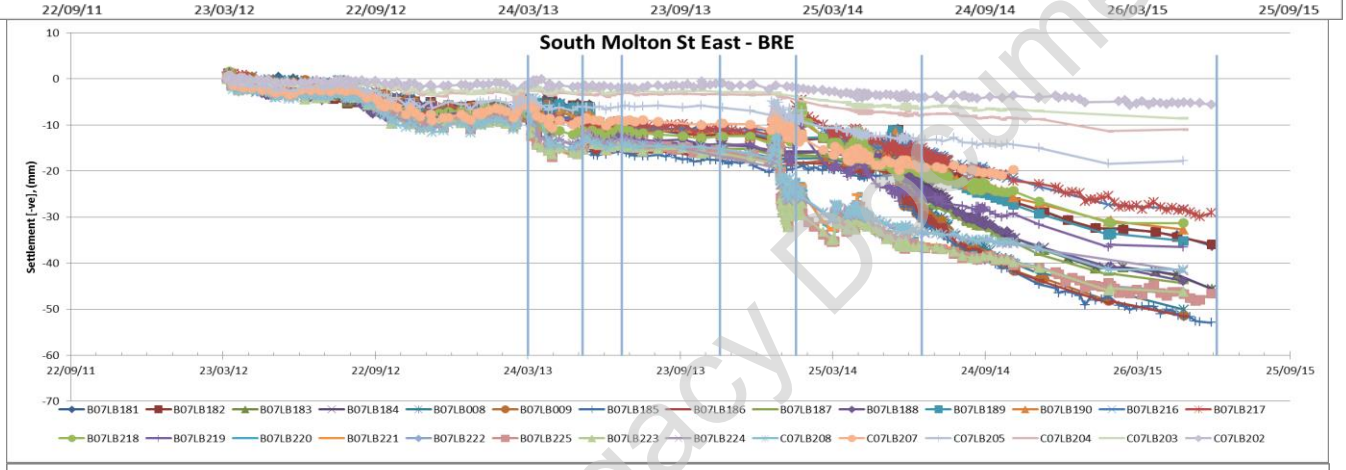


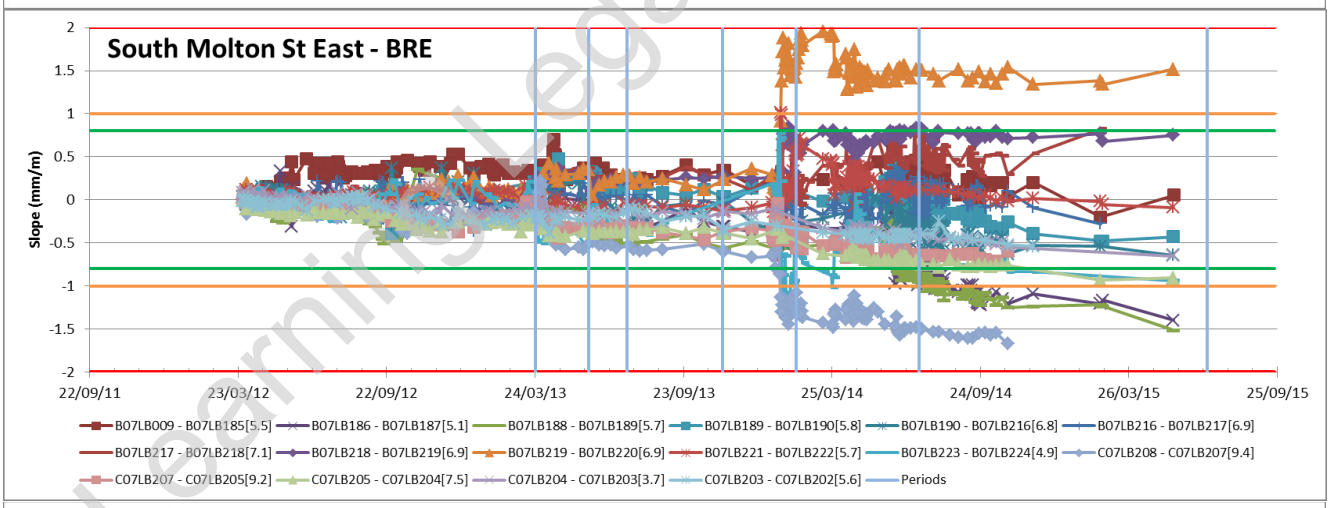
The following points are noted:

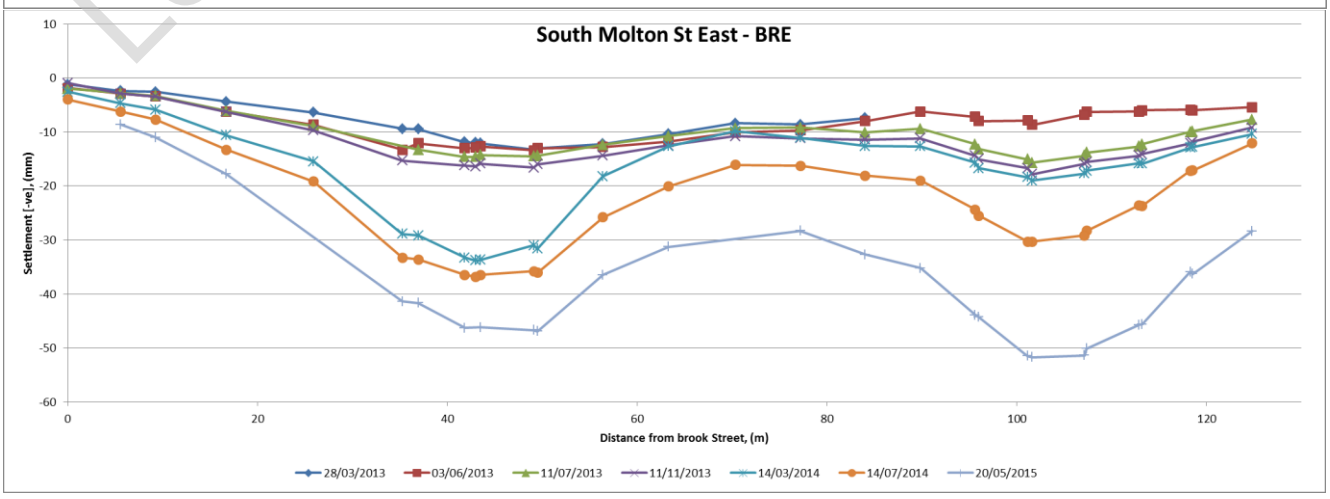
- The Globe Yard east façade is within the plan extent of the GS2 array.
- The key events are the EBRT in Period C and PTE / CP5 in Period F. Settlement reached 15mm prior to tunnelling but was reduced by pretreatment and pre-TBM jack grouting to about 10mm at the end of Period A. The EBRT and subsequent consolidation settlement increased the maximum settlement to about 20mm at the end of Period D. Uplift is apparent from grouting during PTE and CP5 at the end of Period F settlement had increased to 38mm including some post construction consolidation.
- The settlement during Period E was sufficient to generate an amber trigger in one location (B07LB201 - B07LB202) at the north end of the profile.
- It is noted that at the end of these activities the settlement was about 28mm and that there has been 15mm consolidation settlement over a period of 11 months.
- The rate of post construction settlement has continuously reduced throughout Period G. No excavation works have been undertaken by BFK in Period G.
- The time plot confirms that the consolidation settlement is relatively uniform with all points showing similar behaviour. However, the most recent reading (20/05/15) suggests that a second amber trigger has occurred (B07LB202-B07LB204), albeit it is still close to the range of earlier readings.
- The slopes are essentially constant within the repeatability of the data. By inspection, there are no deflection ratio triggers.

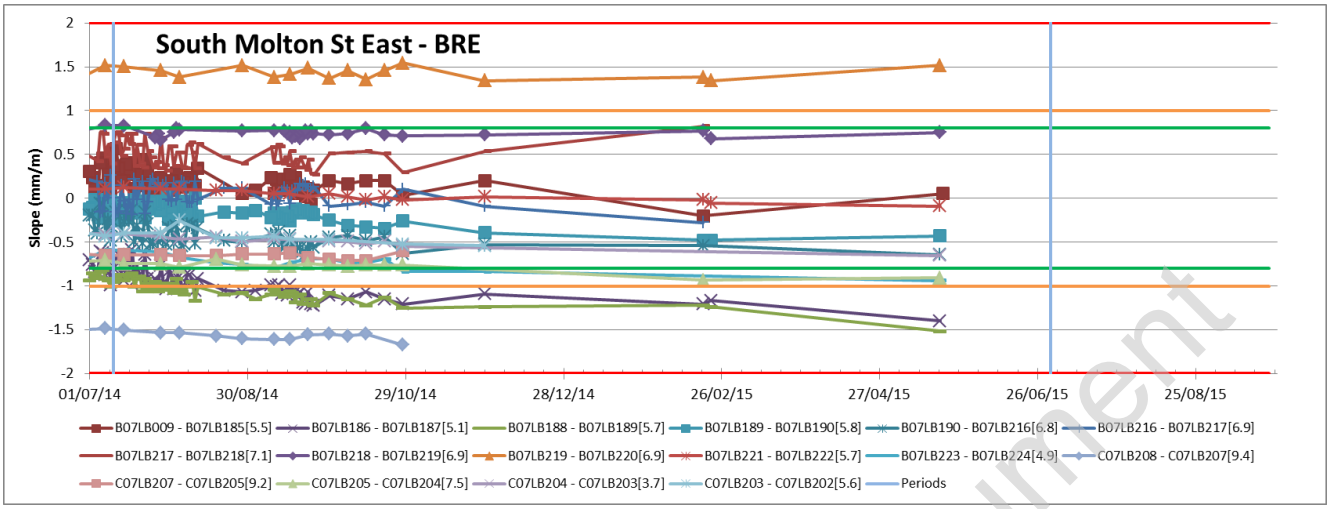
4.8. South Molton Street - East







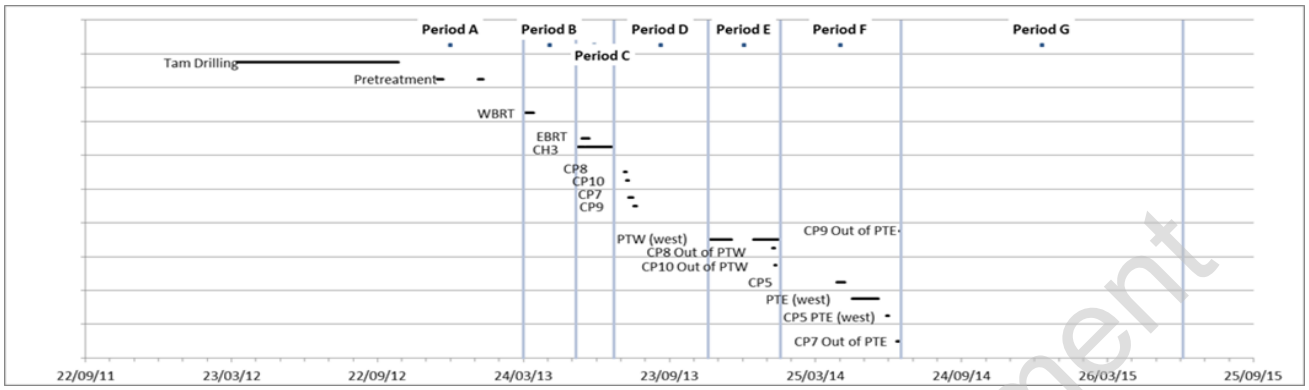


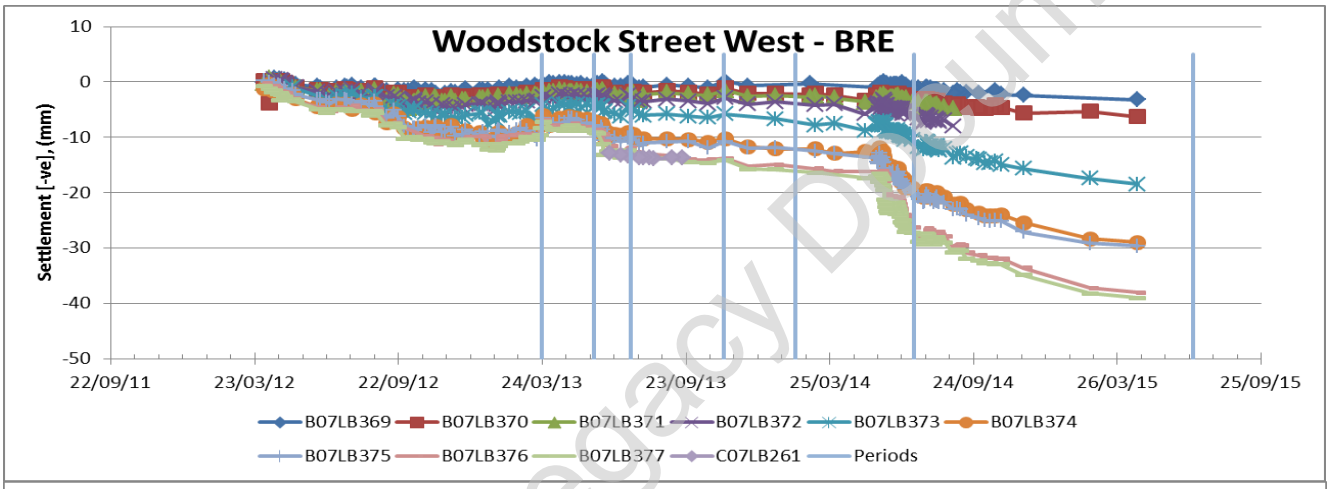


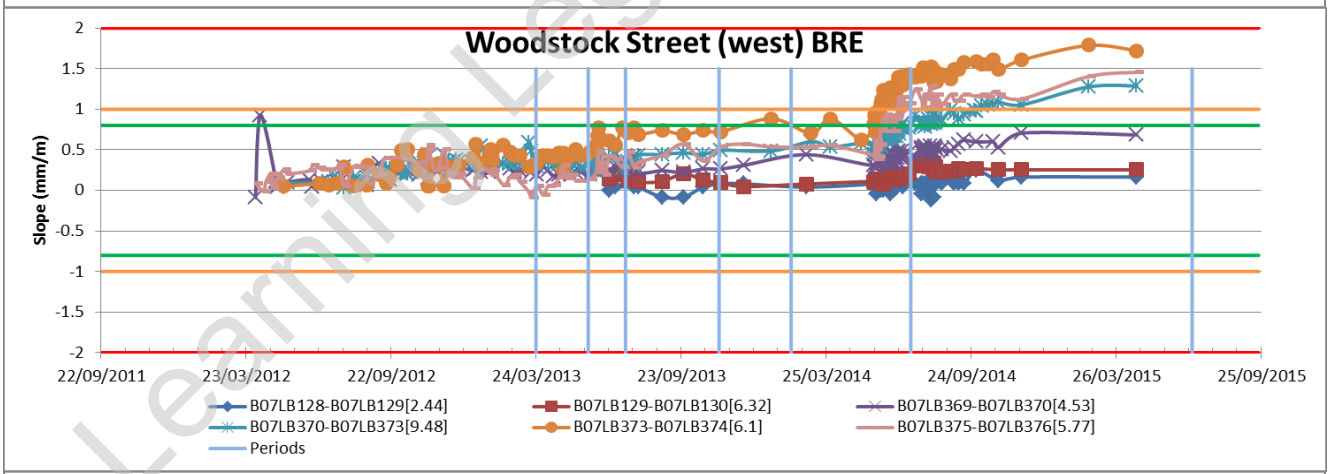
The following points are noted:

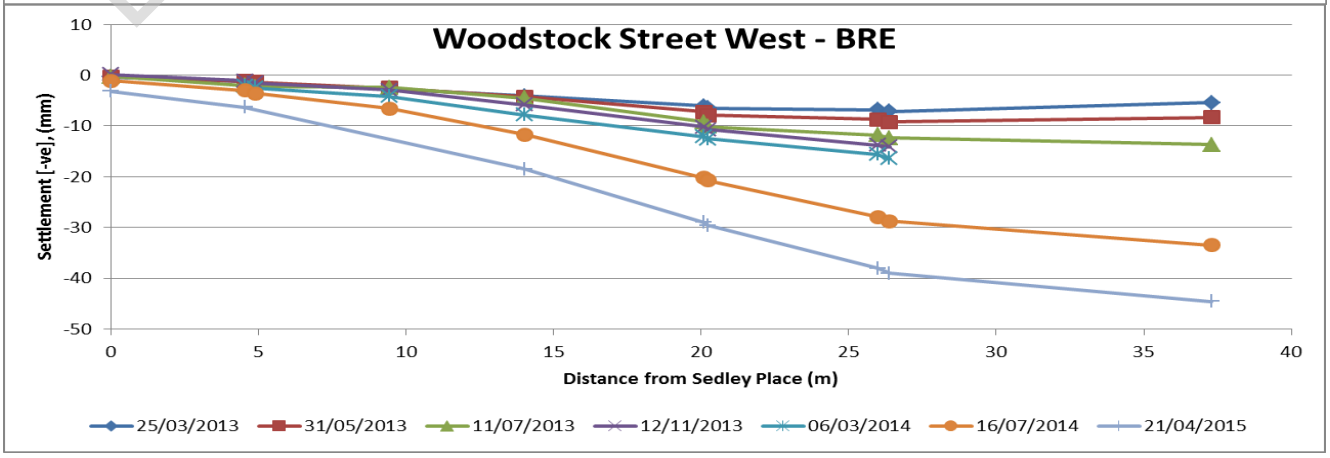
- The South Molton Street east façade is within the plan extent of the GS2 array up to approximately 100m from Brook Street, just short of the centreline of PTE. The profile is therefore affected by both westbound and eastbound tunnels as well as CP5 at its southern end, i.e. by tunnelling in Periods B, C, E and F.
- Settlement reached a maximum of 10mm prior to tunnelling at the end of Period A. The WBRT and EBRT, with subsequent consolidation settlement, increased the maximum settlement to about 17 - 18mm over the tunnel centrelines at the end of Period D. In Period E the PTW increased the maximum settlement to ~33mm over the tunnel. Similarly in Period F the PTE resulted in a total settlement of 30mm above its centreline. Uplift is apparent from grouting during CP5 but by the end of Period F settlement over PTW had increased to 37mm including some post construction consolidation.
- The settlement during Period E was sufficient to generate amber triggers in two locations (B07LB219 - B07LB220 and C07LB207 - C07LB208) towards the south end of the profile to either side of the PTW centreline. Two further amber triggers occurred during Period F and at the start of Period G associated with PTE (B07LB186 - B07LB187 and B07LB188 - B07LB189) – only the points to the south of the PTE centreline are within the GS2 area.
- The rate of post construction settlement has continuously reduced throughout Period G. The increase in settlement is about 10mm over PTW and 20mm over PTE. No excavation works have been undertaken by BFK in Period G.
- The slopes have continued to increase gradually within Period G, however the rate generally appears to be reducing, taking into consideration the repeatability of the data. By inspection, there are no deflection ratio triggers.

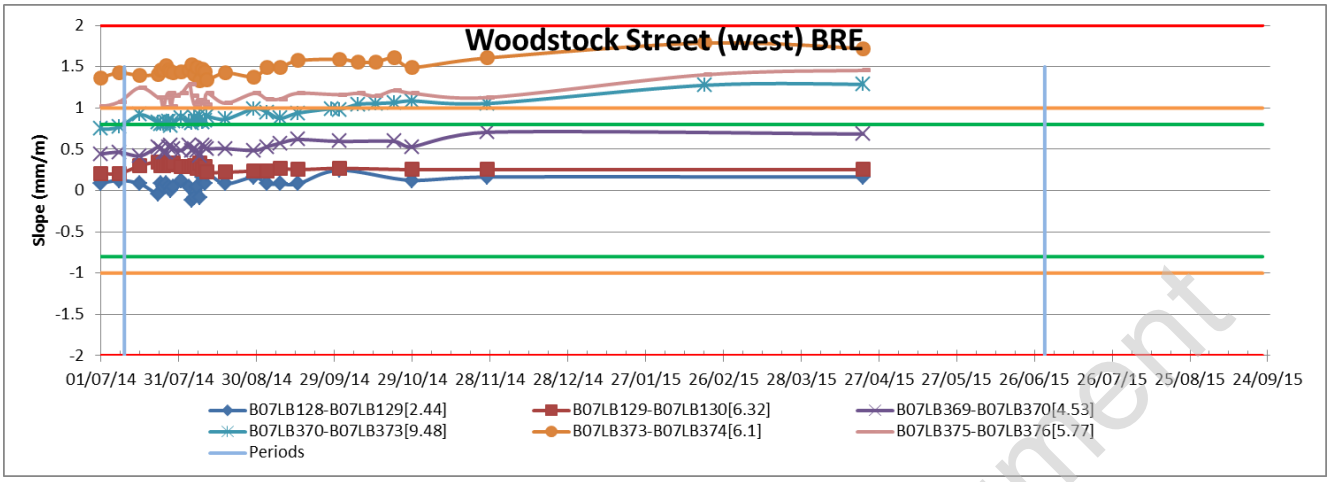
4.9. Woodstock Street - West







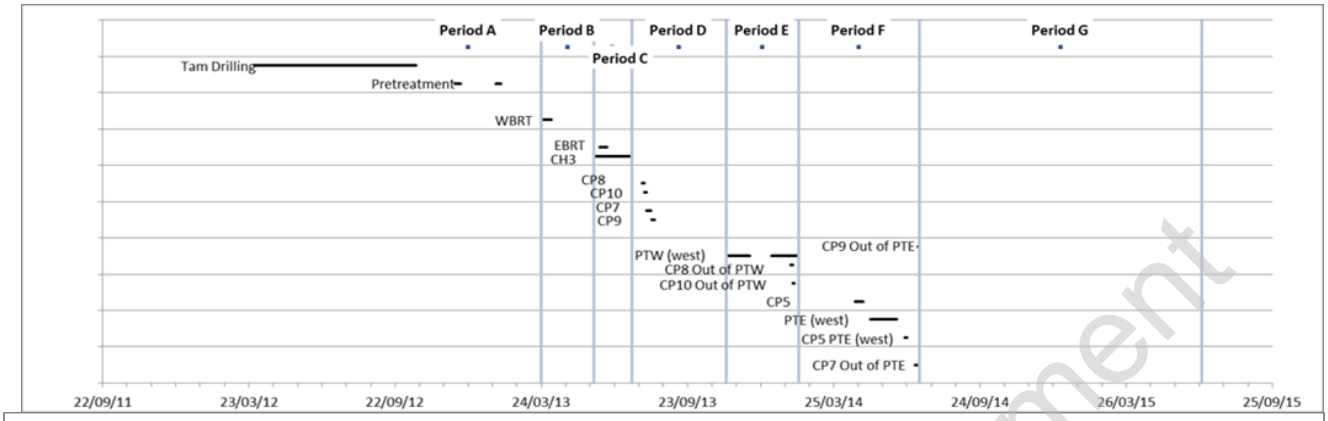


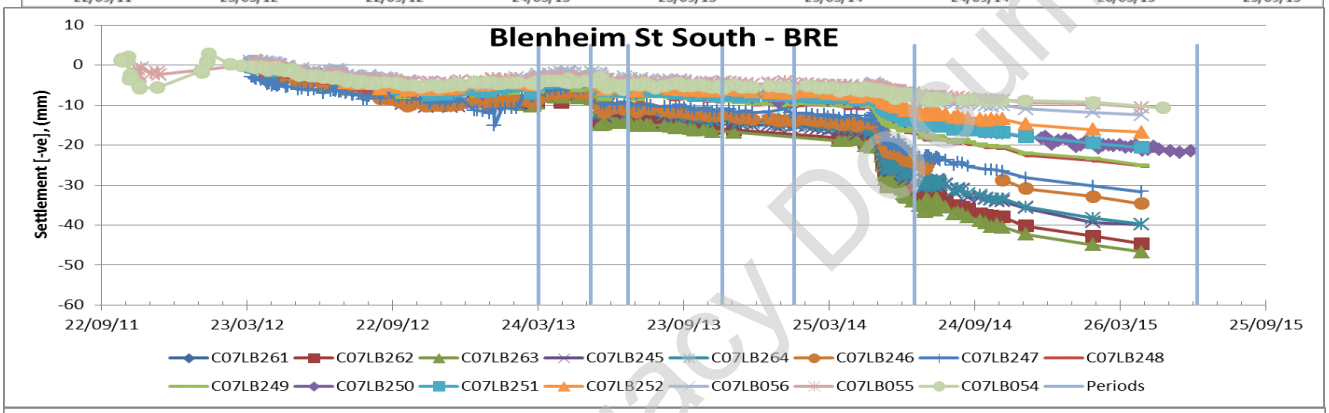


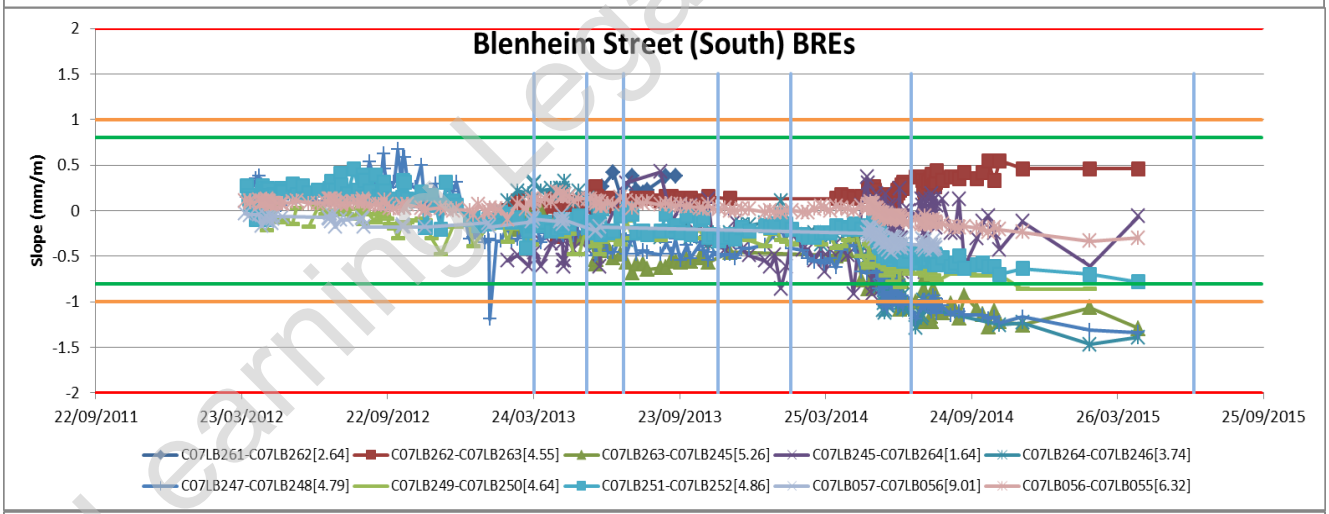
The following points are noted:

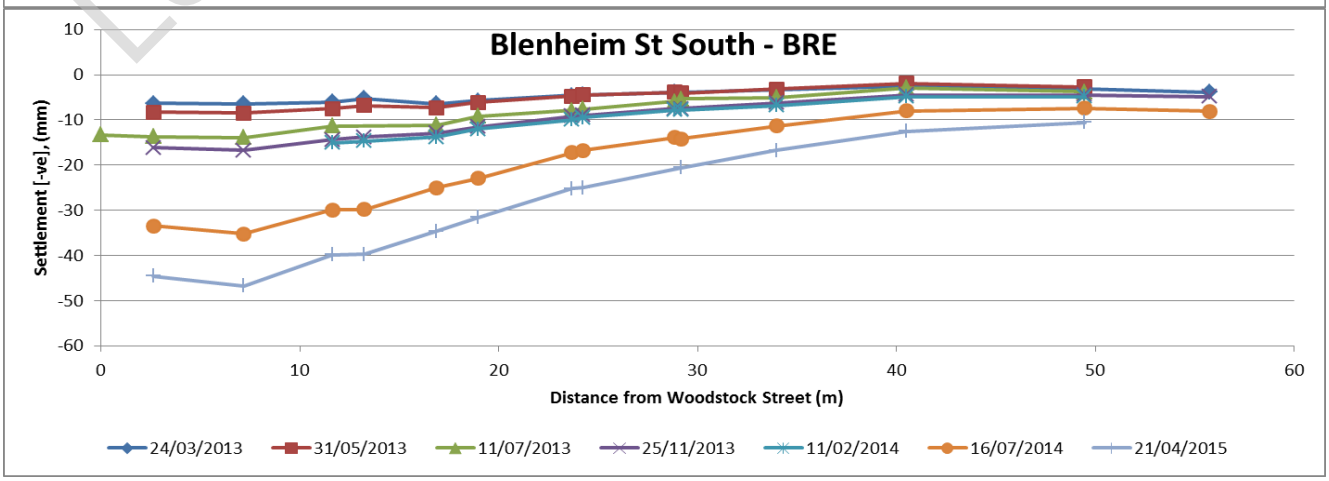
- The Woodstock Street west façade extends from over the EBRT / PTE northwards and is outside the GS2 arrays from distance 0 to ~22m.
- The key construction events are the EBRT in Period C and PTE / CP5 in Period F.
- At the end of Period B, prior to the EBRT, about 10mm settlement had occurred with the maximum at the southern end of the profile. In Periods B, C and D an increase of ~7mm was recorded with about half of this associated with volume loss settlement. During and following PTE and CP5 in Period F, settlement increased to just under 30mm. A further 10mm settlement has occurred in Period G following completion of construction.
- Three amber slope triggers occurred during Period F. By inspection, there are no deflection ratio triggers.
- The rate of settlement has progressively decreased during Period G and although the slopes have increased somewhat, they are now stabilising.

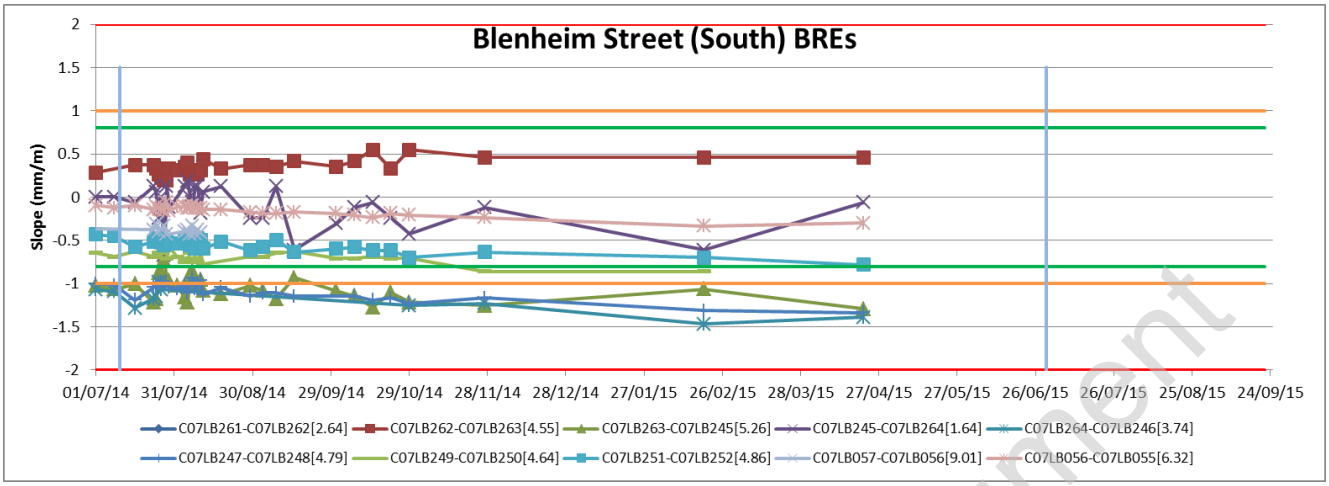
4.10. Blenheim Street – South







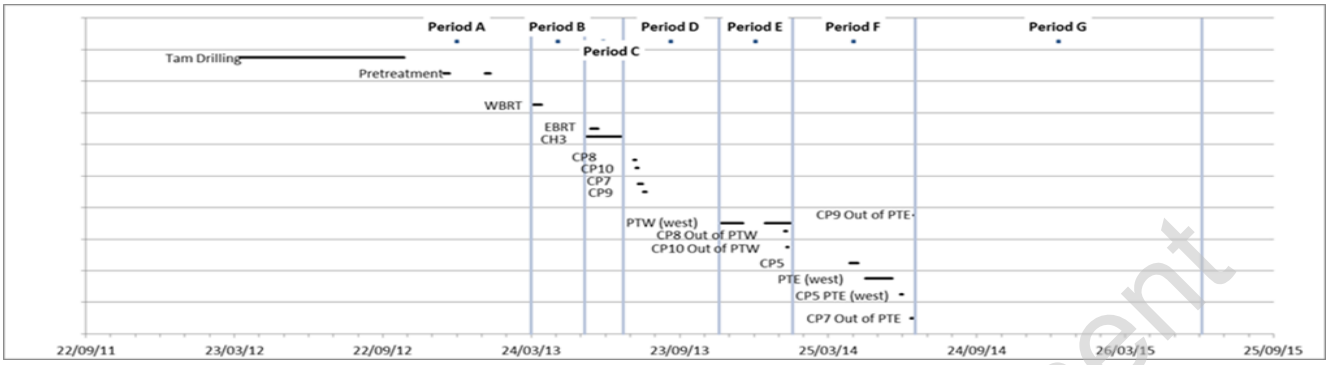


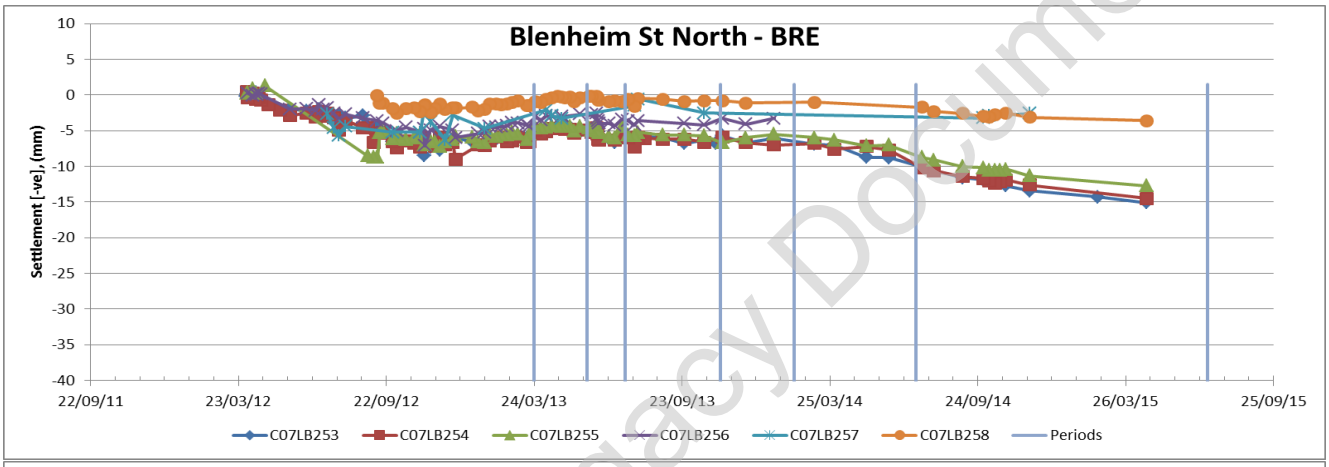


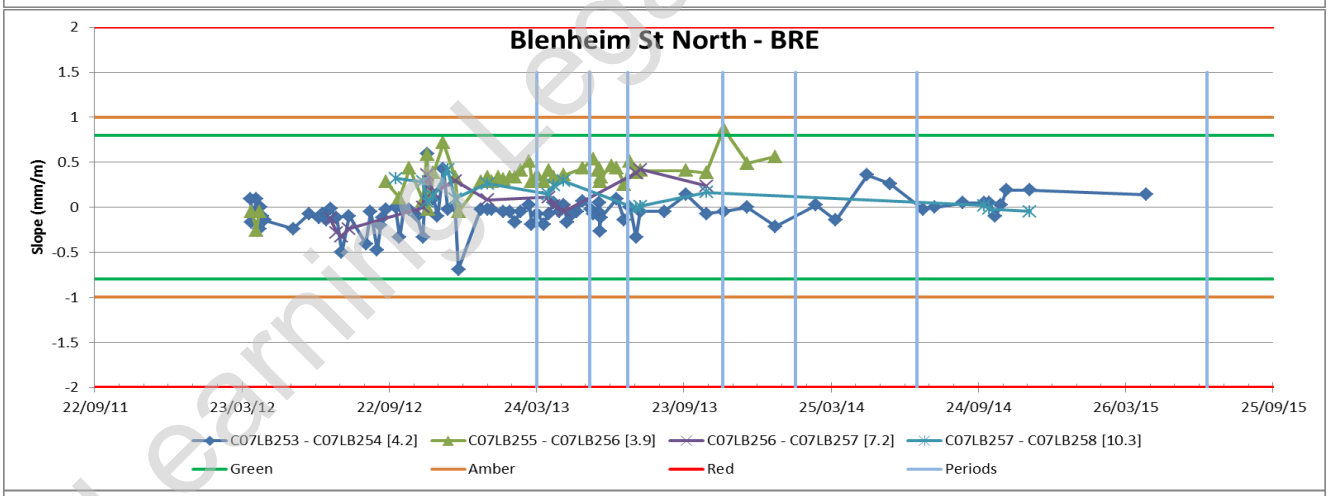
The following points are noted:

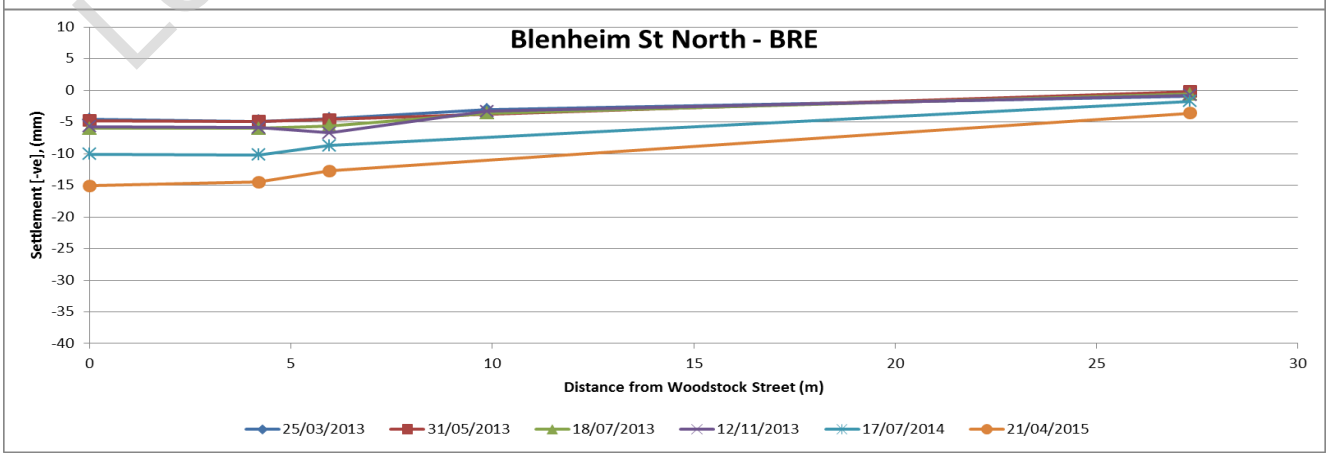
- The Blenheim Street south façade extends from over the PTE / CP5 junction with increasing offset towards New Bond Street and is outside the GS2 arrays from distance 40m onwards.
- The key construction events are the EBRT in Period C and PTE / CP5 in Period F.
- At the end of Period B, prior to the EBRT, about 10mm settlement had occurred with the maximum at the south-western end of the profile. In Periods B, C and D an increase of ~7mm was recorded with about half of this associated with volume loss settlement. During and following PTE and CP5 in Period F, settlement increased to ~35mm. A further 12mm settlement has occurred in Period G following completion of construction.
- Three amber slope triggers occurred during Period F. By inspection, there are no deflection ratio triggers.
- The rate of settlement has progressively decreased during Period G and although the slopes have increased somewhat, they are now stabilising.

4.11. Blenheim Street – North





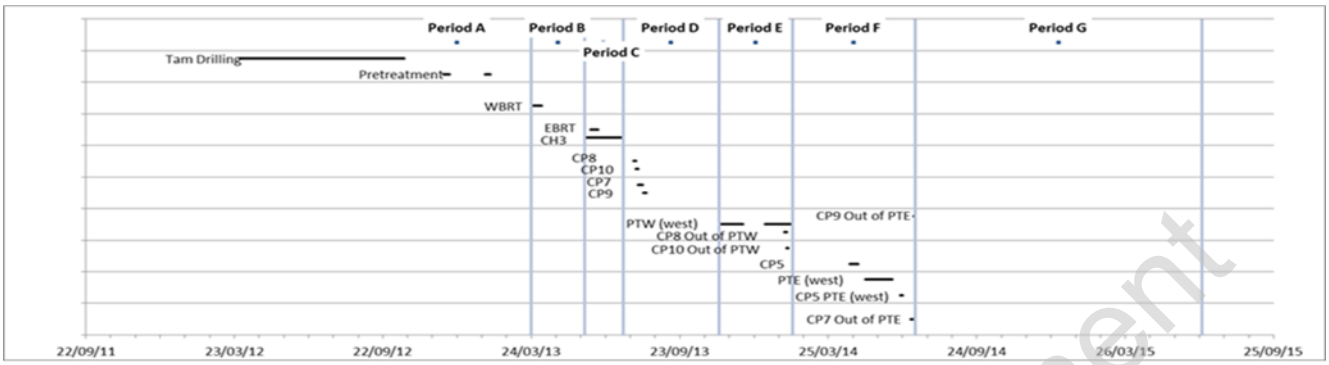


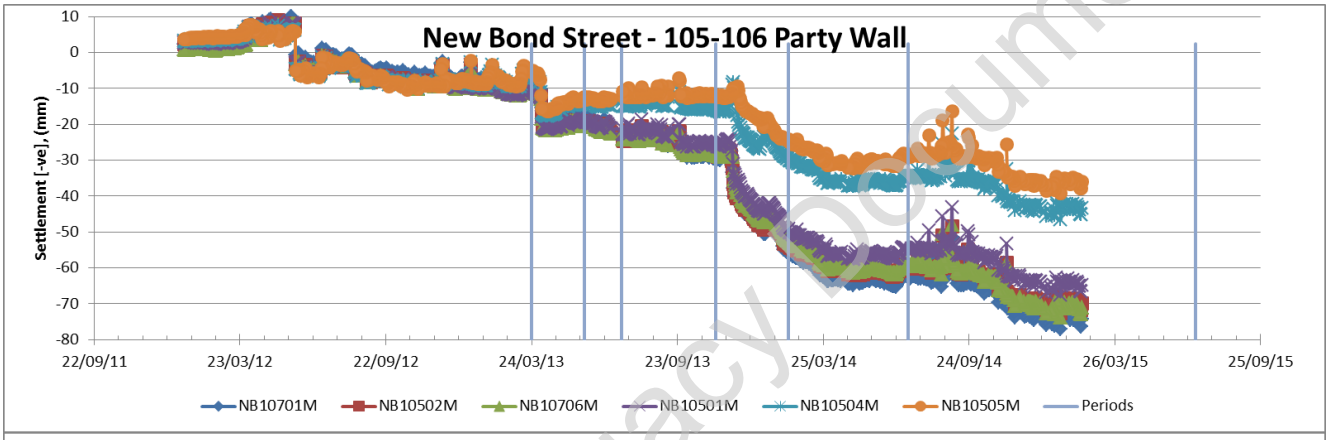


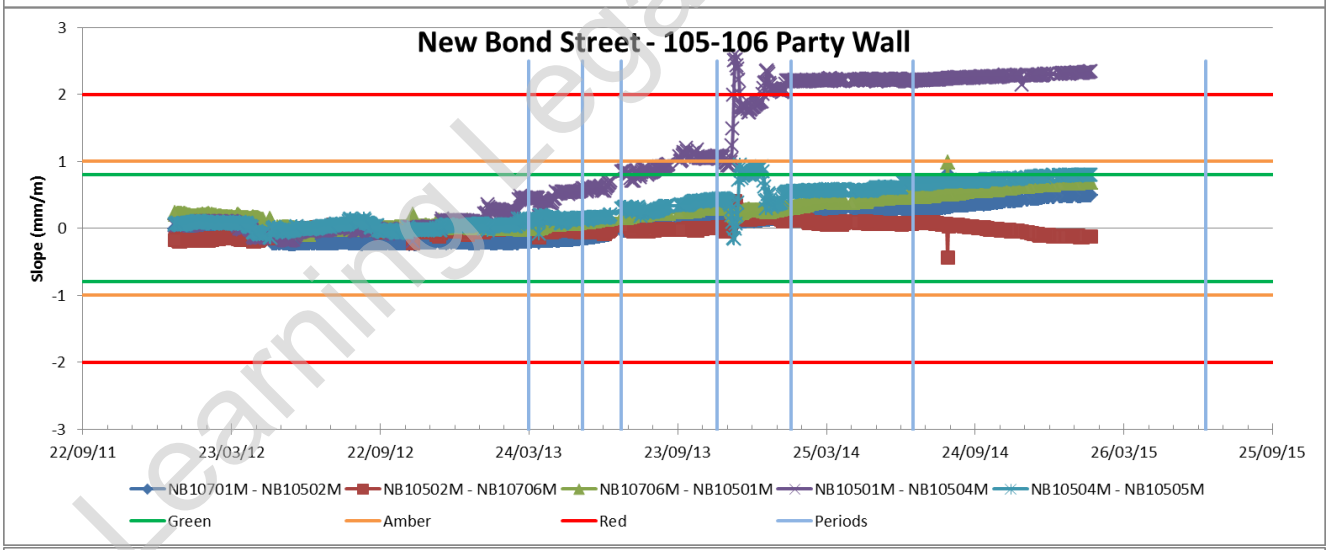
The following points are noted:

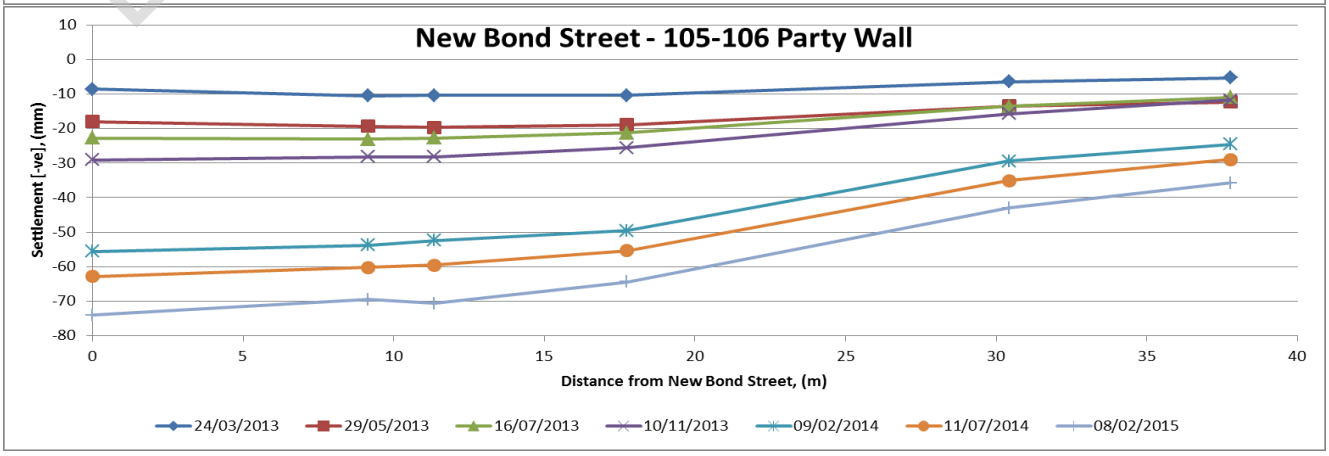
- The Blenheim Street north façade extends from the northern perimeter of the GS2 array adjacent to the PTE / CP5 junction with increasing offset towards New Bond Street and is outside the GS2 arrays.
- The key construction events are the EBRT in Period C and PTE / CP5 in Period F.
- At the end of Period B, prior to the EBRT, about 5mm settlement had occurred with the maximum at the south-western end of the profile. In Periods B, C and D an increase of ~2mm was recorded with most of this associated with volume loss settlement. During and following PTE and CP5 in Period F, settlement increased to ~10mm. A further 5mm settlement has occurred in Period G following completion of construction.
- There are no slope triggers and, by inspection, there are no deflection ratio triggers.
- The rate of settlement has progressively decreased during Period G and the slopes are stable.

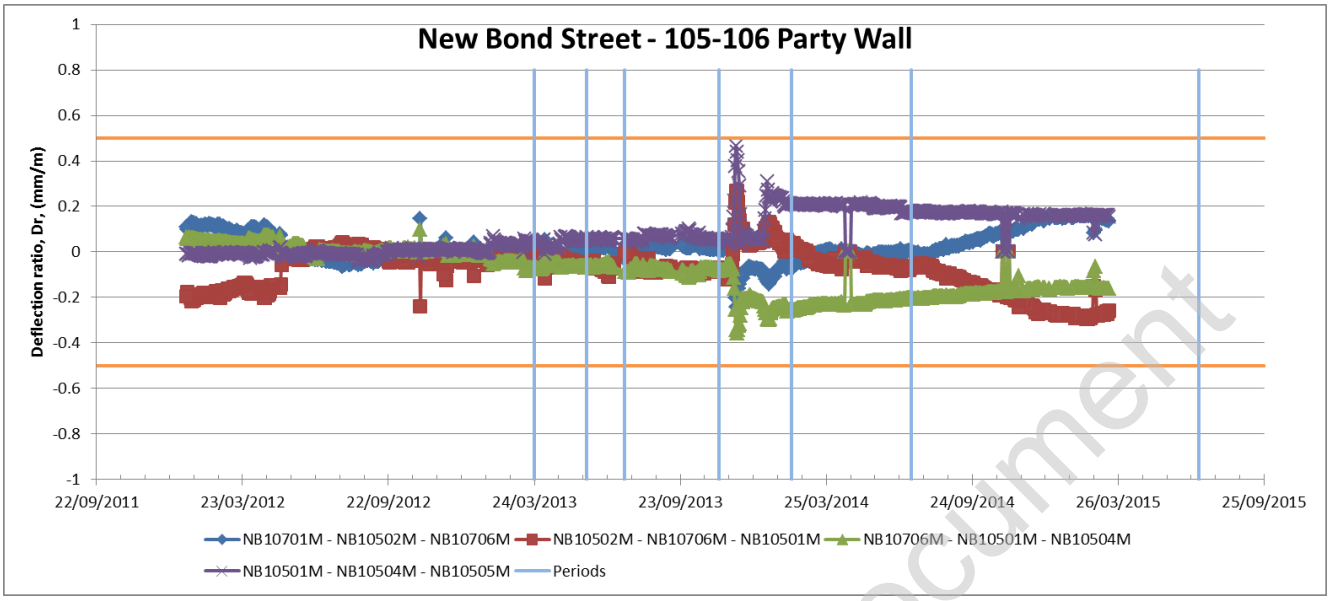
4.12. HLC – 105-106 New Bond Street Party Wall











The following points are noted:

- The south party wall of 105-106 New Bond Street lies within the GS5 array and is coincident with the maximum settlement recorded on the west façade of New Bond Street (refer to Section 4.2). The party wall extends to the east façade of Haunch of Venison Yard (HoVY) (refer to Section 4.4). The most notable event was however the construction of PTW in Period E (see Section 3.6).
- At the end of Period A, prior to tunnelling, the maximum settlement was ~10mm but there was only minor variation over the full length of the party wall.
- In Period B, the WBRT generated a maximum of 10mm settlement on New Bond Street and around 5mm at HoVY.
- The construction of the EBRT and CH3 in Period C increased the settlement slightly on New Bond Street with negligible increase at HoVY.
- In Period D the only works were the CP excavations: the increase in settlement was less than 10mm, however again there was negligible increase in HoVY. This differential movement was sufficient to generate an amber trigger level (NB10501M – NB10504M).
- The construction of PTW substantially increased the settlement to a maximum of ~55mm. The settlement at New Bond Street was again significantly greater than on HoVY. The PTW generated a red slope trigger.
- In Period F, the increase in settlement was small and approximately uniform with the maximum slope not increasing further. The construction of PTE produced no significant effect.
- Post construction, in Period G, settlement has continued to increase. As expected the movements are relatively uniform and hence the impact on slopes is minor.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate with and associated minor increase in the maximum slope. ETH excavation and secondary lining works in the tunnels have been undertaken in Period G.
- 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.

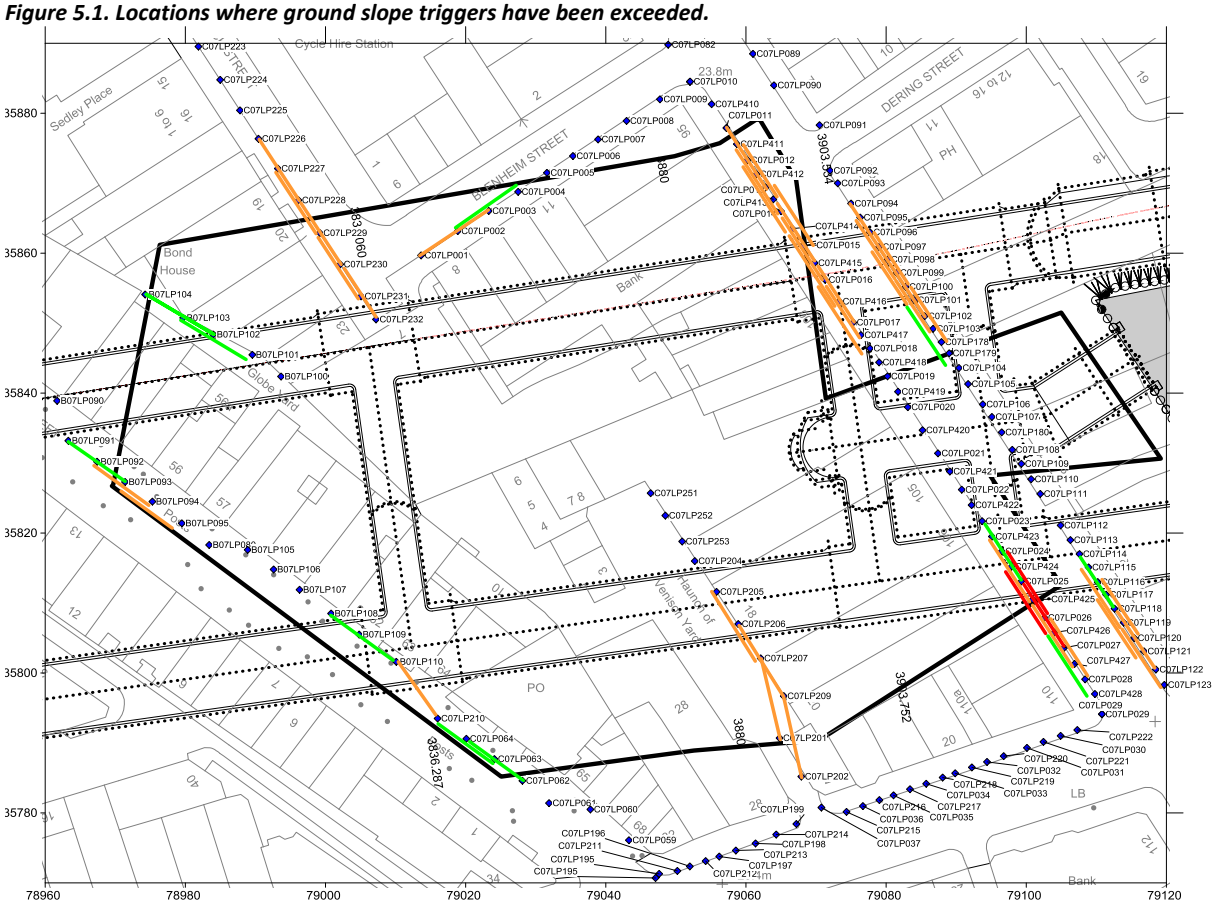
Slope triggers are as follows:

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

Comparison of Figures 4.1 and 5.1 shows that slope triggers on buildings and on the ground have occurred in similar locations. This is as expected since no significant differential between building settlement and the adjacent pavements has been identified at reviews during construction. Consequently the commentary on the PLP monitoring data is essentially similar to that for the BRE data presented in Section 4.

The GS2 arrays extend below the east side of New Bond Street but the buildings to the east of New Bond Street are primarily within the GS3 and GS5 area and the data for the north and south sections of this PLP profile will be included in the relevant reports.

Figure 5.1. Locations where ground slope triggers have been exceeded.



PLP monitoring data from the kerb lines within the footprint of GS2 are presented in the following sections. 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.

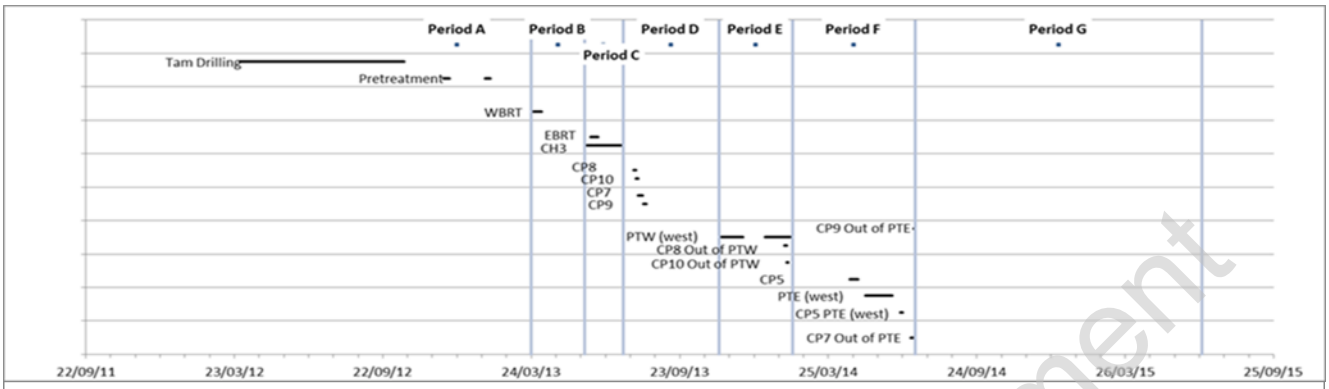
5. Time slope history since the completion of tunnelling i.e. construction Period G.
6. Deflection ratio plots are provided as necessary.

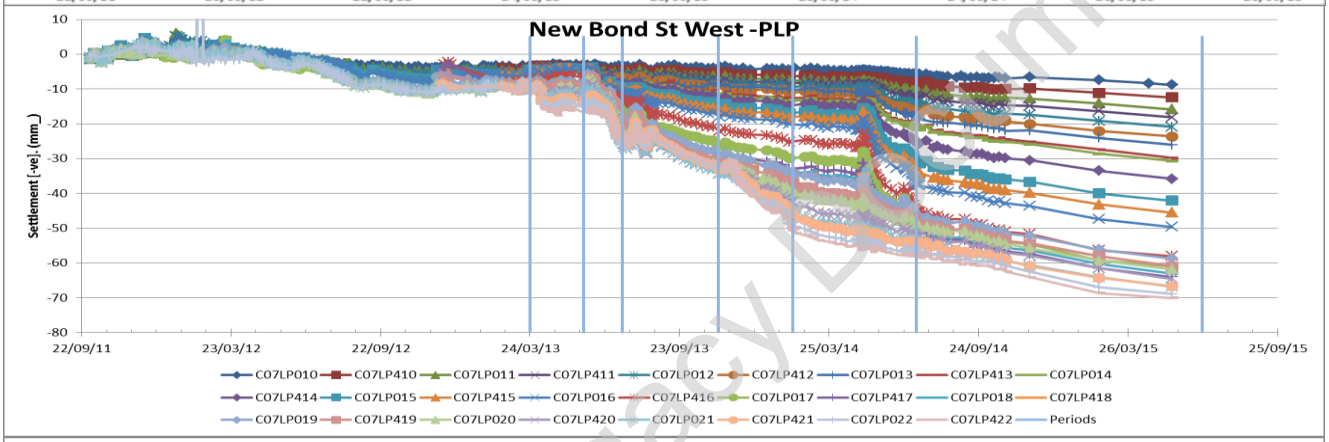
All available data is plotted in these figures. It is noted that where a point is blocked or destroyed these affects 2 slope calculations and 3 deflection ratio calculations.

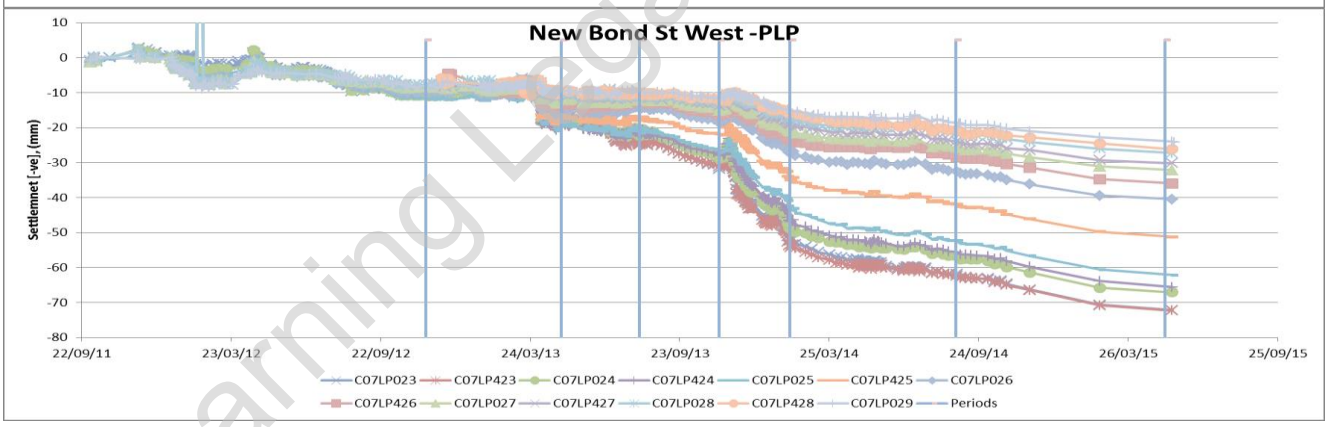
Table 5.1 Details of trigger breaches on PLP

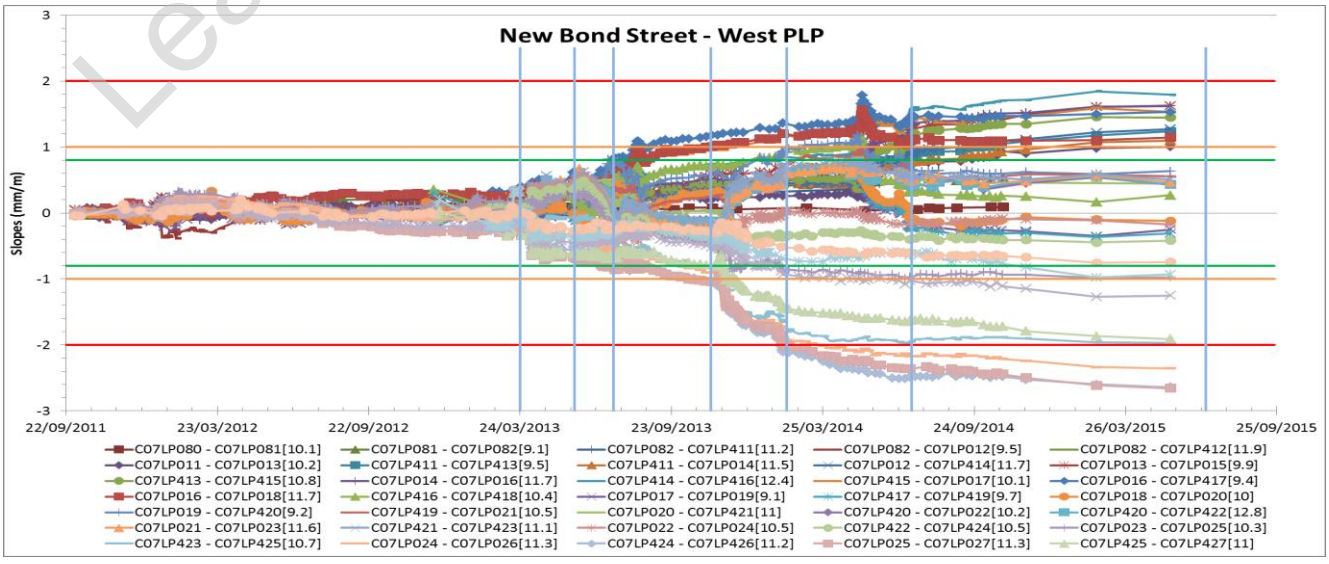
Point Numbers	Maximum Level	Comment	Date exceeded	Maximum (mm/m)	Current (mm/m)
New Bond Street - West					
C07LP011 - C07LP013	Amber	Gradual increase - stabilising	19/05/2015	1.00	1.00
C07LP411 - C07LP413	Amber	Gradual increase - stabilising	06/10/2014	1.24	1.24
C07LP411 - C07LP014	Amber	Gradual increase - stabilising	19/02/2015	1.10	1.10
C07LP012 - C07LP414	Amber	Stable ± 0.1 over 12 months	15/09/2014	1.28	1.27
C07LP013 - C07LP015	Amber	Gradual increase - stabilising	26/05/2014	1.63	1.63
C07LP413 - C07LP415	Amber	Stable ± 0.1 over 12 months	16/06/2014	1.46	1.45
C07LP014 - C07LP016	Amber	Gradual increase - stabilising	23/05/2014	1.62	1.62
C07LP414 - C07LP416	Amber	Stable ± 0.1 over 12 months	11/05/2014	1.84	1.79
C07LP415 - C07LP017	Amber	Gradual increase - stabilising	11/12/2013	1.65	1.53
C07LP016 - C07LP417	Amber	Gradual increase - stabilising	18/08/2013	1.79	1.53
C07LP016 - C07LP018	Amber	Stable ± 0.1 over 12 months	11/11/2013	1.56	1.14
C07LP023 - C07LP025	Green	Gradual increase - stabilising	03/12/2013	0.99	0.97
C07LP423 - C07LP425	Amber	Gradual increase - stabilising	22/11/2013	1.97	1.97
C07LP024 - C07LP026	Red	Gradual increase - stabilising	27/11/2013	2.36	2.36
C07LP424 - C07LP426	Red	Gradual increase - stabilising	28/10/2013	2.64	2.64
C07LP025 - C07LP027	Red	Gradual increase - stabilising	14/10/2013	2.66	2.66
C07LP425 - C07LP427	Amber	Gradual increase - stabilising	28/11/2013	1.91	1.91
C07LP026 - C07LP028	Amber	Stable ± 0.1 over 12 months	08/05/2014	1.27	1.25
C07LP426 - C07LP428	Green	Stable ± 0.1 over 12 months	26/11/2014	0.98	0.93
Brook Street (north)					
No Breaches					
Haunch Of Venison Yard - East					
C07LP202 - C07LP209	Amber	Gradual increase - stabilising	09/05/2014	1.26	1.26
C07LP201 - C07LP207	Amber	Gradual increase - stabilising	05/02/2014	1.51	1.51
C07LP209 - C07LP206	Amber	Gradual increase - stabilising	09/01/2014	1.61	1.59
C07LP207 - C07LP205	Amber	Gradual increase - stabilising	23/02/2015	1.08	1.08
Globe Yard - East					
B07LP101 - B07LP103	Green	Gradual increase - stabilising	02/06/2014	0.95	0.92
B07LP102 - B07LP104	Green	Gradual increase - stabilising	13/07/2014	0.95	0.95
South Molton Street - East					
B07LP091 - B07LP093	Green	Stable ± 0.1 over 12 months	14/10/2014	0.93	0.93
B07LP092 - B07LP094	Amber	Gradual increase - stabilising	28/11/2014	1.12	1.12
B07LP093 - B07LP095	Amber	Gradual increase - stabilising	02/09/2014	1.31	1.26
B07LP108 - B07LP110	Green	Stable ± 0.1 over 12 months	29/03/2014	1.41	0.88
B07LP110 - C07LP064	Amber	Gradual increase - stabilising	29/03/2014	1.39	1.39
C07LP210 - C07LP063	Green	Stable ± 0.1 over 12 months	19/02/2015	0.89	0.89
C07LP064 - C07LP062	Green	Stable ± 0.1 over 12 months	04/08/2014	0.97	0.97
Woodstock Street - West					
C07LP226-C07LP228	Amber	Gradual increase - stabilising	14/10/2014	1.22	1.22
C07LP227-C07LP229	Amber	Gradual increase - stabilising	03/06/2014	1.64	1.64
C07LP228-C07LP230	Amber	Gradual increase - stabilising	02/06/2014	1.65	1.65
C07LP229-C07LP231	Amber	Gradual increase - stabilising	03/06/2014	1.40	1.40
C07LP230-C07LP232	Amber	Borderline Amber trigger - stable	20/04/2015	1.00	1.00
Blenheim Street - South					
C07LP001-C07LP003	Amber	Gradual increase - stabilising	26/11/2014	1.07	1.05
C07LP002-C07LP004	Green	Gradual increase - stabilising	26/11/2014	0.86	0.84

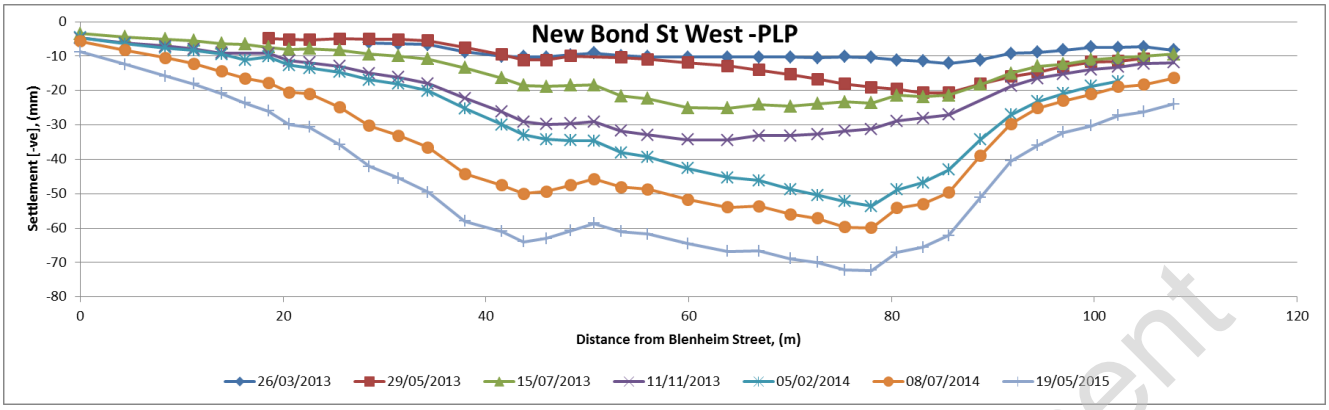
5.2. New Bond Street – west

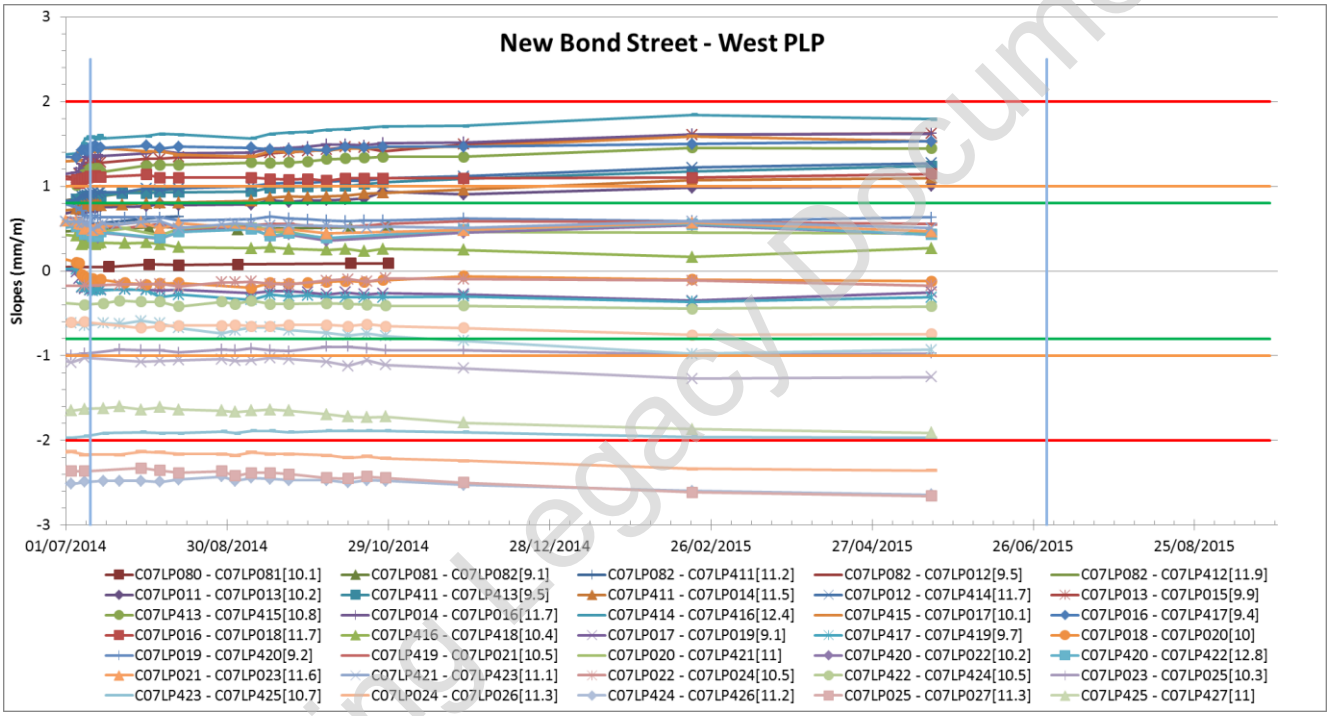


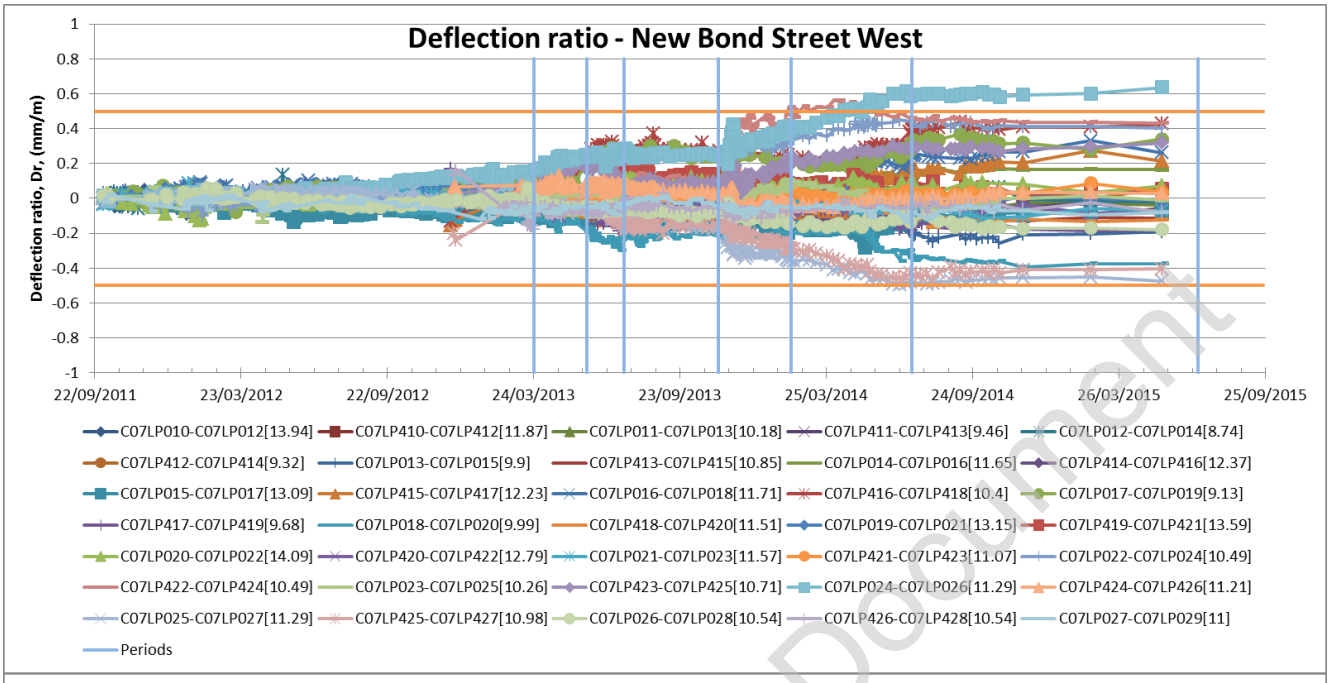


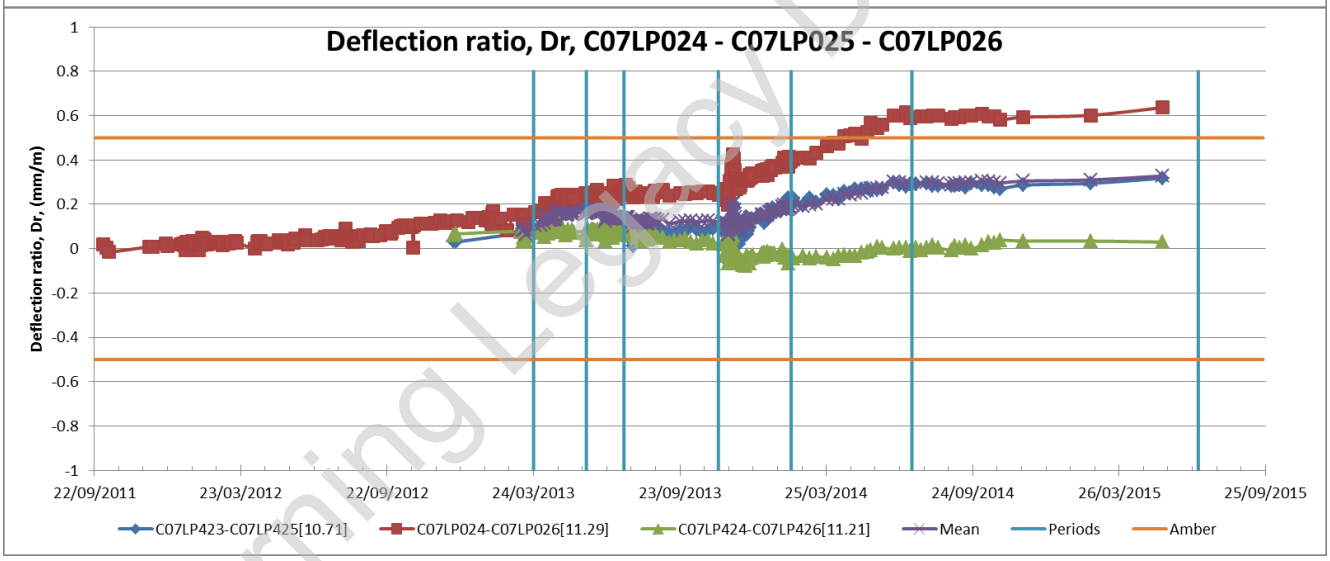


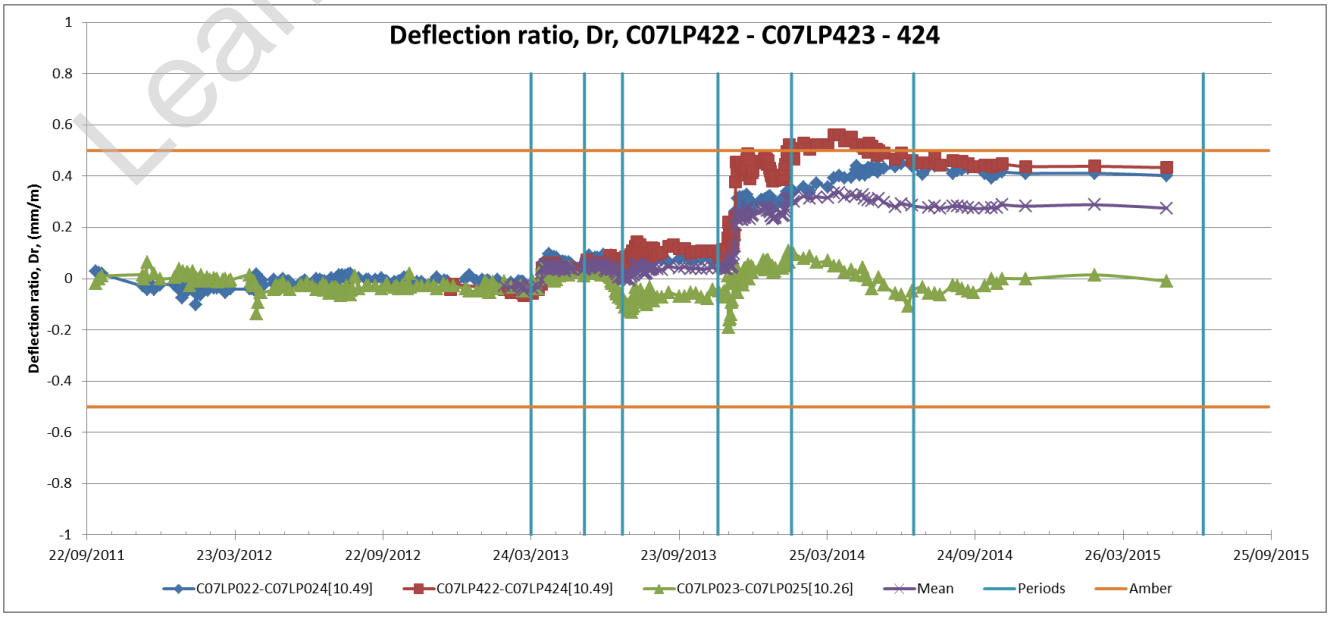








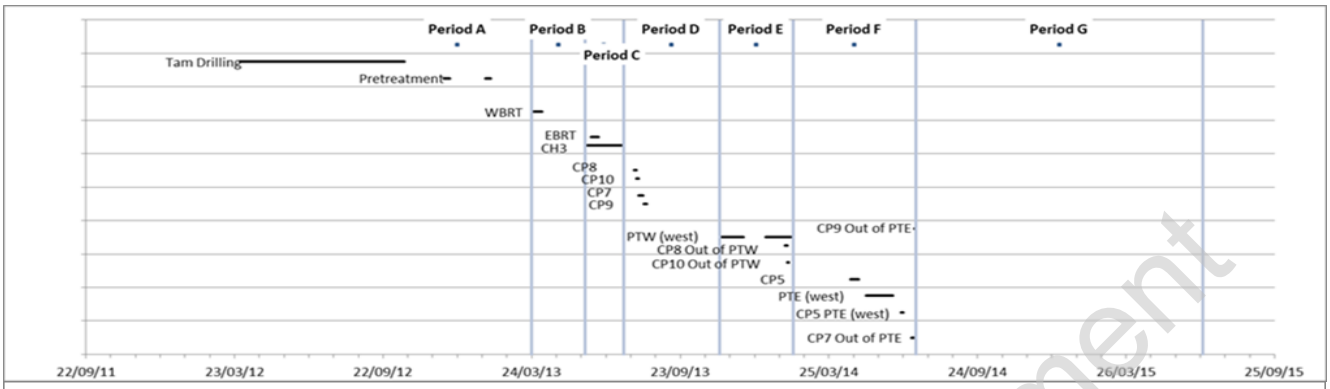


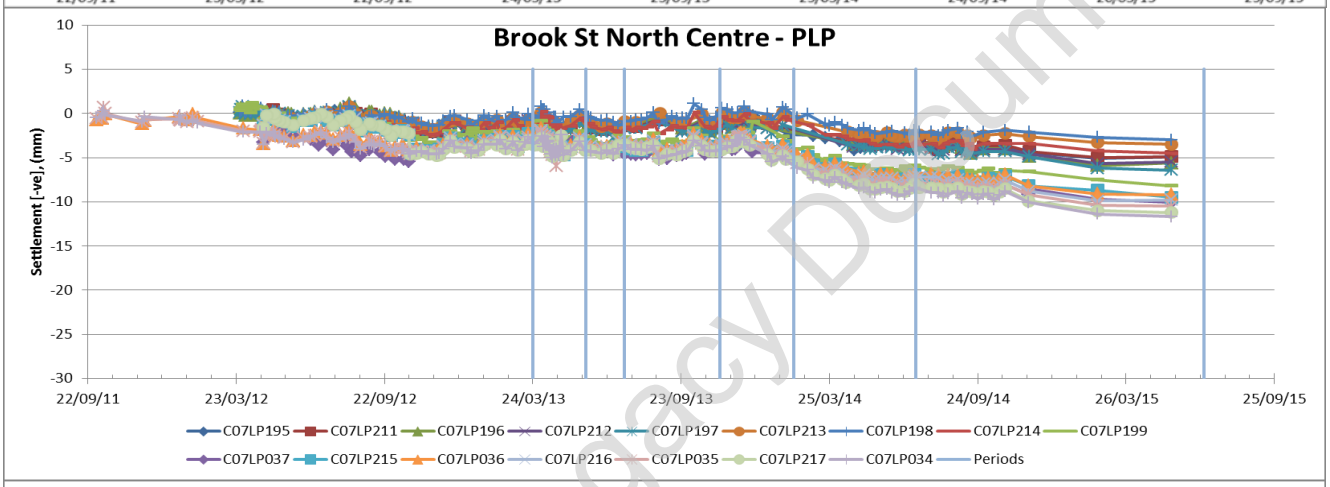


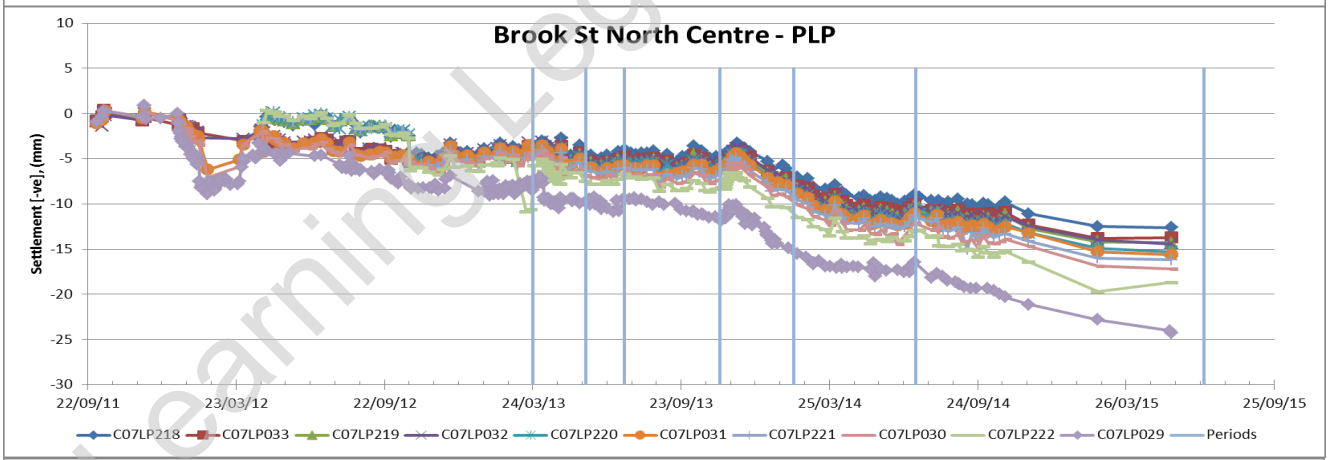
The following points are noted:

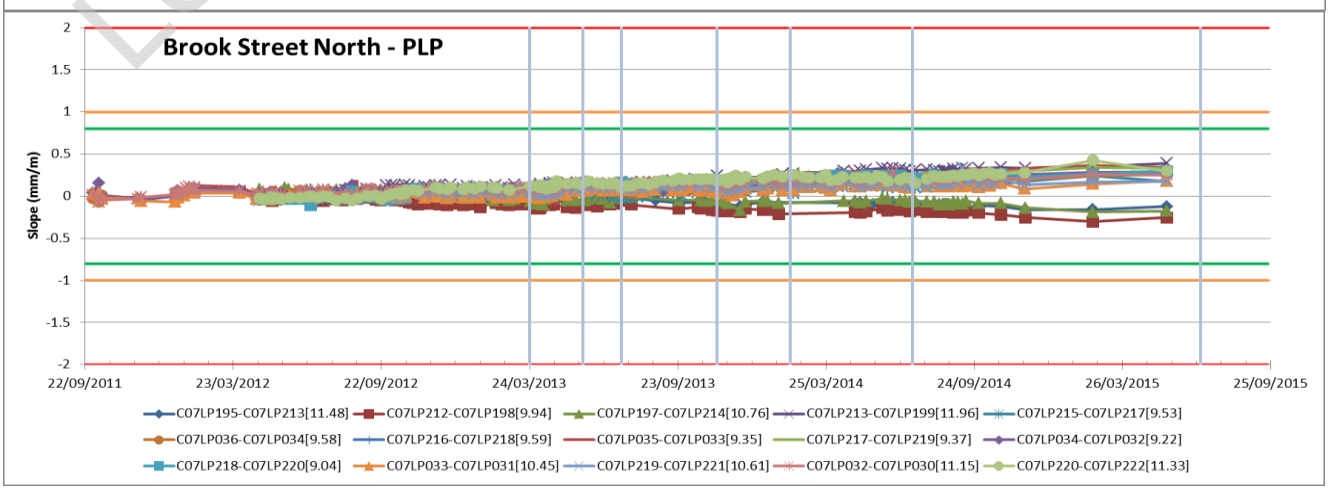
- The most southerly part of the New Bond Street west pavement is within the GS5 array (from distance 90m): data from all points are presented.
- The New Bond Street west PLP profile traverses the entire extent of the tunnels and consequently the key events vary with location. The most notable event was however the construction of PTW in Period E (see Section 3.6).
- The profiles of settlement presented herein are very similar to those for the building façade monitoring described in Section 4.2.
- At the end of Period A, prior to tunnelling, the maximum settlement was ~10mm but there was only minor variation over the full length of the façade.
- In Period B, the WBRT generated a further 10mm settlement with a trough extending from distance 60m to 103m at Brook Street (nos. 104 to 110 New Bond Street).
- The construction of the EBRT and CH3 increased the settlement over the full extent of the façade but generated an approximately symmetrical trough with a maximum settlement of 25mm, slightly less than on the adjacent building. Slopes were maintained below the amber trigger level.
- In Period D the only works were the CP excavations, the increase in settlement was less than 10mm and this tended to widen the trough reducing some slope but increasing others: at the end of Period D there were three amber slope triggers and several other slopes close to the amber level.
- The construction of PTW changed the form of the settlement profile and substantially increased the slopes, with two values close to the red trigger. The concurrent compensation grouting did not control the settlement at C07LB035 on the south party wall of 105-106 New Bond Street: the settlement of the adjacent PLP was only slightly smaller. The small additional movements associated with CP8 and CP10 stubs were sufficient to cause two red triggers at C07L424 - C07LP426 and C07L025 - C07LP027 at the end of Period E and a further red trigger early in Period F at C07L024 - C07LP026.
- In Period F, the construction of PTE produced a much less marked effect than for PTW but increased slopes at the northern end of the façade sufficiently to generate further amber triggers, as listed in Table 5.1.
- Post construction, in Period G, settlement has continued to increase. As expected the movements are relatively uniform and hence the impact on slopes is minor. Nevertheless the change in slope has been sufficient to produce further amber slope triggers, as listed in Table 5.1.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate albeit confirmed by few sets of readings. ETH excavation and secondary lining works in the tunnels have been undertaken in Period G.
- There are a total of 14 amber and 3 red triggers on slope. There have also been two “individual” deflection ratios in excess of the amber trigger value: these occurred in Period F. The DR reached ~0.6mm/m in both cases. The value centred on C07LP025 has subsequently remained stable and that at C07LP423 has decreased to below 0.5mm/m. In accordance with the C122 I&M plan, a “15m rolling average” has been calculated for both locations and these confirm that the amber deflection ratio trigger has not been breached.

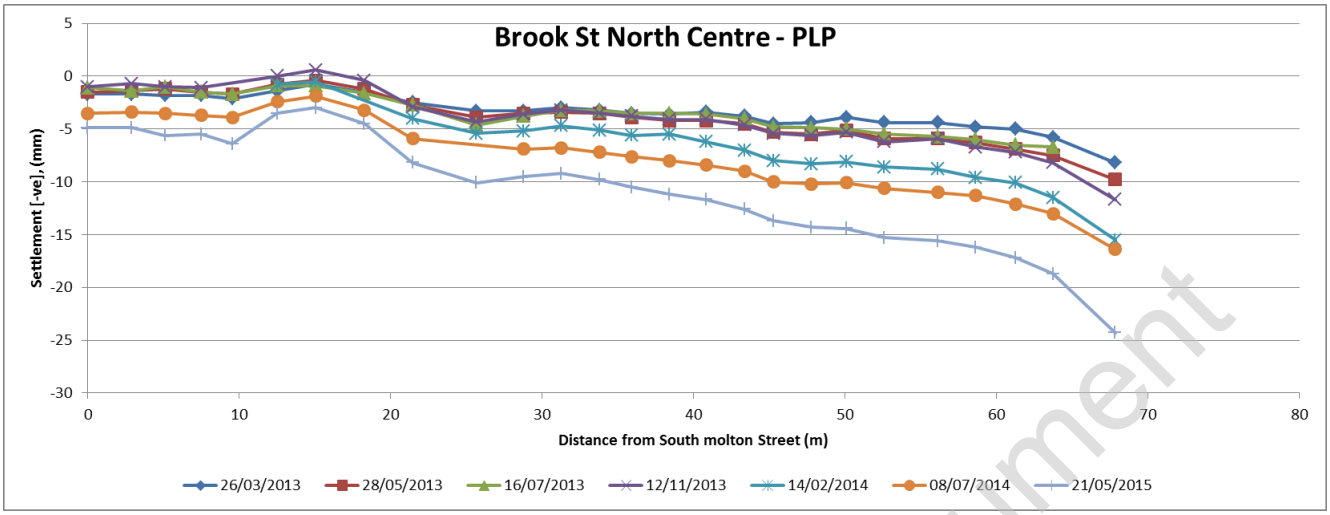
5.3. Brook Street – North

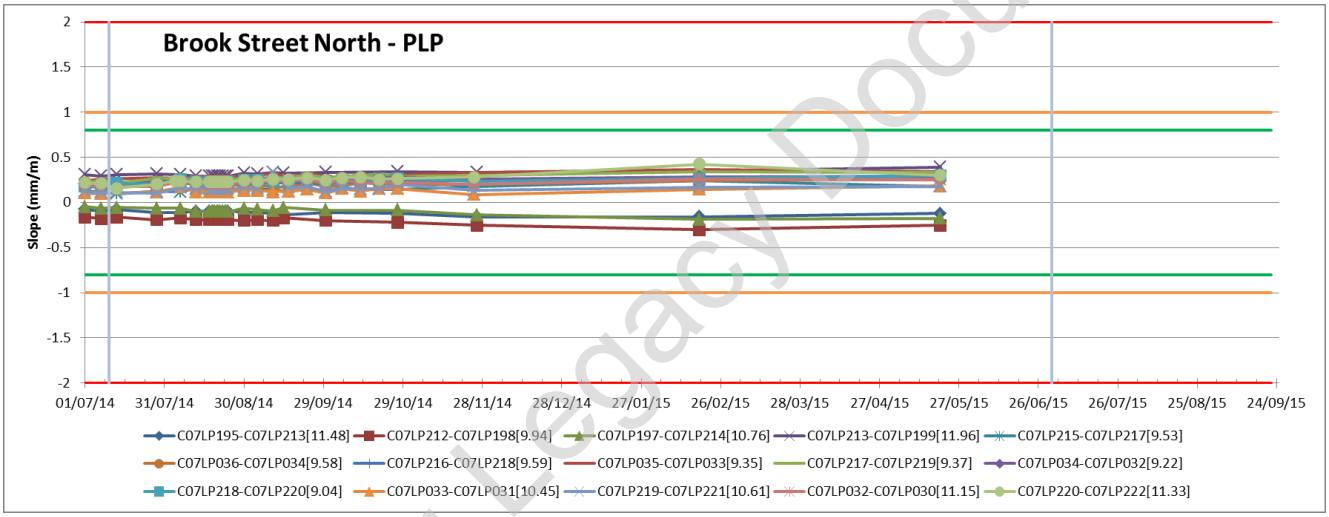








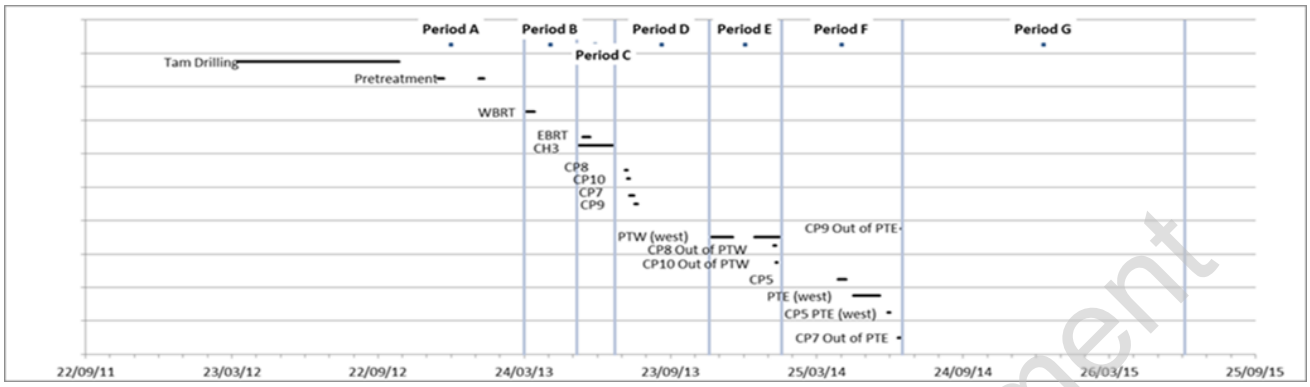


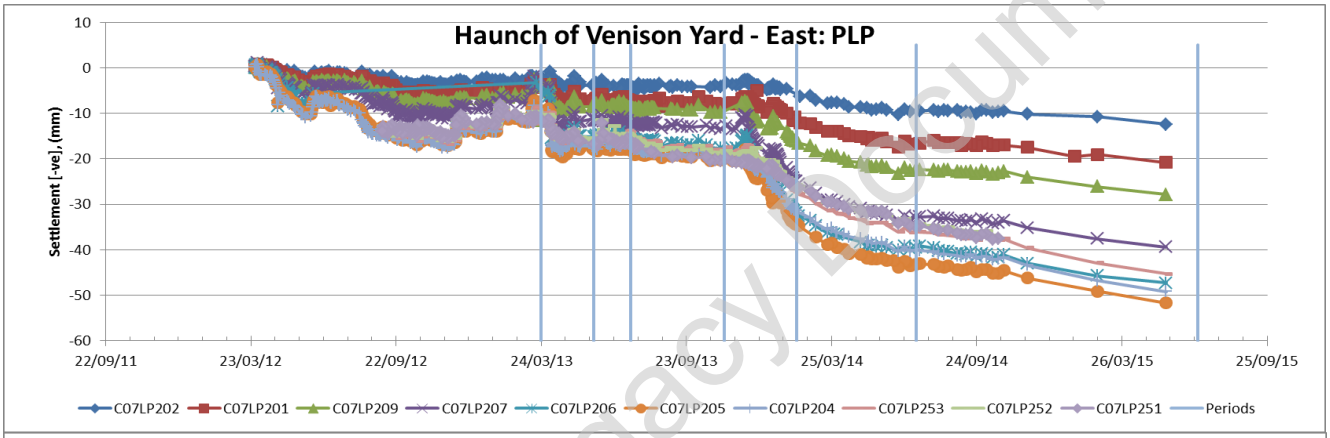


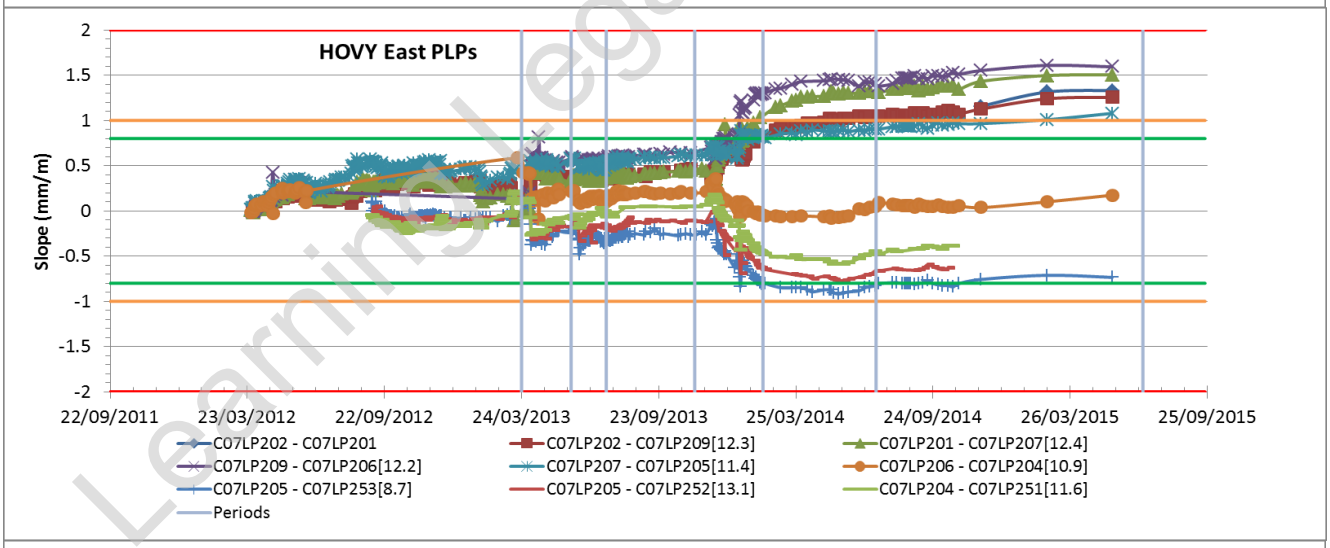
The following points are noted:

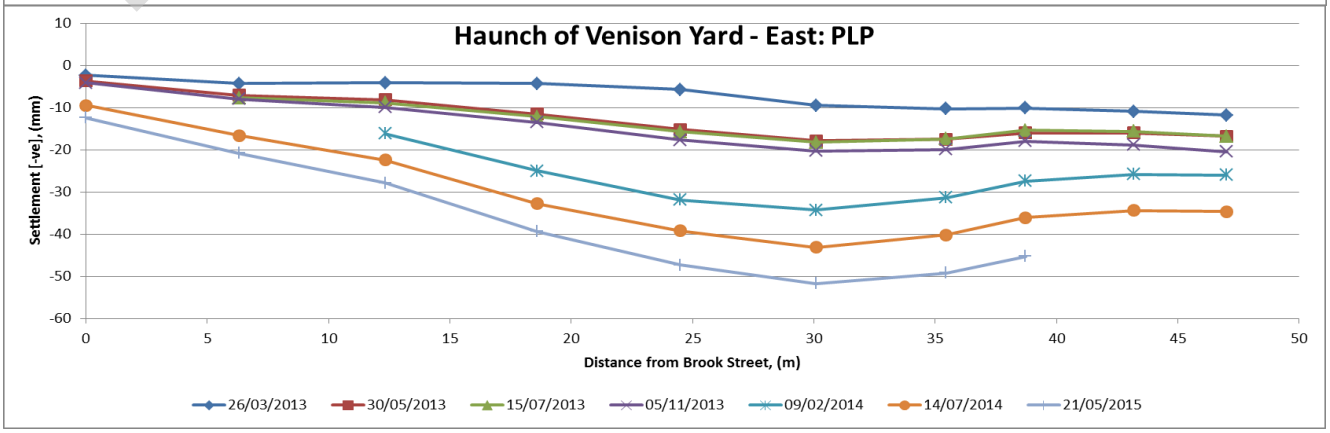
- The Brook Street north PLP profile between South Molton Street and New Bond Street is outside the plan extent of the GS2 array: the eastern end is covered by GS5 arrays but the western end is outside the predicted 10mm contour (see Figure 3.1.1) and is therefore not within the grouting area.
- The settlement of the PLP along Brook Street north are essentially similar to those on the adjacent building façade increasing from ~5mm at South Molton Street to ~20mm at New Bond Street.
- The key events are the WBRT in Period B and PTW in Period E. Settlement was less than 5mm prior to tunnelling and only increased by a few millimetres due to the WBRT and subsequent consolidation settlement. Settlement was less than 10mm prior to the PTW in Period E. Uplift is apparent from grouting during PTW and at the end of Period E settlement was only about 10mm.
- It is noted that at the end of these activities the settlement was about 10mm and that there has been 10mm consolidation settlement over a period of 16 months.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate albeit confirmed by few sets of readings. ETH excavation 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.
- No slope triggers have occurred and the slopes are essentially constant. By inspection, there are no deflection ratio triggers.

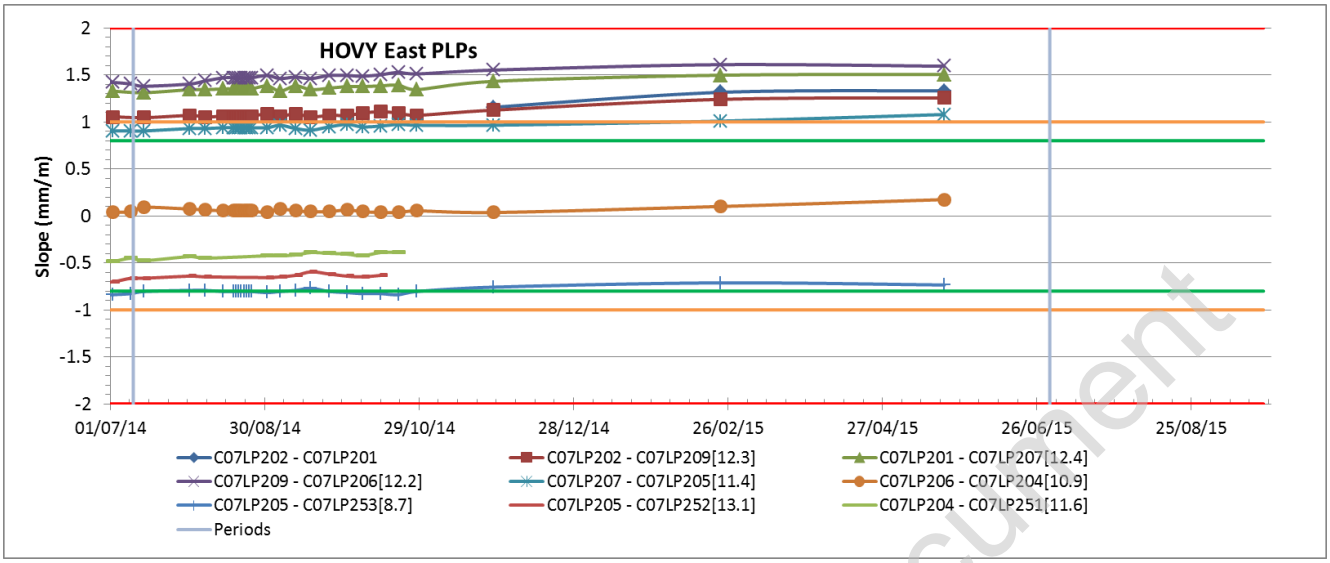
5.4. Haunch of Venison Yard – East







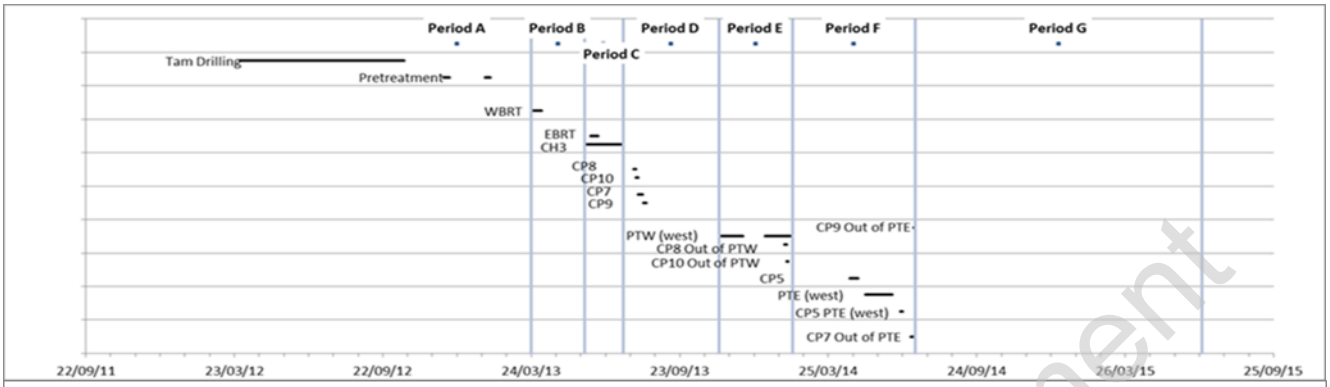


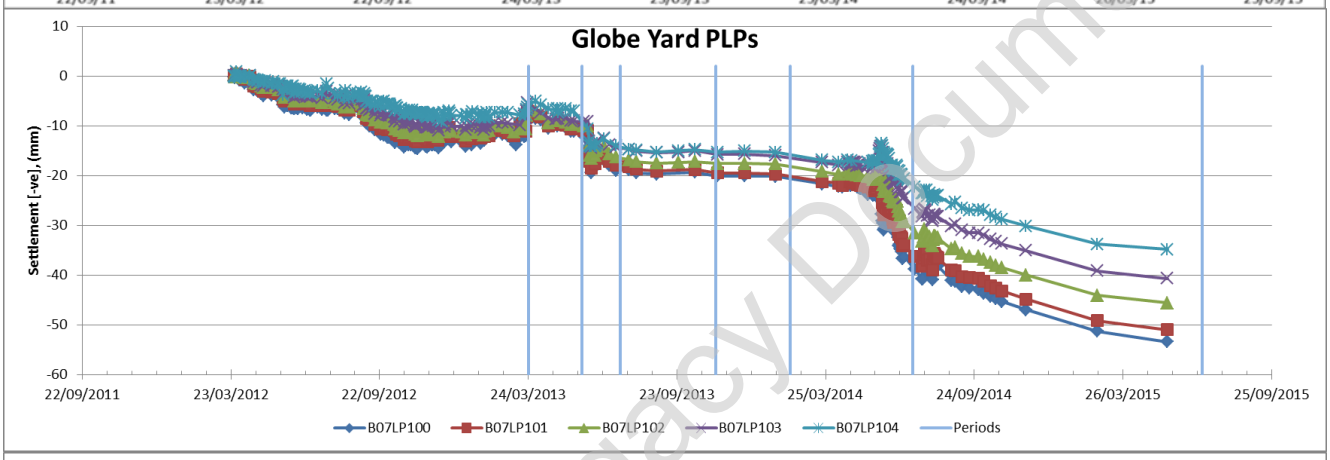


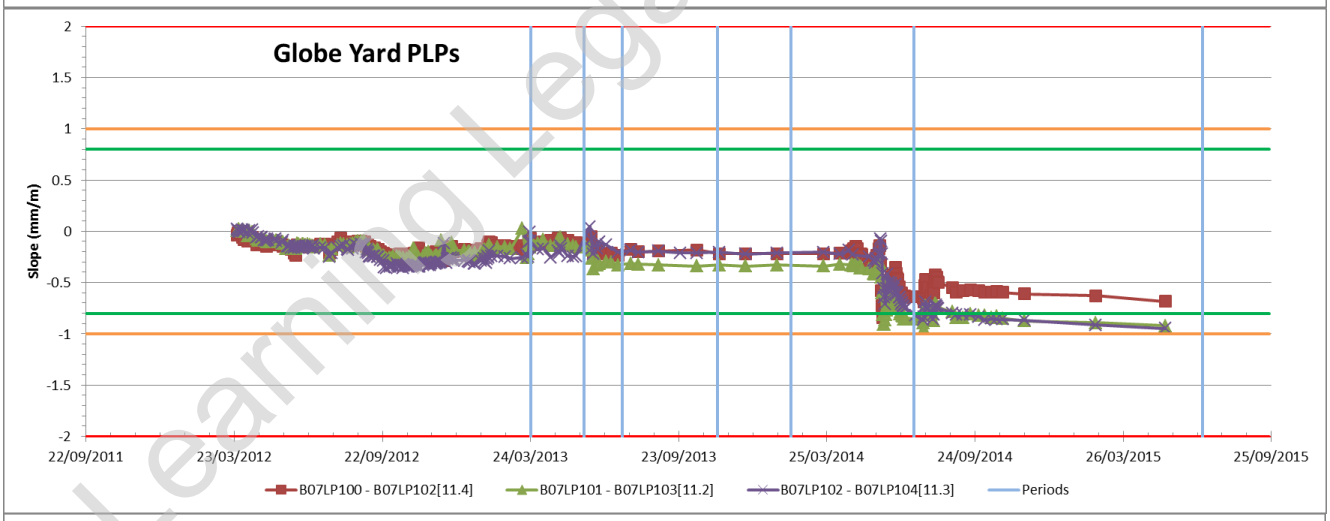
The following points are noted:

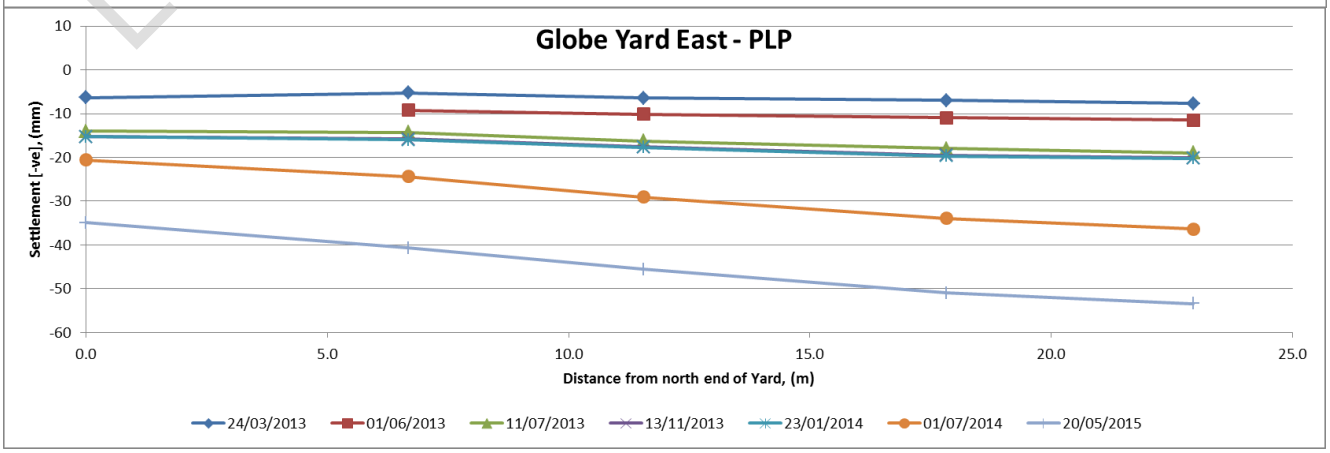
- The Haunch of Venison Yard east PLP profile is within the plan extent of the GS2 array except at its southern end adjacent to Brook Street.
- The settlement of the PLP along the east side of Haunch of Venison Yard is essentially similar to those on the adjacent building façade increasing from ~10mm at Brook Street to ~50mm at the northern end of the Yard.
- The key events are the WBRT in Period B and PTW in Period E. Settlement reached 15mm prior to tunnelling but was reduced by pretreatment and pre-TBM jack grouting to about 10mm at the end of Period A. The WBRT and subsequent consolidation settlement increased the maximum settlement to about 20mm at the end of Period D. Uplift is apparent from grouting during PTW and at the end of Period E settlement had increased to 35mm including post construction consolidation.
- The settlement during Period E was sufficient to generate 3 amber triggers on points to the south of the tunnel (distances 10 to 26m).
- It is noted that at the end of these activities the settlement was about 35mm and that there has been 15mm consolidation settlement over a period of 16 months.
- The rate of post construction settlement was continuously reducing to the end of Period F. In Period G, from about October 2014, there has been an apparent small increase in rate albeit confirmed by few sets of readings. ETH excavation 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.
- Two amber slope triggers occurred during construction and a further three pairs of PLP are at or above the amber due to post construction movements. The slopes are either constant or increasing marginally within the repeatability of the data. By inspection, there are no deflection ratio triggers.

5.5. Globe Yard – East





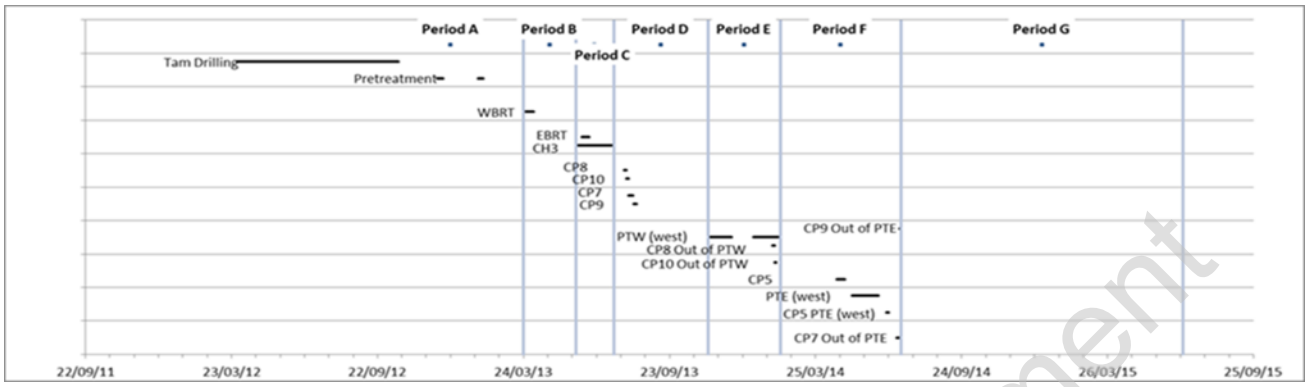


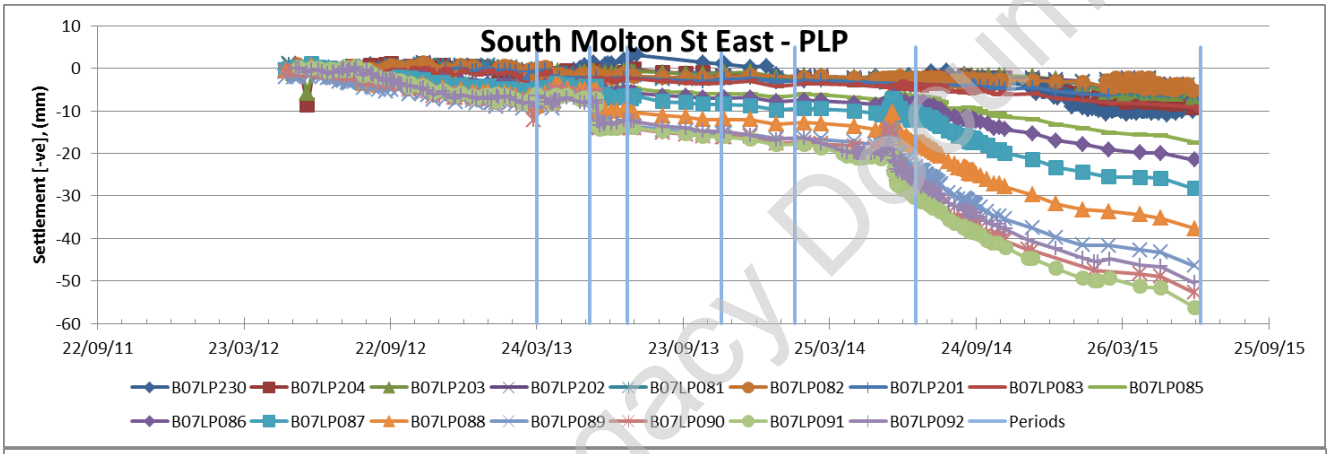


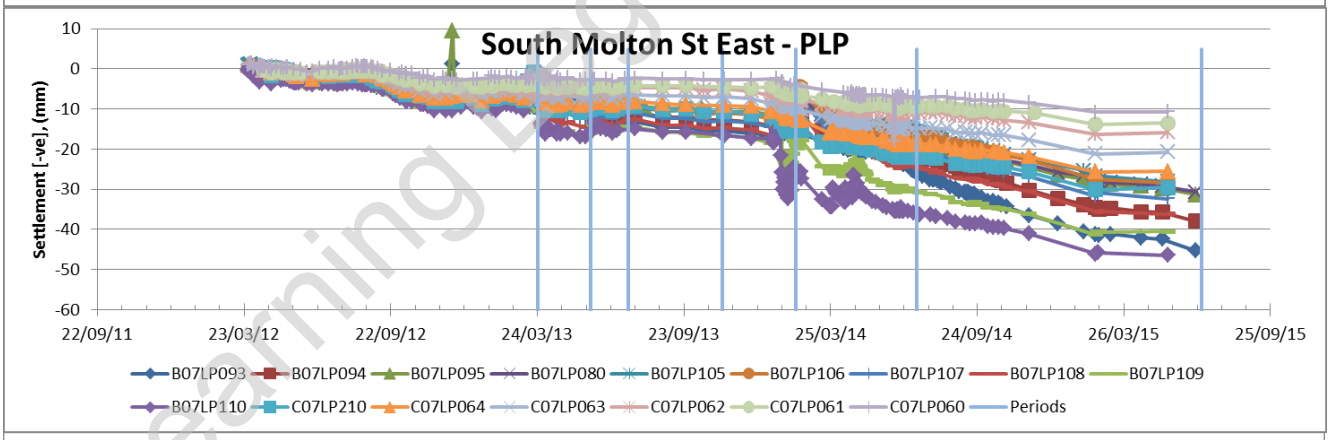
The following points are noted:

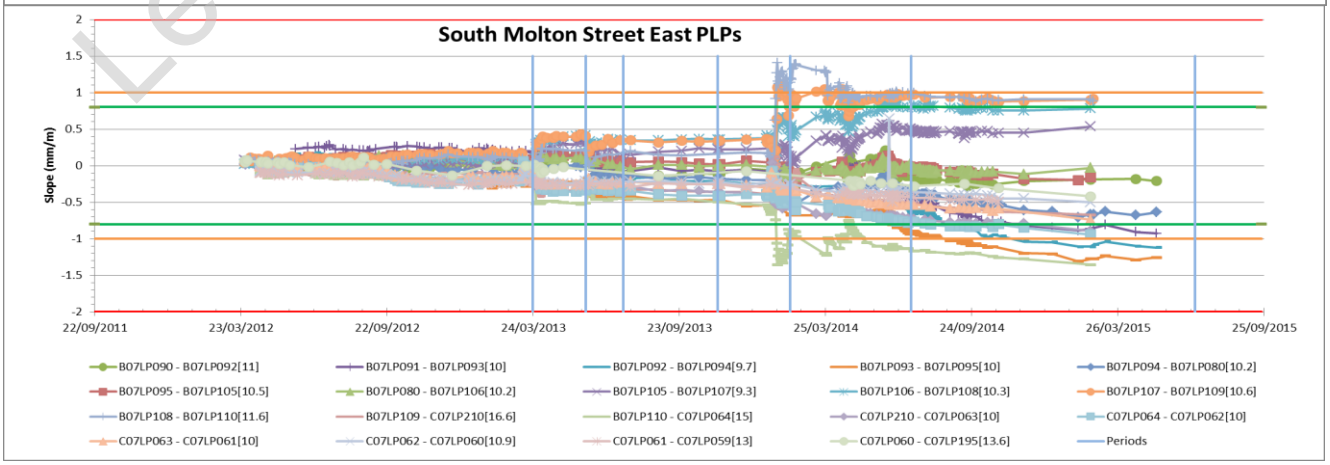
- The Globe Yard east PLP profile is within the plan extent of the GS2 array but only extends part of the way along the adjacent façade.
- The settlement of the PLP along the east side of Globe Yard are essentially similar to those on the adjacent building façade increasing from ~35mm at the north end to just over 50mm at the other end of the profile (~23m distance).
- The key events are the EBRT in Period C and PTE / CP5 in Period F. Settlement reached 15mm prior to tunnelling but was reduced by pretreatment and pre-TBM jack grouting to about 10mm at the end of Period A. The EBRT and subsequent consolidation settlement increased the maximum settlement to about 20mm at the end of Period D. Uplift is apparent from grouting during PTE and CP5 at the end of Period F settlement had increased to 38mm including some post construction consolidation.
- No amber triggers have occurred.
- It is noted that at the end of these activities the settlement was about 28mm and that there has been 15mm consolidation settlement over a period of 11 months.
- The rate of post construction settlement has continuously reduced throughout Period G. Secondary lining works in the tunnels have been undertaken in Period G.
- The time plot confirms that the consolidation settlement is relatively uniform with all points showing similar behaviour.
- The slopes are gradually increasing but stabilising within the repeatability of the data. By inspection, there are no deflection ratio triggers.

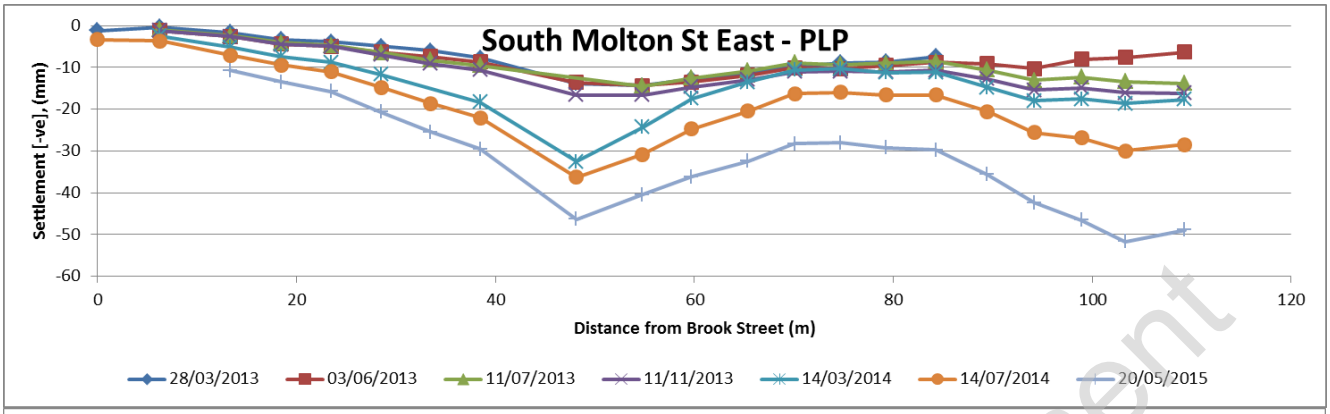
5.6. South Molton Street – East

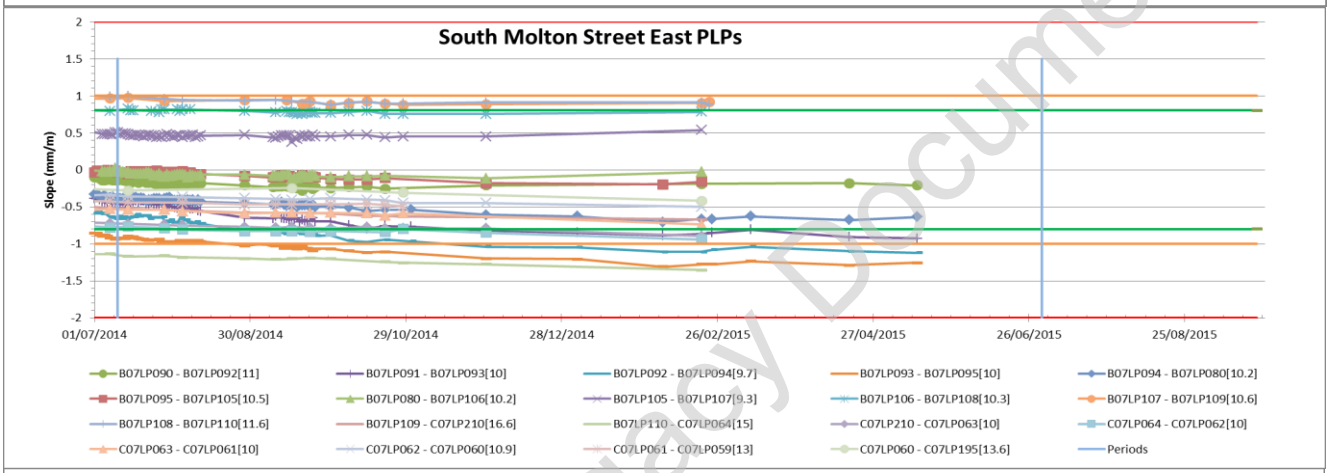


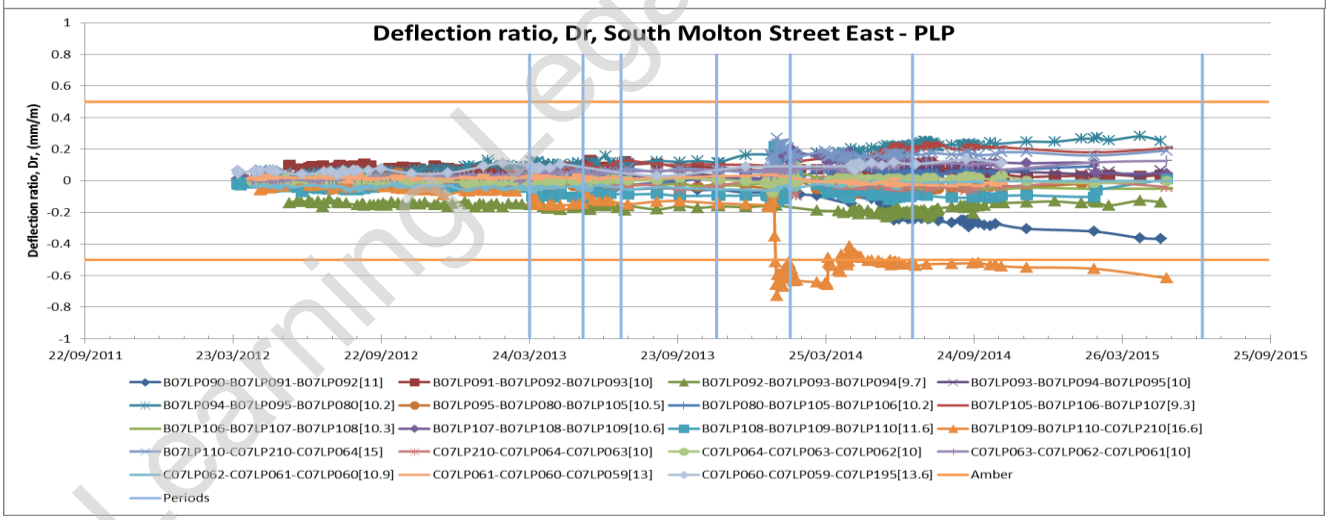


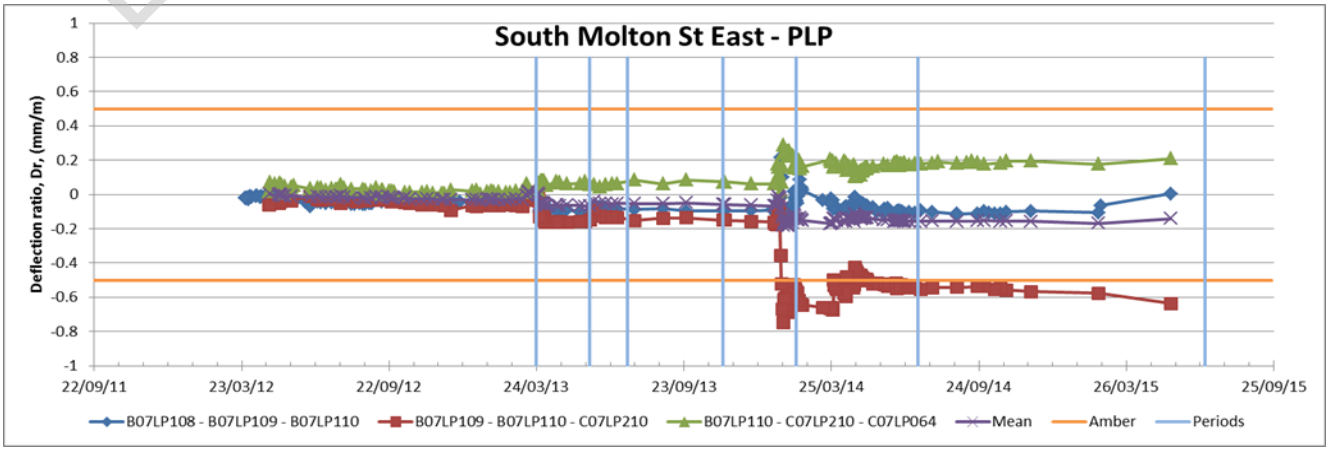








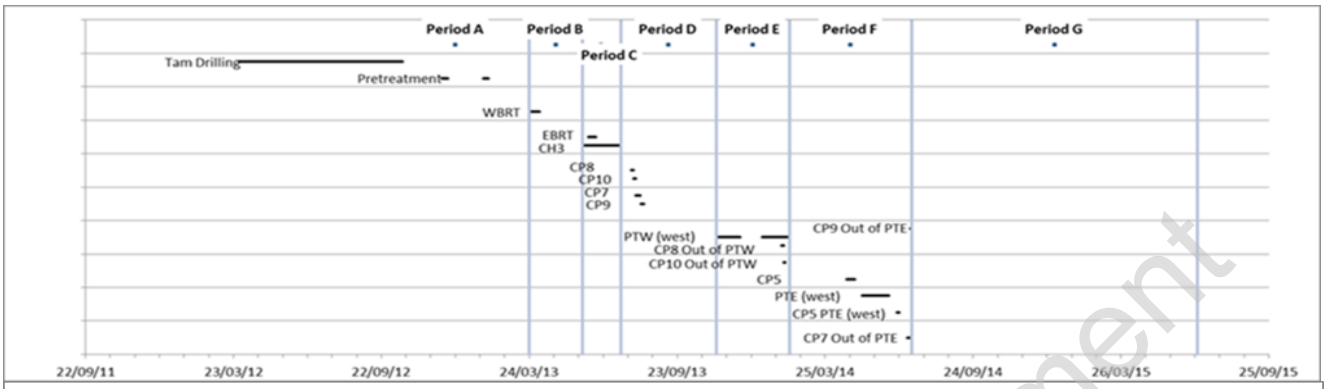


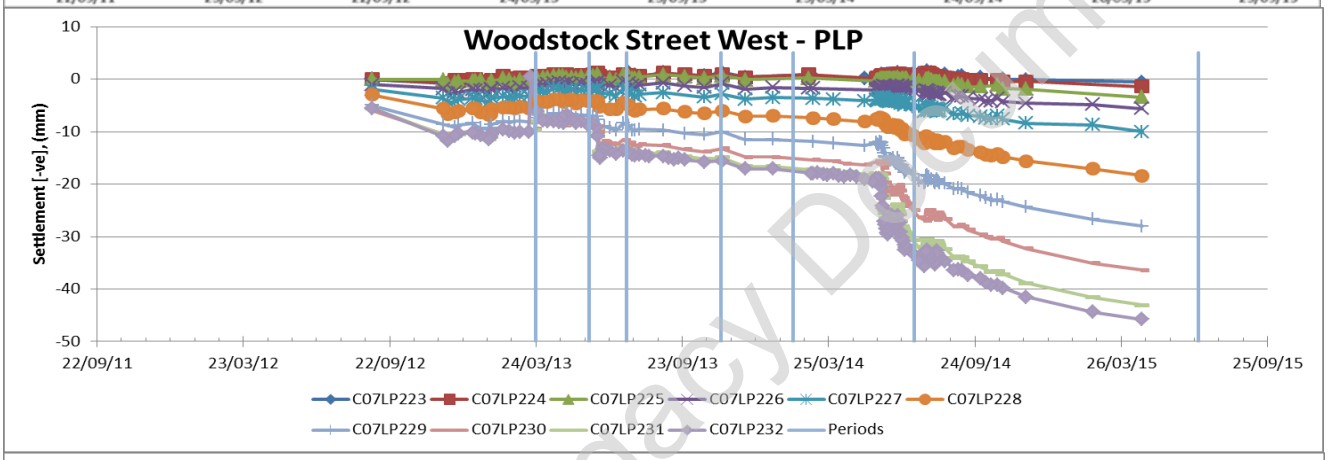


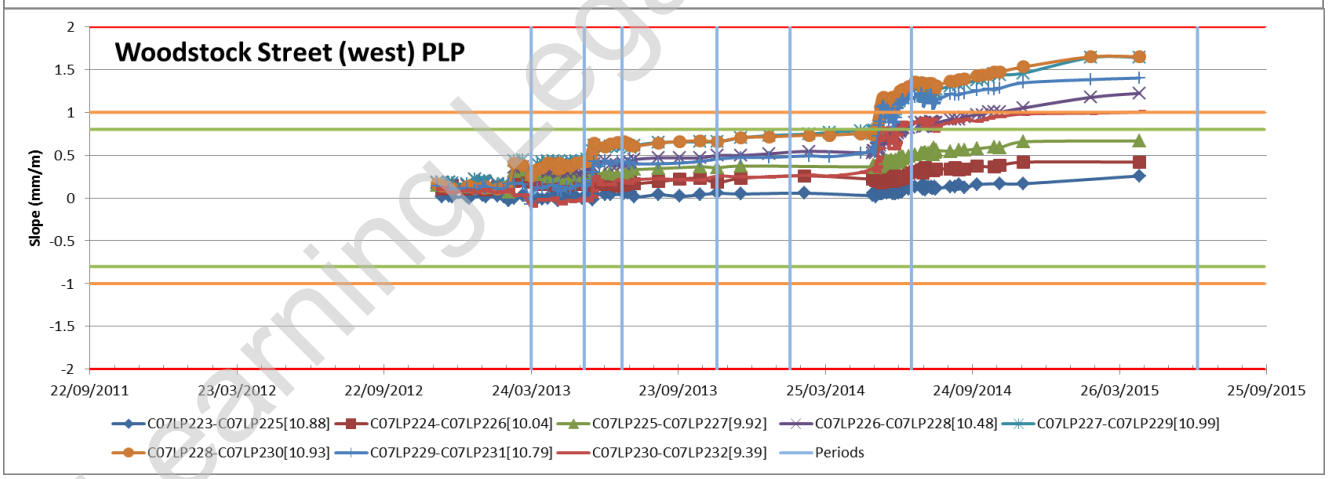
The following points are noted:

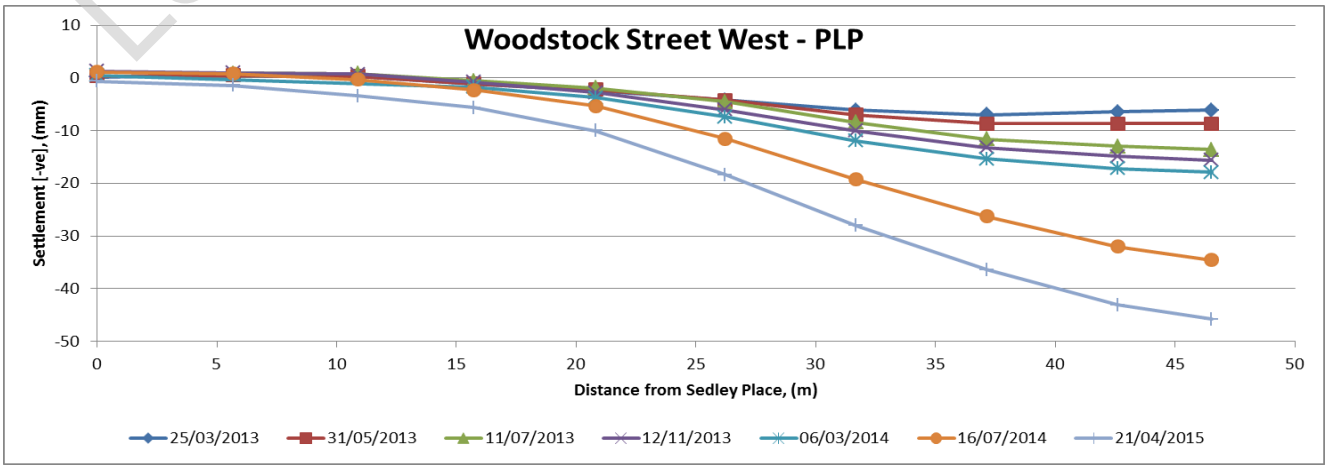
- The South Molton PLP profile is within the plan extent of the GS2 array up to approximately 100m from Brook Street, just short of the centreline of PTE. The profile is therefore affected by both westbound and eastbound tunnels as well as CP5 at its southern end, i.e. by tunnelling in Periods B, C, E and F.
- The overall magnitude of settlement on the South Molton Street PLPs is similar to those on the adjacent building facades with about 45mm over the PTW and just over 50mm over the PTE. However, there is a significant difference in the form of the settlement trough in that the PLP have a much sharper transition in slope direction over the two tunnel centrelines. It is noted that the PLP are not all installed on a continuous kerb line and that some points are installed very close to the building line. These latter points are probably located over pavement vaults and as experienced elsewhere (e.g. Dean Street at TCR) the small differences in settlement between the building and the ground can generate apparent trigger breaches.
- Settlement reached a maximum of 10mm prior to tunnelling at the end of Period A. The WBRT and EBRT with subsequent consolidation settlement increased the maximum settlement to about 17 - 18mm over the tunnel centrelines at the end of Period D. In Period E the PTW increased the maximum settlement to ~31mm over the tunnel. Similarly in Period F the PTE resulted in a total settlement of 30mm above the centreline. Uplift is apparent from grouting during CP5 but by the end of Period F settlement over PTW had increased to 37mm including some post construction consolidation.
- The settlement during Period E was sufficient to generate three amber triggers (B07LB107 - B07LB109; B07LB108 - B07LB110; B07LB110 - B07LB210).
- The rate of post construction settlement has continuously reduced throughout Period G, albeit that the latest reading appears to be low. The increase in settlement is about 10mm over PTW and 20mm over PTE. Secondary lining works in the tunnels have been undertaken in Period G.
- The slopes have either increased or decreased gradually during Period G due to the difference in the magnitude of movement over the two platform tunnels. The location of the final slope triggers are listed in Table 5.1. All of the slopes are stable or stabilising.
- There has been one “individual” deflection ratio in excess of the amber trigger value (1:/2000 or 0.5mm/m) which occurred in Period E. The DR reached a maximum of ~0.75mm/m but subsequently decreased before stabilising at about 0.6mm/m. In accordance with the C122 I&M plan (C122-OVE-C2-RGN-C125-50015), a “15m rolling average” has been calculated for both location and this confirms that the amber deflection ratio trigger has not been breached.

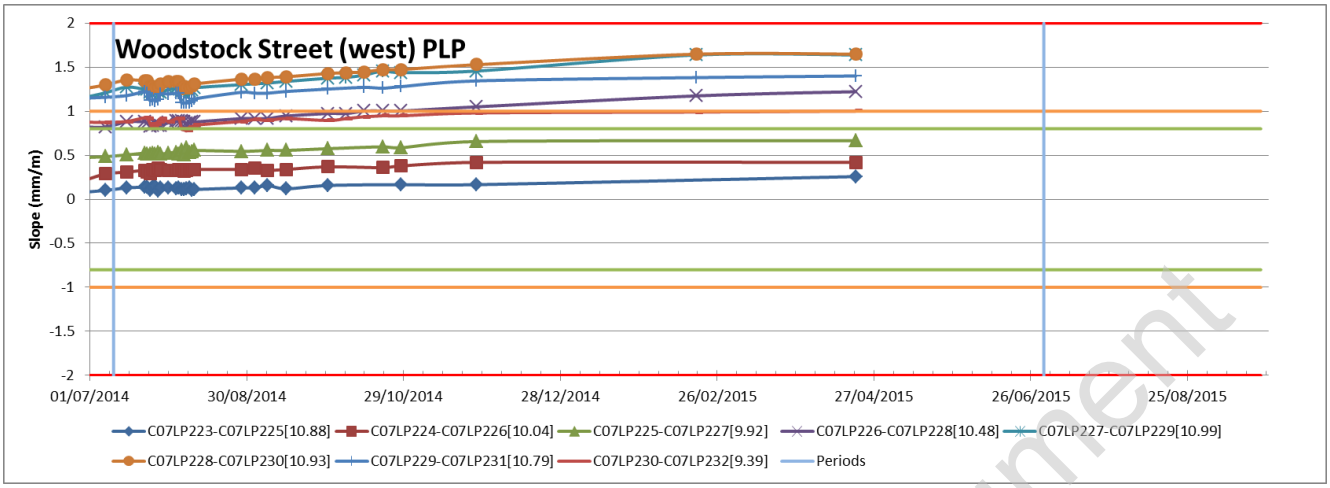
5.7. Woodstock Street – West







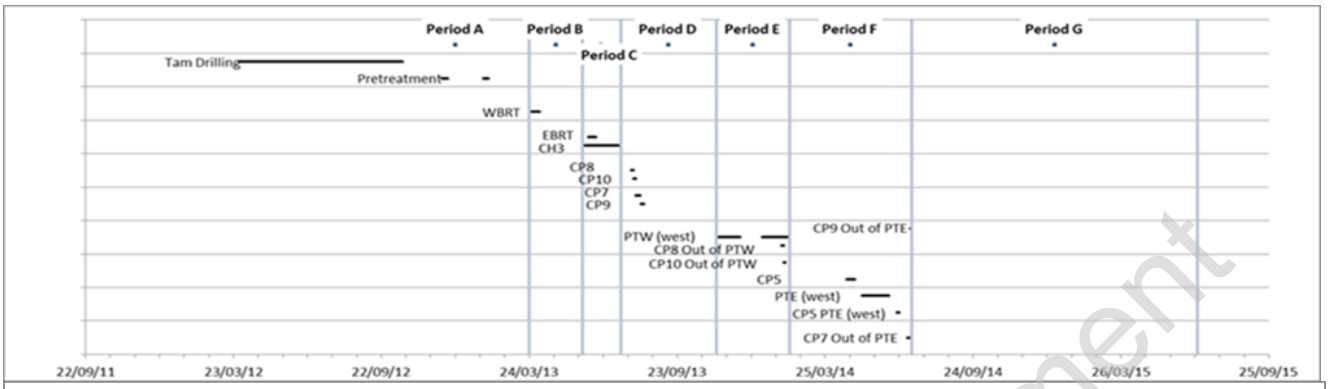


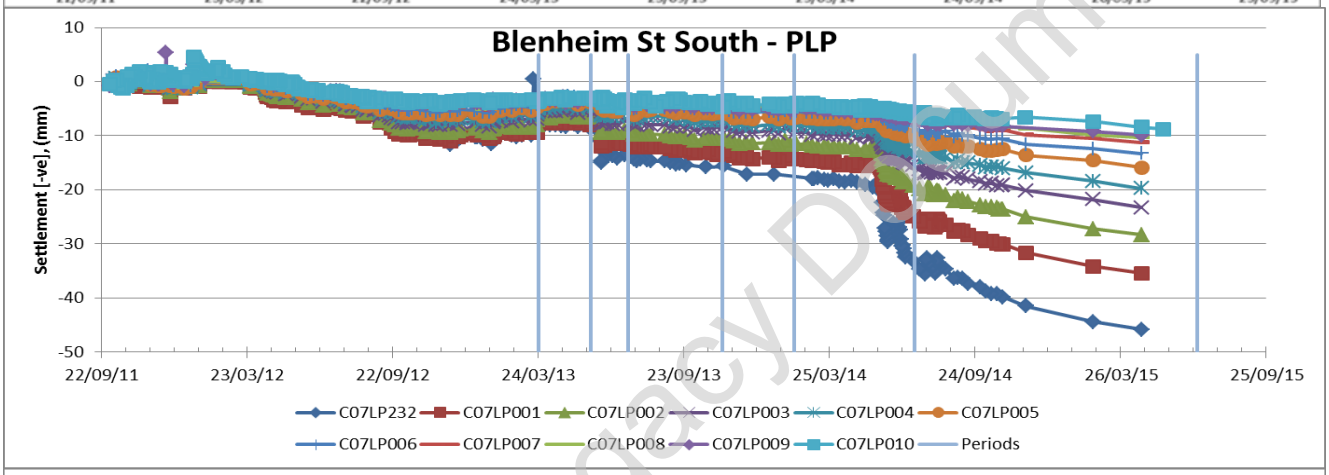


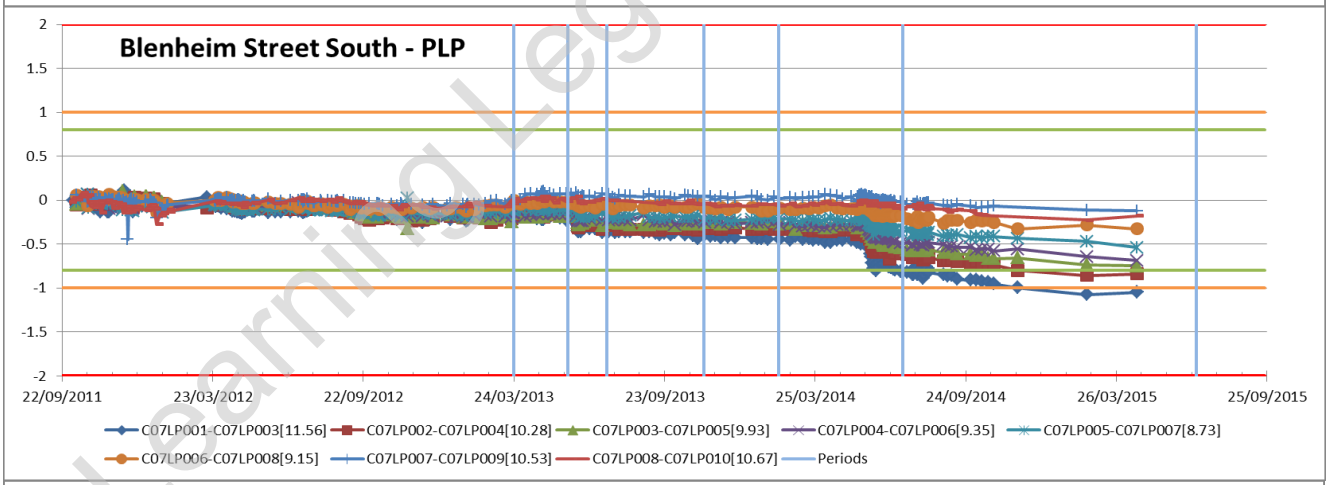
The following points are noted:

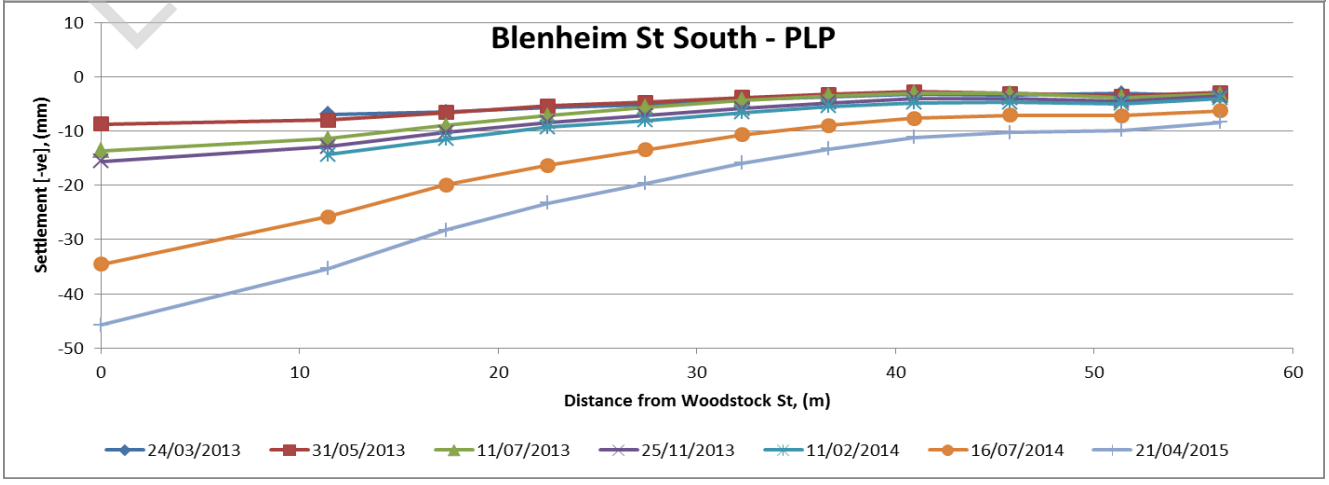
- The Woodstock Street west PLP profile extends from over the EBRT / PTE northwards and is outside the GS2 arrays from distance 0 to ~27m.
- The settlement of the PLP along the west side of Woodstock Street is essentially similar to those on the adjacent building façade increasing from 5mm at Sedley Place to ~45mm at Blenheim Street.
- The key construction events are the EBRT in Period C and PTE / CP5 in Period F.
- At the end of Period B, prior to the EBRT, about 10mm settlement had occurred with the maximum at the southern end of the profile. In Periods B, C and D an increase of ~7mm was recorded with about half of this associated with volume loss settlement. During and following PTE and CP5 in Period F, settlement increased to just over 30mm. A further 10mm settlement has occurred in Period G following completion of construction.
- Two amber slope triggers occurred during Period F. The rate of settlement has continuously reduced during Period G, however, a further three amber triggers have been exceeded, as listed in Table 5.1. The slopes are either stable or stabilising. By inspection, there are no deflection ratio triggers.

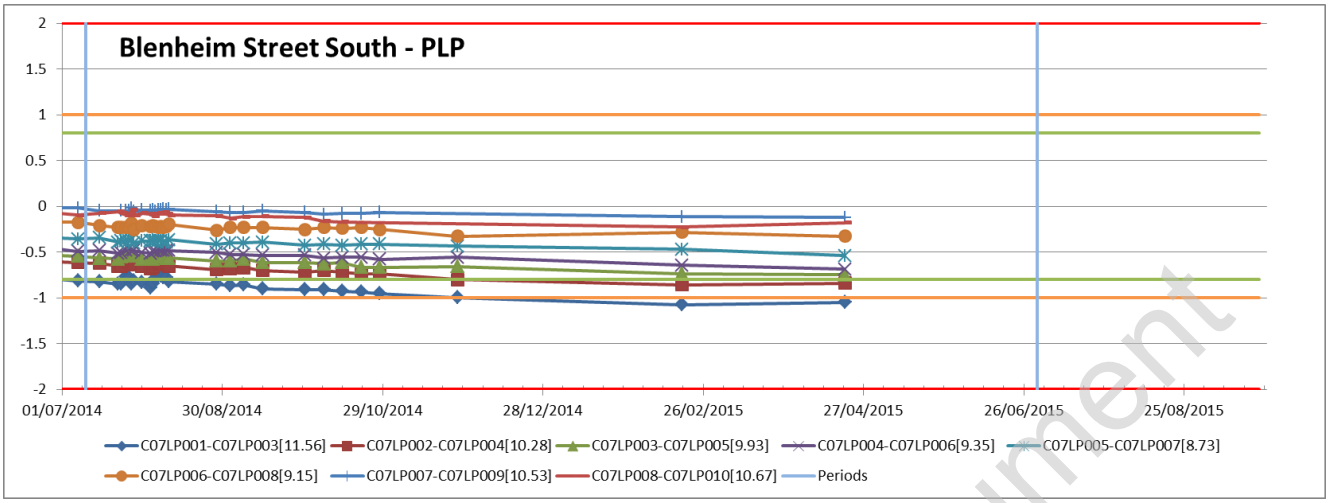
5.8. Blenheim Street - South











The following points are noted:

- The Blenheim Street south façade extends from over the PTE / CP5 junction with increasing offset towards New Bond Street and is outside the GS2 arrays from distance 40m onwards.
- The settlement of the PLP along the south side of Blenheim Street is essentially similar to those on the adjacent building façade increasing from ~10mm at New Bond Street to ~45mm at Woodstock Street.
- The key construction events are the EBRT in Period C and PTE / CP5 in Period F.
- At the end of Period B, prior to the EBRT, about 10mm settlement had occurred with the maximum at the western end of the profile. In Periods B, C and D an increase of ~7mm was recorded with about half of this associated with volume loss settlement. During and following PTE and CP5 in Period F, settlement increased to ~35mm. A further 12mm settlement has occurred in Period G following completion of construction.
- No amber slope triggers occurred during Period F. The rate of settlement has continuously reduced during Period G, however, one amber trigger has been exceeded. The slopes are either stable or stabilising. 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 2. 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 prime purpose of compensation grouting is to reduce the volume loss settlements associated with tunnelling since the associated slopes and curvatures are used to determine the need for protective measures: in general, this objective 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 and pre-TBM grout jacking reversed these movements within the constraints of the Works Information which limits uplift to 5mm.
- The exclusion zone specified in the SCoGM over the tunnel face placed significant constraints on concurrent grouting for the Cross Passages between the platform and concourse tunnels because of their short length.
- 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). There is one “individual” deflection ratio on buildings in excess of the Amber trigger value, on the west façade of New Bond Street. For PLPs “rolling average” values calculated in accordance with the C122 I&M plan have not exceeded the Amber trigger value.
- Grout jacking has been undertaken on numerous occasions to reduce settlements and slopes in various locations; up to 250mm equivalent thickness of grout has been injected below New Bond Street.
- Tunnelling was completed in July 2014, over 11 months ago and the final episode of grout jacking was undertaken in early August 2014: since that time the increase in movements has been reviewed on a daily, weekly or monthly basis at SRG and / or CTC meetings and it has been concluded that further grouting to reduce movements could not be justified given the risk of increased damage from any significant episodes of grout jacking. Consequently, no further grouting has been undertaken.

7. CONCLUSION

It is concluded that no further grouting from GS2 will be required and that the Grout Shaft and associated automatic monitoring systems can be decommissioned. The key factors leading to this conclusion are:

- It is 11 months since the completion of tunnelling and compensation grouting: ongoing post construction settlements have been under continual review at daily, weekly or 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'etre* of the Specification is to minimise damage notwithstanding the contractual implication of exceeding Performance Criteria.

Appendix A

Assumptions used to produce contour plots of grout intensity

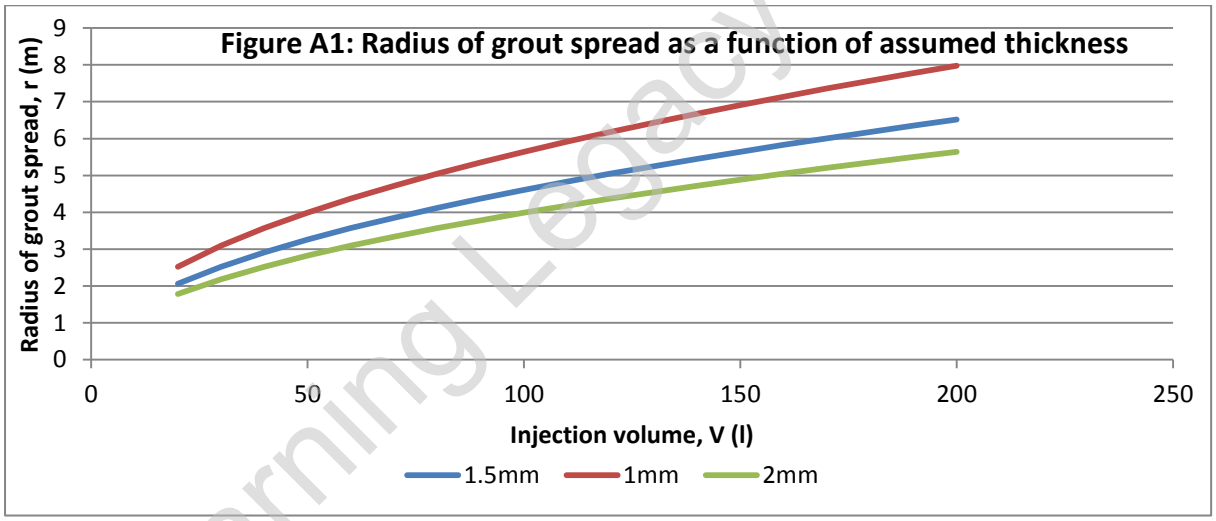
A method of producing a visualisation of the quantity and distribution of grout injected during compensation grouting is useful in interpreting performance. For each injection the volume and the location of the port used are known. The model used is intended to approximate the distribution of grout within 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 governed by the stress conditions at the time of injection which are constantly changing during the construction process. It is known that in London Clay that 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:

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

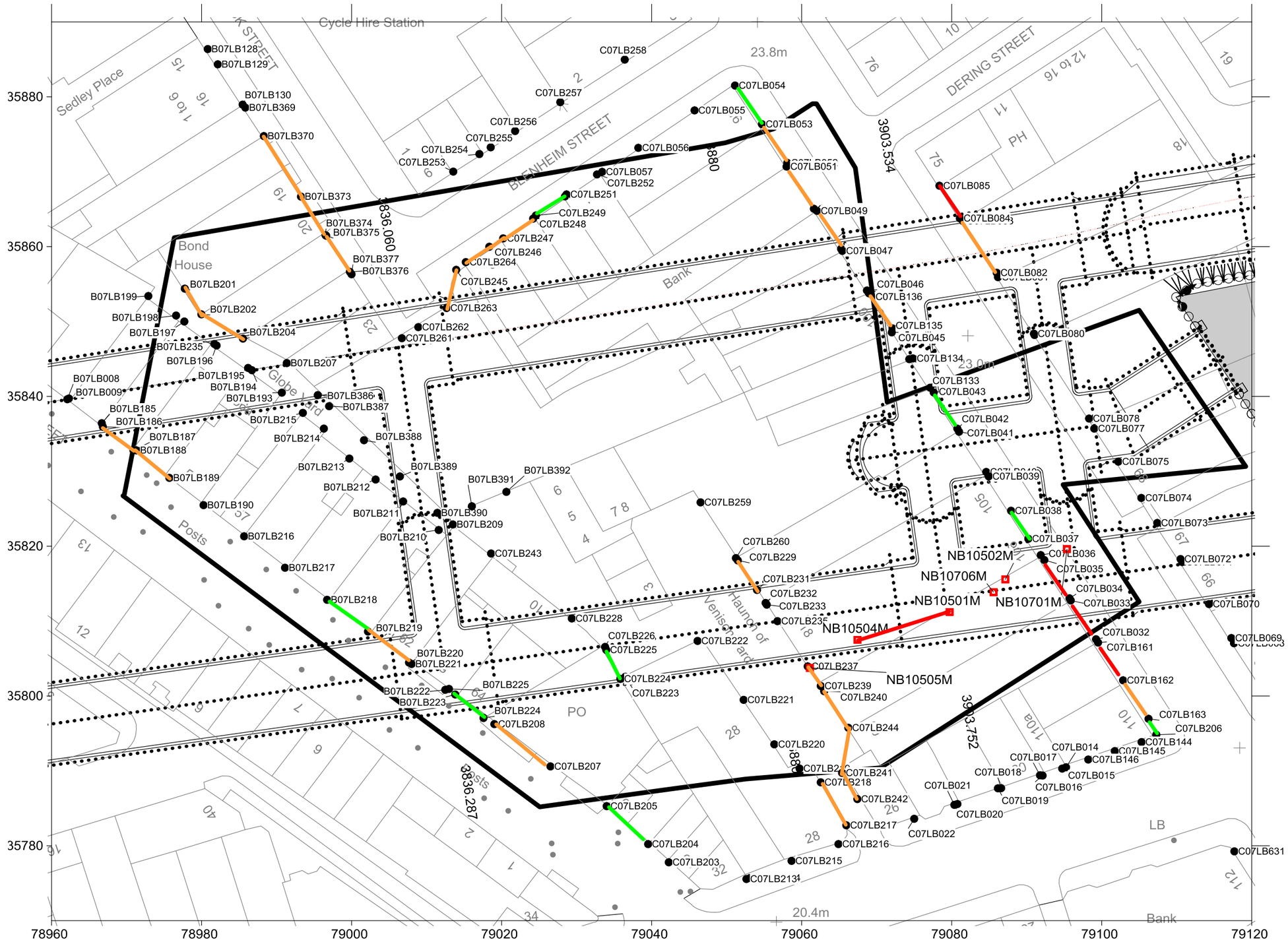


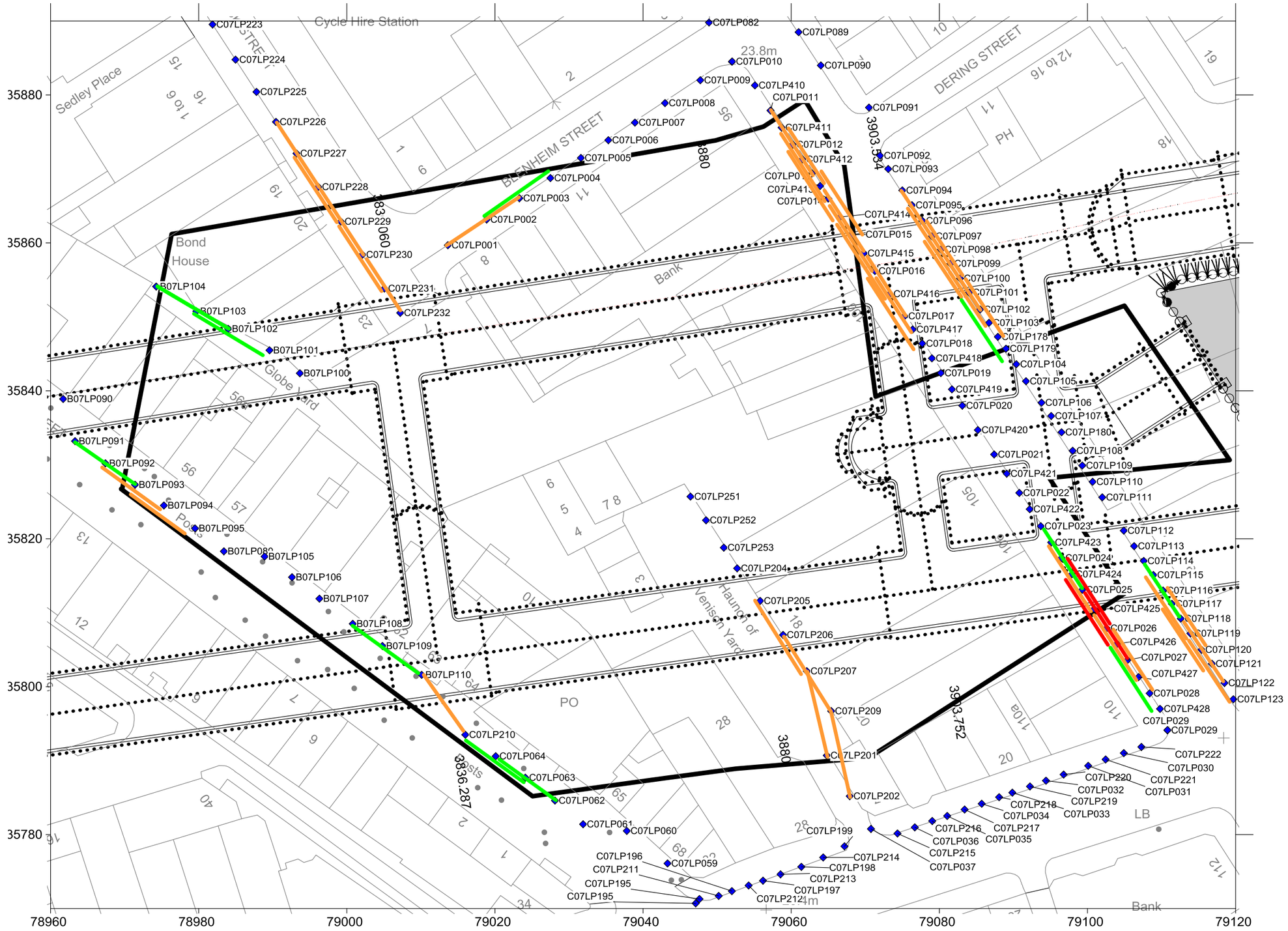
Observation of grout in the ground suggests that a thickness of 1 – 2mm is predominantly achieved. All of the plots included in this report are based on an assumed thickness of 1.5mm. Figure A1 shows the variation in radius for thicknesses of 1.0, 1.5 and 2.0mm.

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

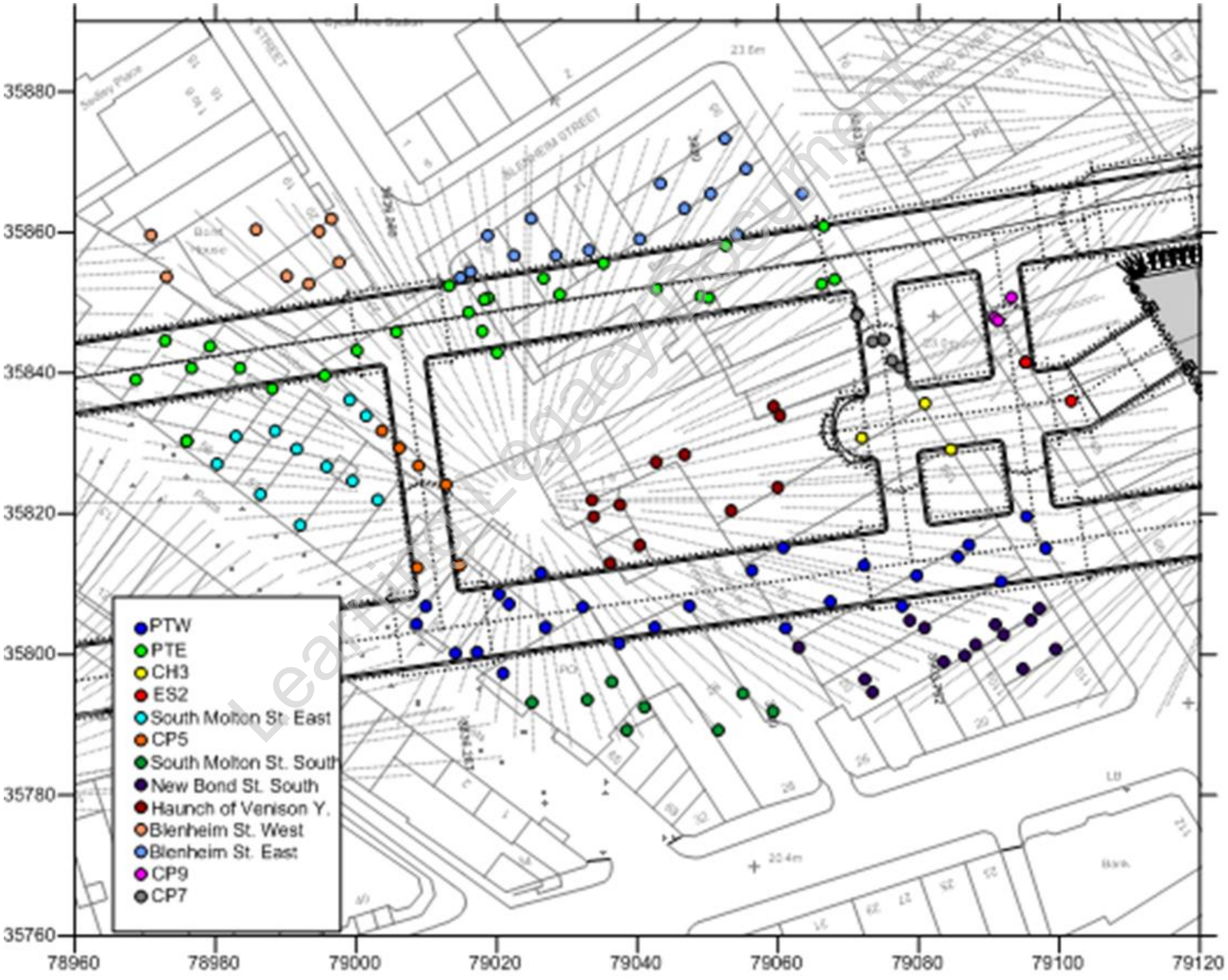
Enlarged version of Figures 4.1 and 5.1 showing location of monitoring points and slope triggers


Cycle Hire Station
Sedley Place
DERING STREET
BEENHEIM STREET
Bond House
Bank
Globe Yard
Posts
PO
Haunch of Venison Yard
PH
23.8m
23.0m
20.4m
LB
3836.060
3903.534
3836.287
3893.752
NB10502M
NB10706M
NB10501M
NB10701M
NB10504M
NB10505M
35880
35860
35840
35820
35800
35780
78960
78980
79000
79020
79040
79060
79080
79100
79120

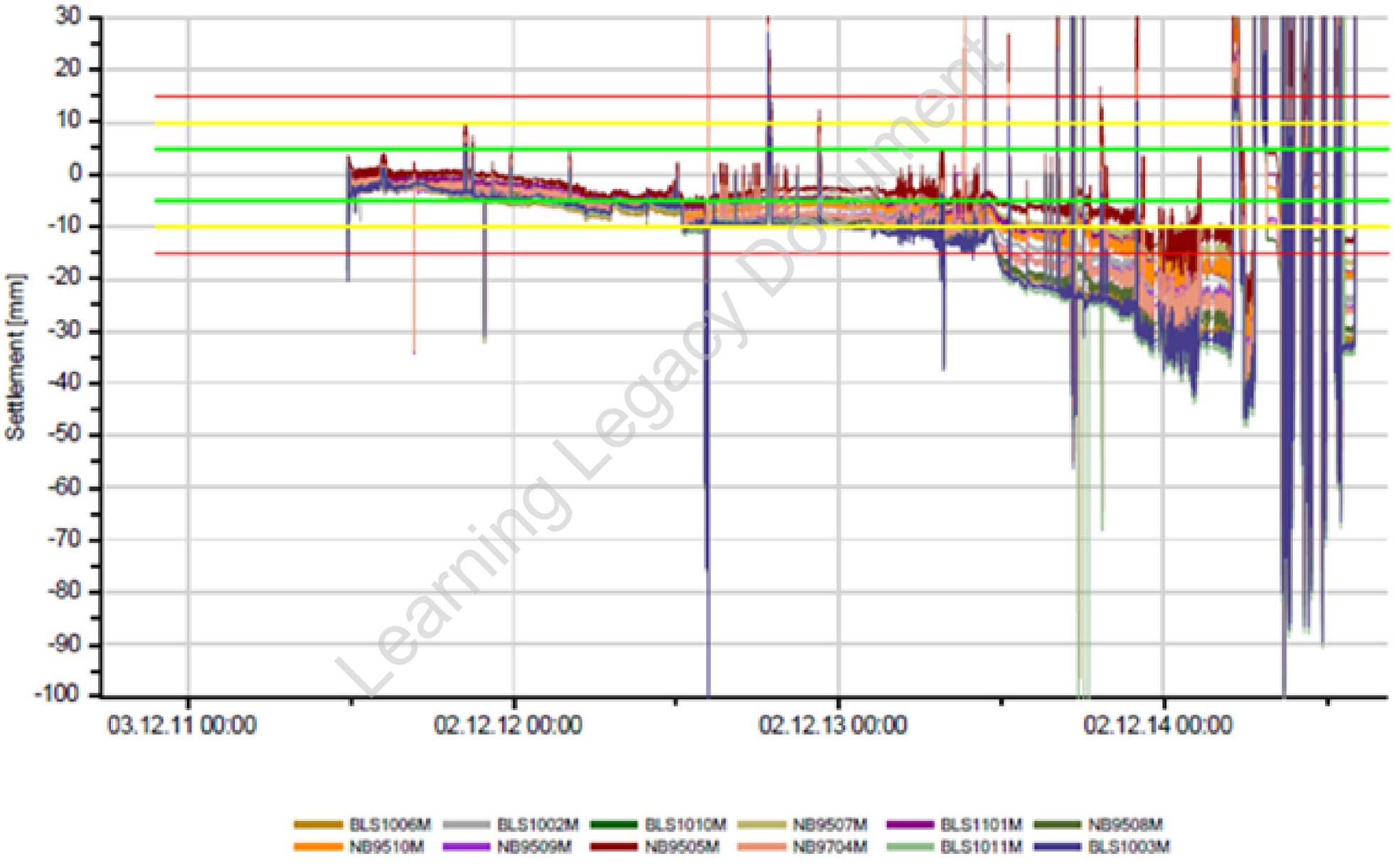

Cycle Hire Station
Sedley Place
BEENHEIM STREET
DERING STREET
Bond House
Bank
Globe Yard
Venison Yard
Haunch of
PO
PH
LB
23.8m
3880
3903.334
3903.752
3836.287
C07LP223
C07LP224
C07LP225
C07LP226
C07LP227
C07LP228
C07LP229
C07LP230
C07LP231
C07LP232
C07LP082
C07LP089
C07LP010
C07LP090
C07LP009
C07LP410
C07LP011
C07LP008
C07LP091
C07LP007
C07LP411
C07LP006
C07LP012
C07LP005
C07LP412
C07LP092
C07LP093
C07LP004
C07LP094
C07LP003
C07LP095
C07LP002
C07LP096
C07LP414
C07LP001
C07LP015
C07LP097
C07LP098
C07LP415
C07LP099
C07LP016
C07LP100
C07LP416
C07LP101
C07LP102
C07LP017
C07LP103
C07LP417
C07LP178
C07LP018
C07LP179
C07LP418
C07LP104
C07LP019
C07LP105
C07LP419
C07LP020
C07LP106
C07LP107
C07LP420
C07LP180
C07LP108
C07LP021
C07LP109
C07LP421
C07LP110
C07LP022
C07LP111
C07LP422
C07LP023
C07LP112
C07LP423
C07LP113
C07LP024
C07LP114
C07LP424
C07LP115
C07LP025
C07LP116
C07LP425
C07LP117
C07LP026
C07LP118
C07LP426
C07LP119
C07LP027
C07LP120
C07LP121
C07LP427
C07LP122
C07LP028
C07LP123
C07LP428
C07LP029
C07LP222
C07LP030
C07LP220
C07LP221
C07LP032
C07LP031
C07LP218
C07LP219
C07LP034
C07LP033
C07LP216
C07LP217
C07LP036
C07LP035
C07LP215
C07LP037
C07LP199
C07LP214
C07LP198
C07LP213
C07LP197
C07LP212
C07LP205
C07LP206
C07LP207
C07LP209
C07LP201
C07LP202
C07LP251
C07LP252
C07LP253
C07LP204
C07LP210
C07LP064
C07LP063
C07LP062
C07LP061
C07LP060
C07LP059
C07LP196
C07LP211
C07LP195
C07LP195
B07LP104
B07LP103
B07LP102
B07LP101
B07LP100
B07LP090
B07LP091
B07LP092
B07LP093
B07LP094
B07LP095
B07LP105
B07LP106
B07LP107
B07LP108
B07LP109
B07LP110
35880
35860
35840
35820
35800
35780
78960
78980
79000
79020
79040
79060
79080
79100
79120

Appendix C

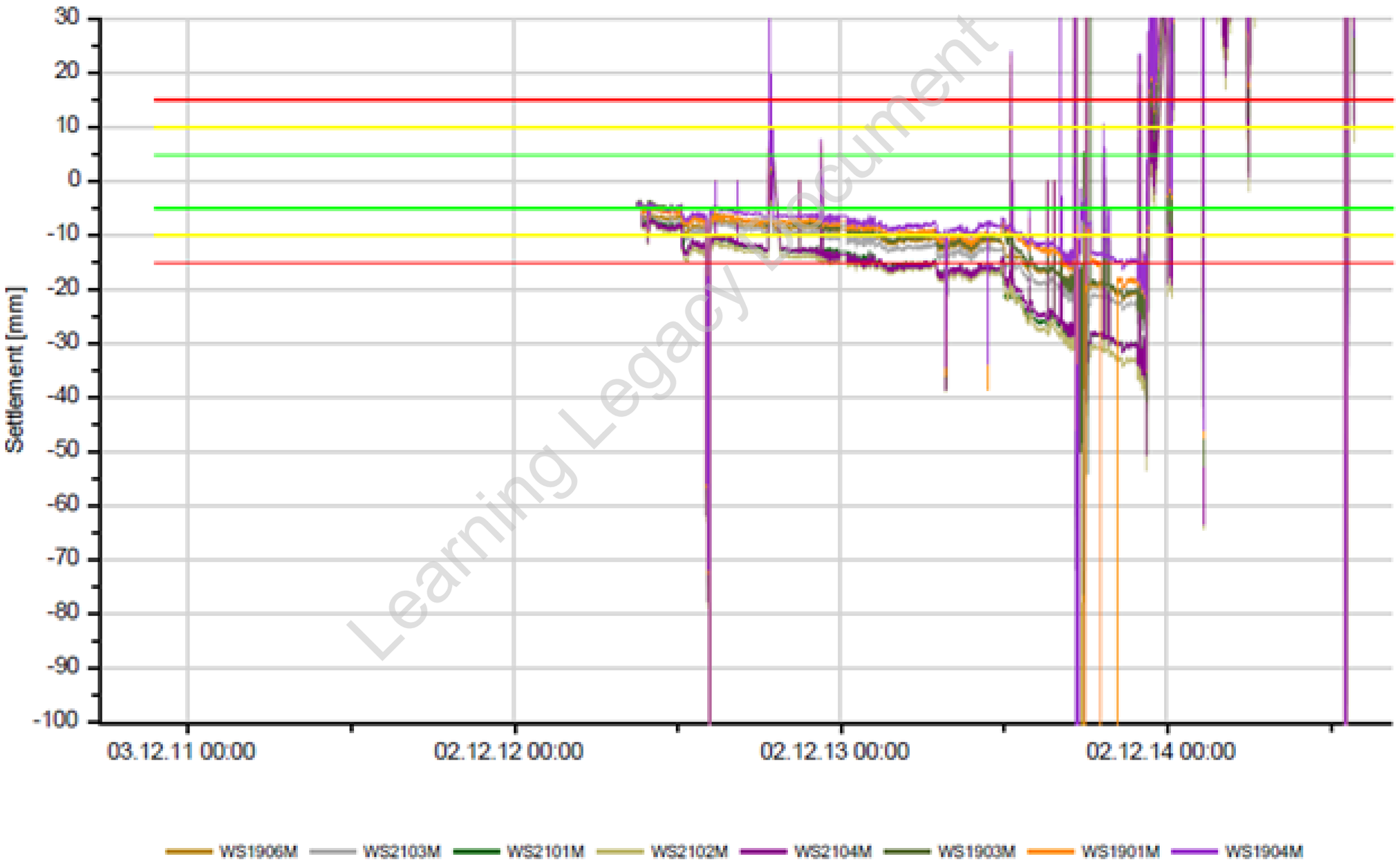
Examples of HLC time plots from Gtc database: Location of sensors

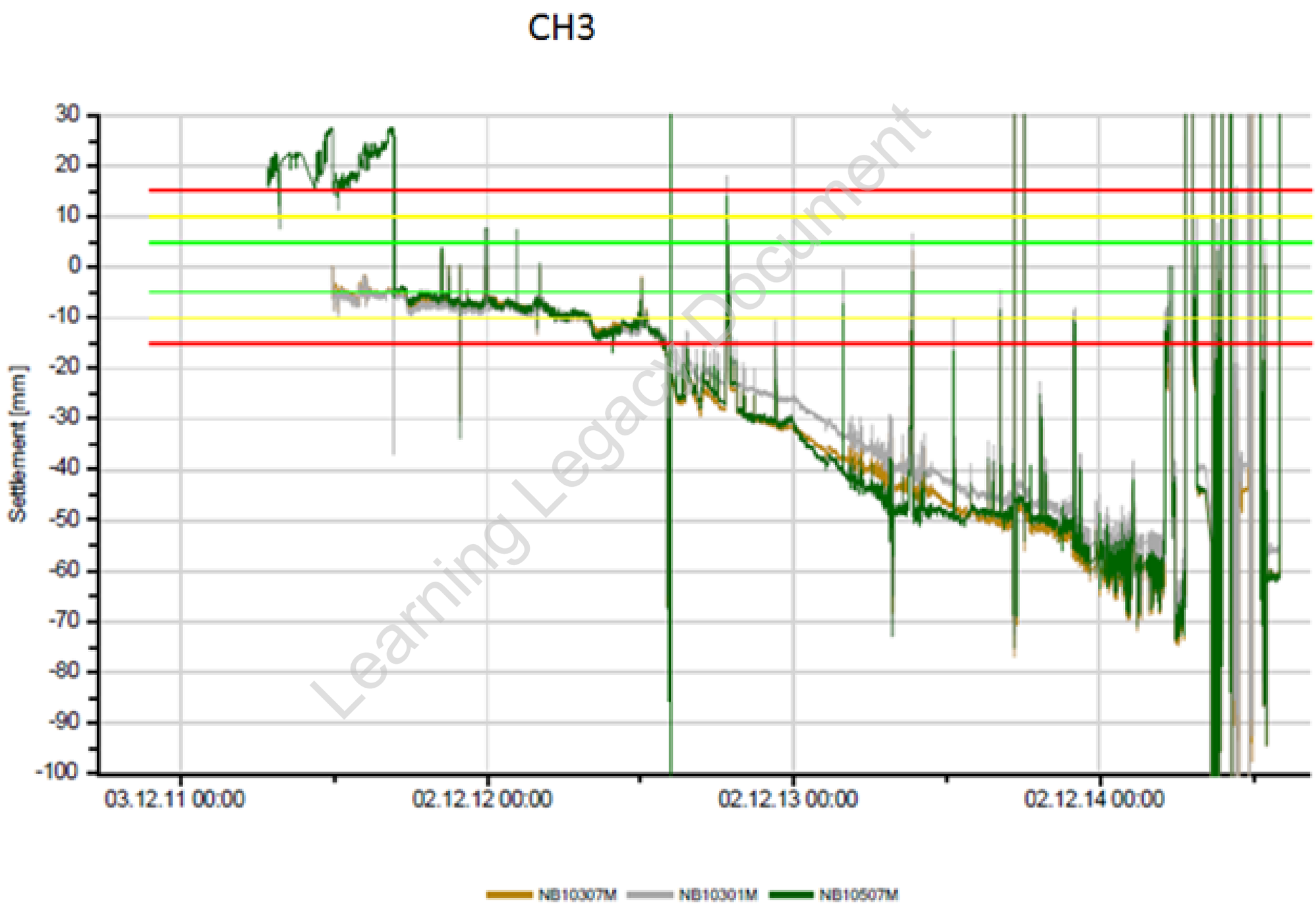


Blenheim St. East

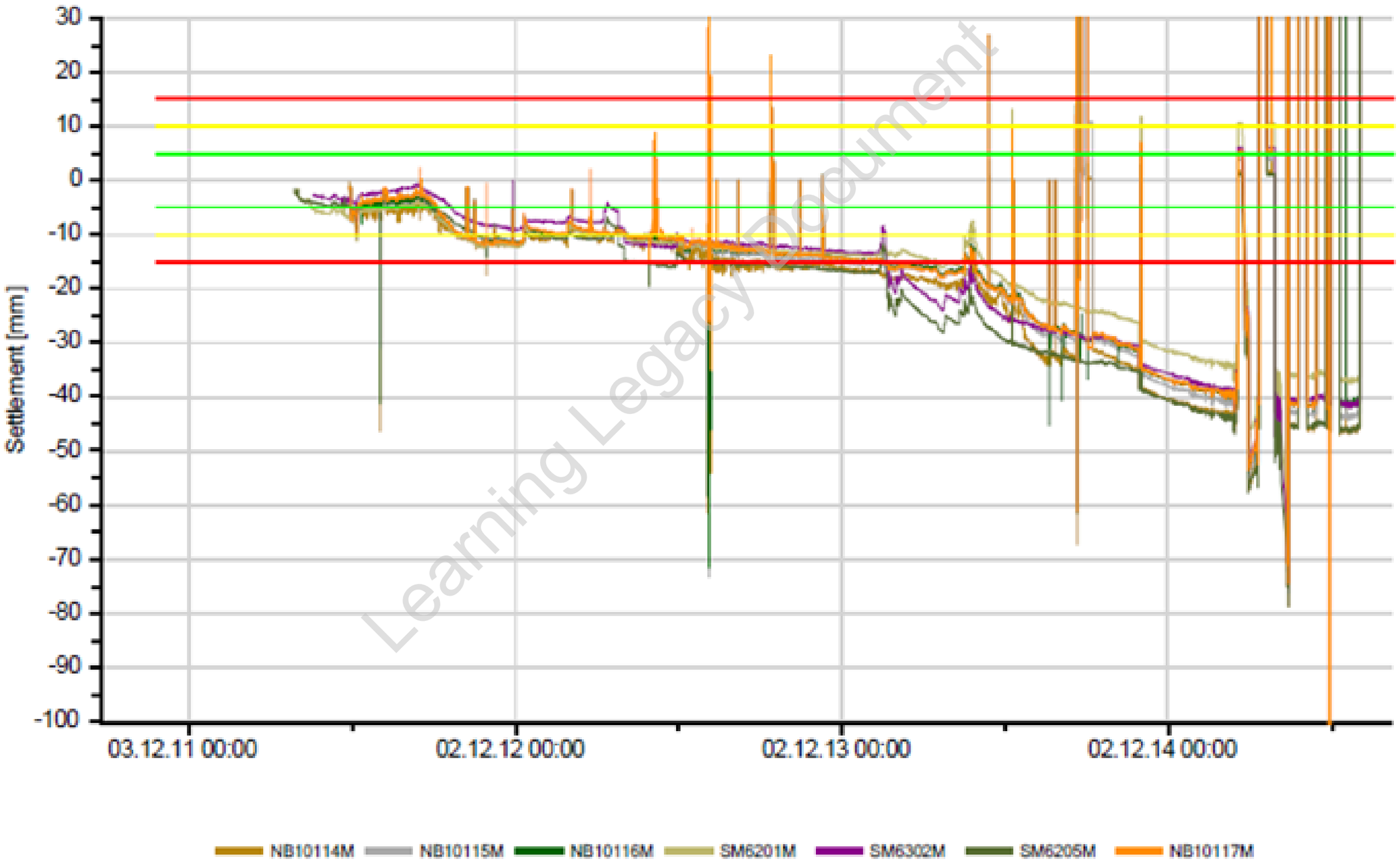


Blenheim St. West

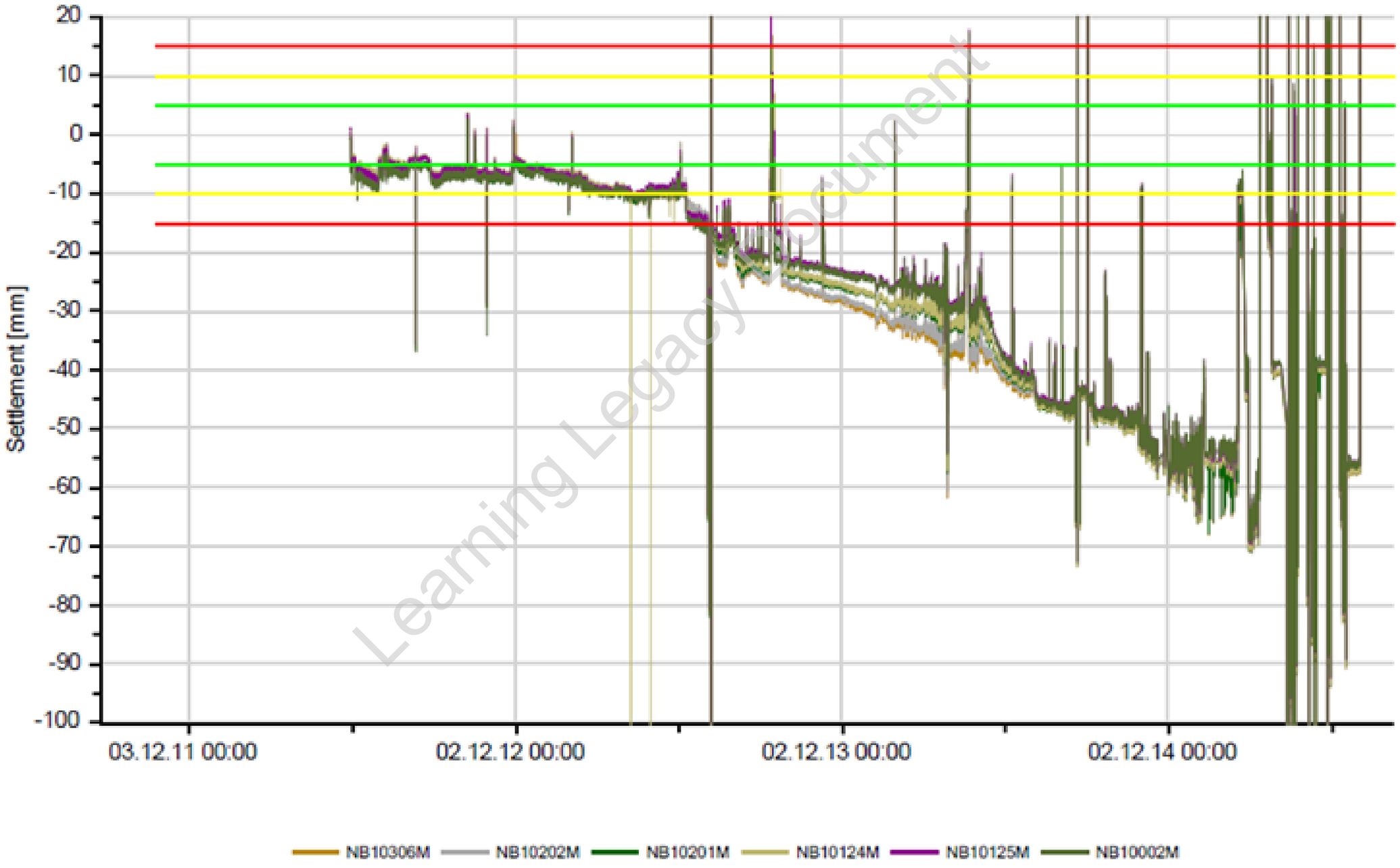




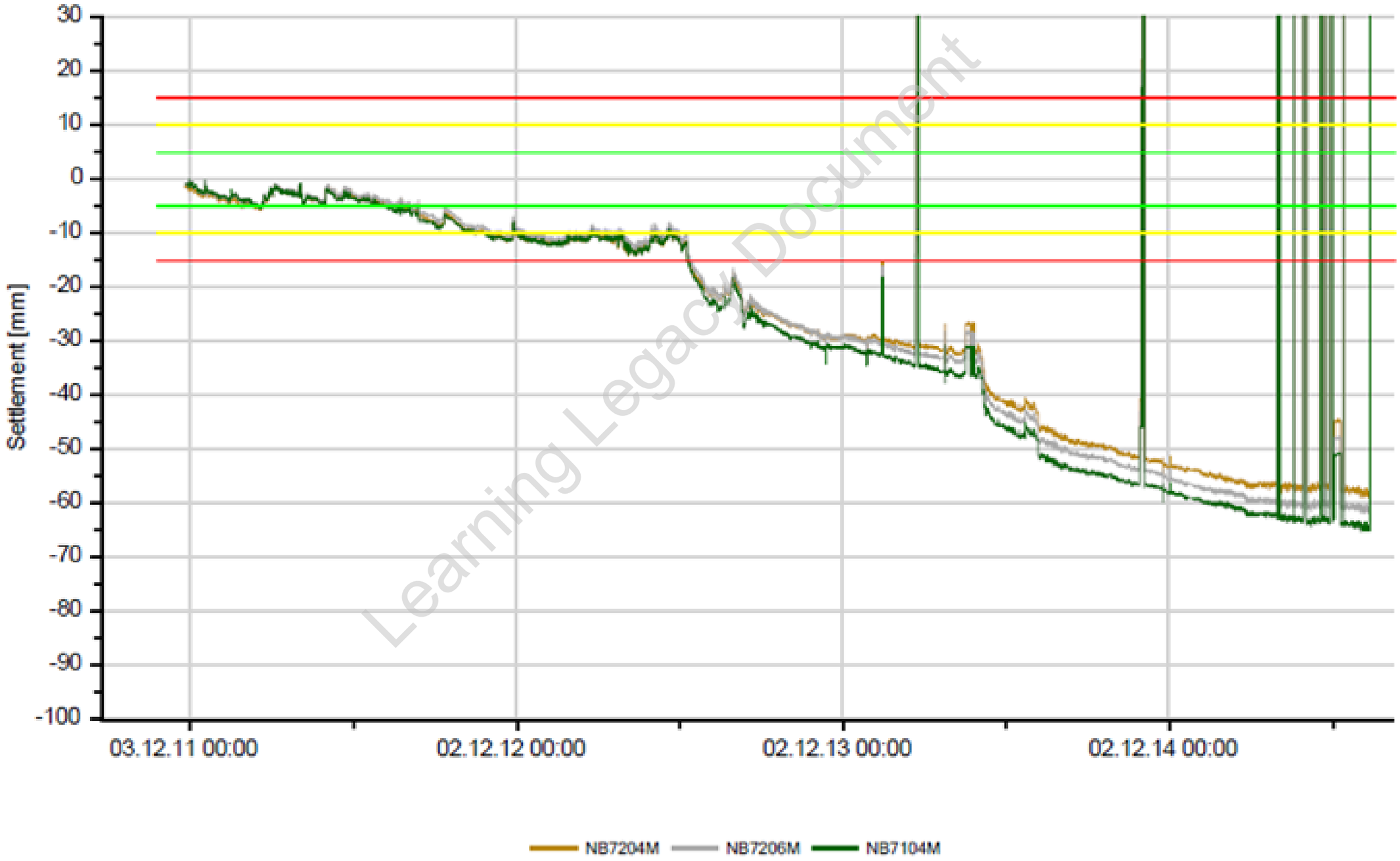
CP5



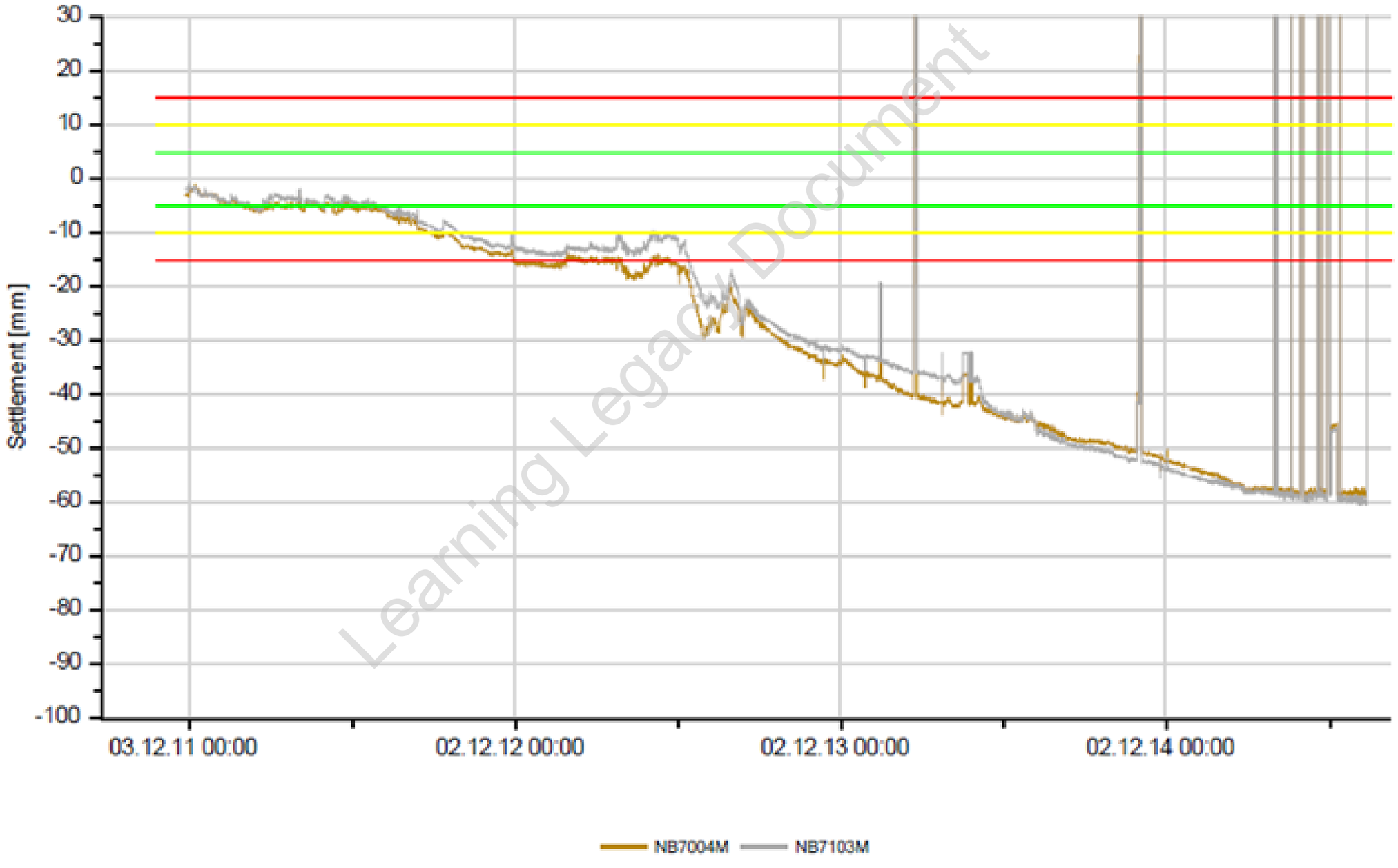
CP7



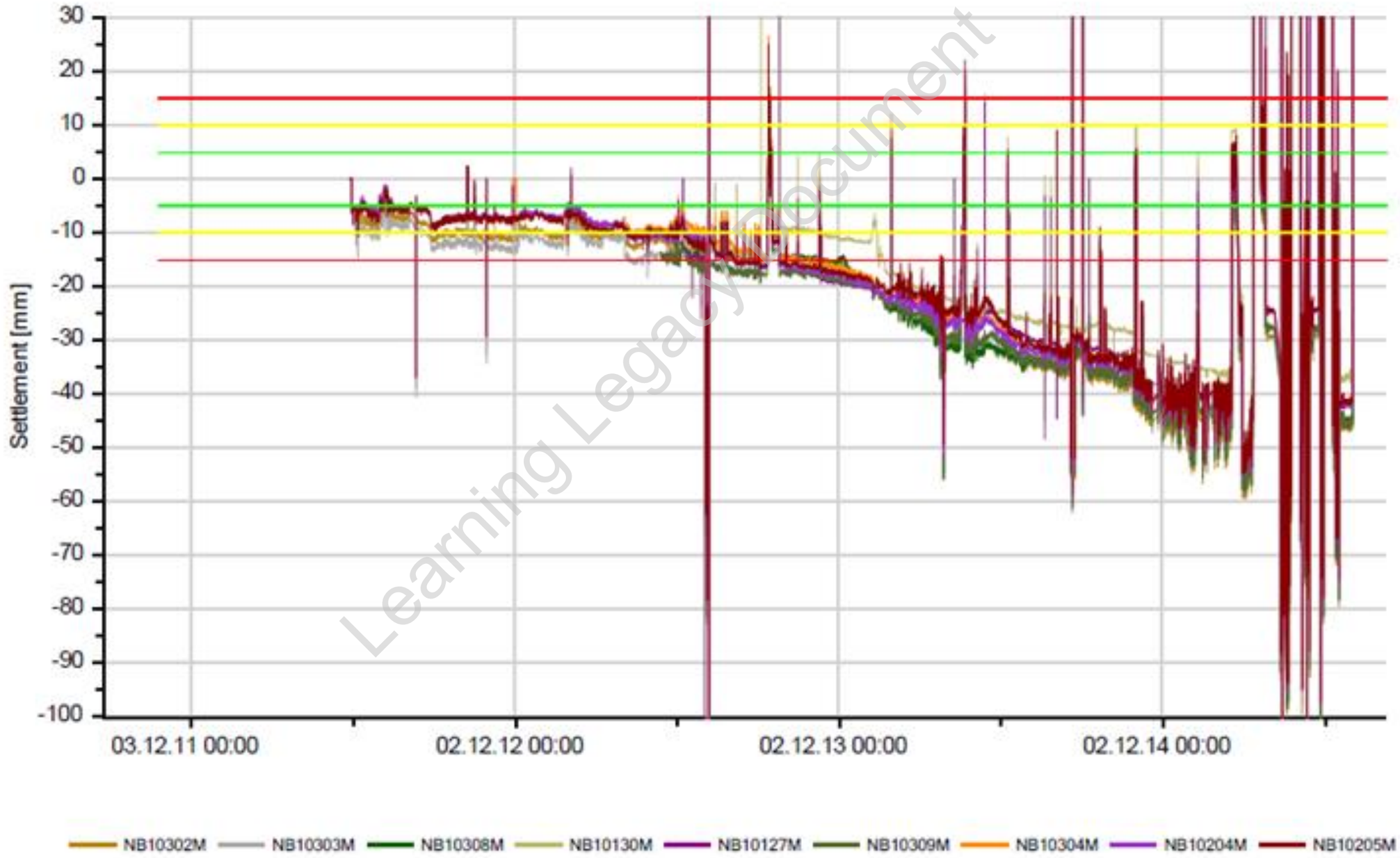
CP9



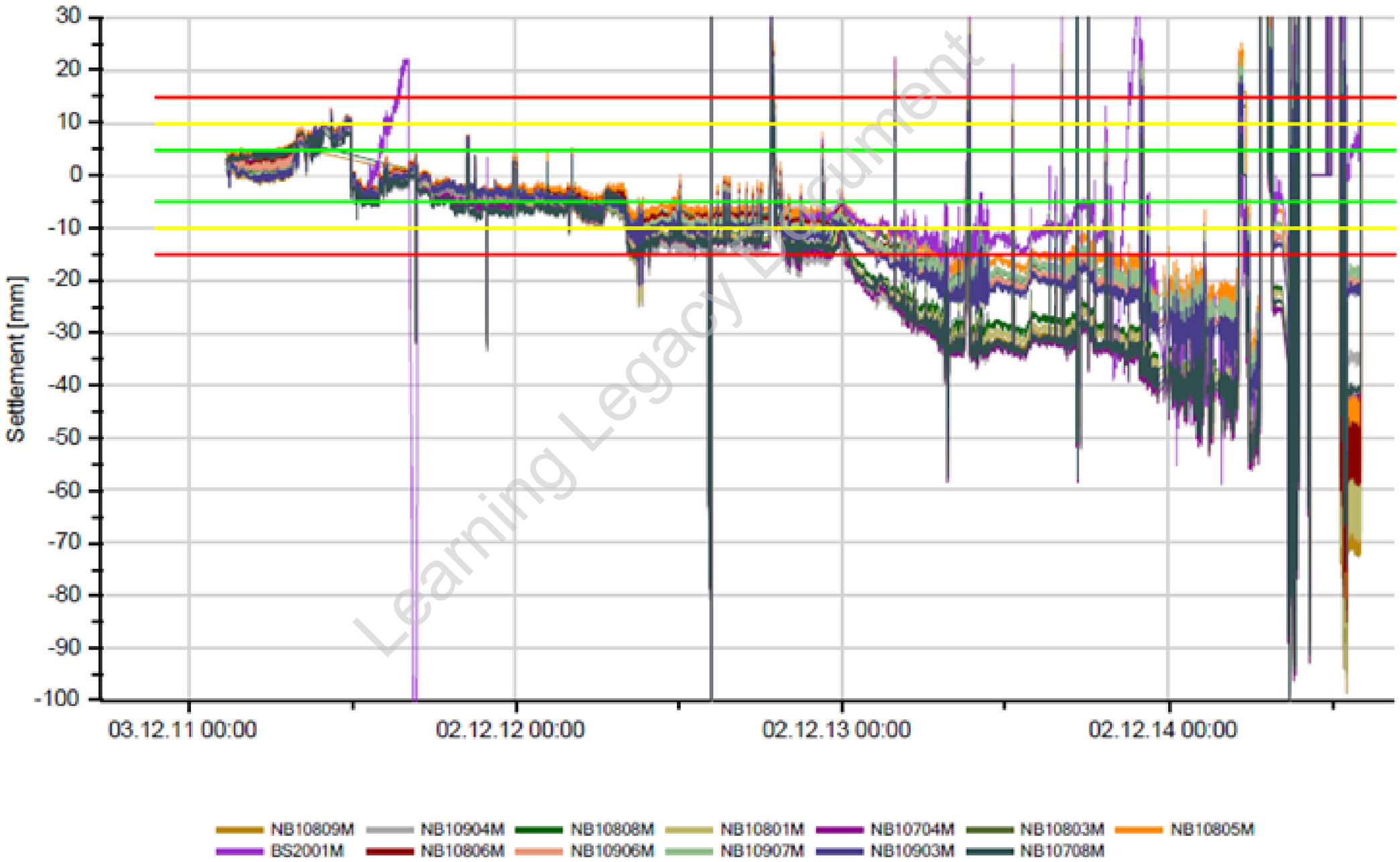
ES2



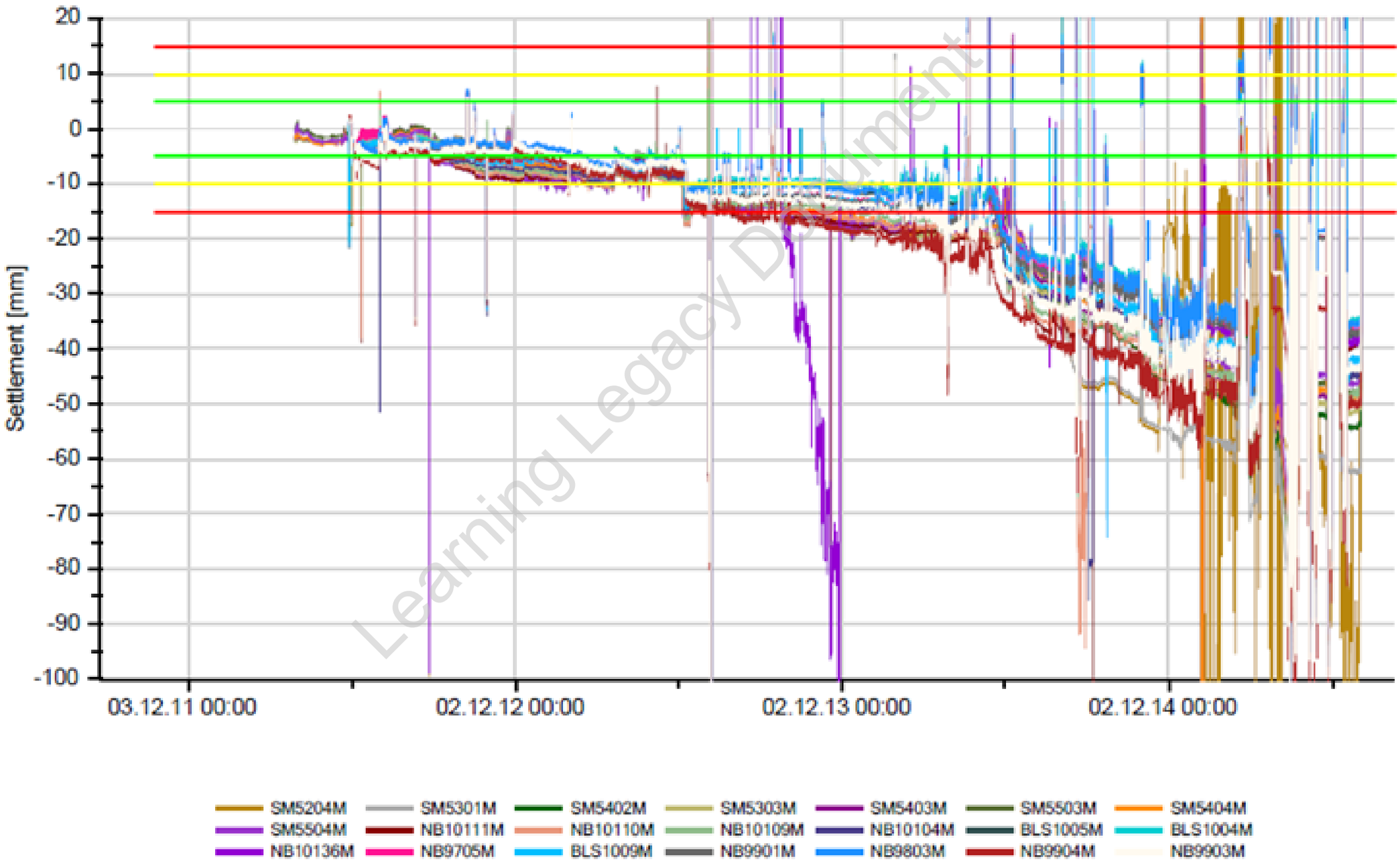
Haunch of Venison Yard



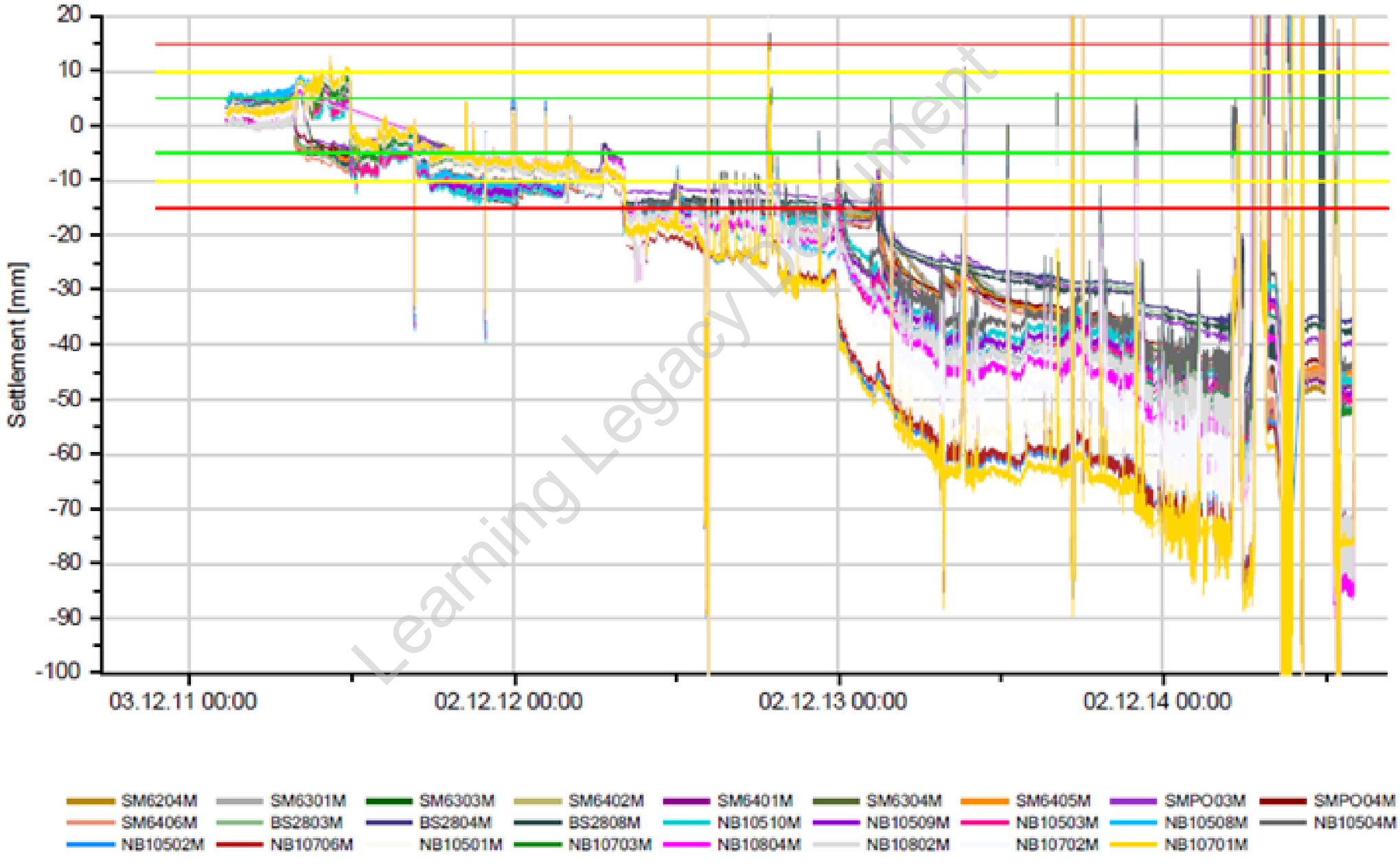
New Bond St. South



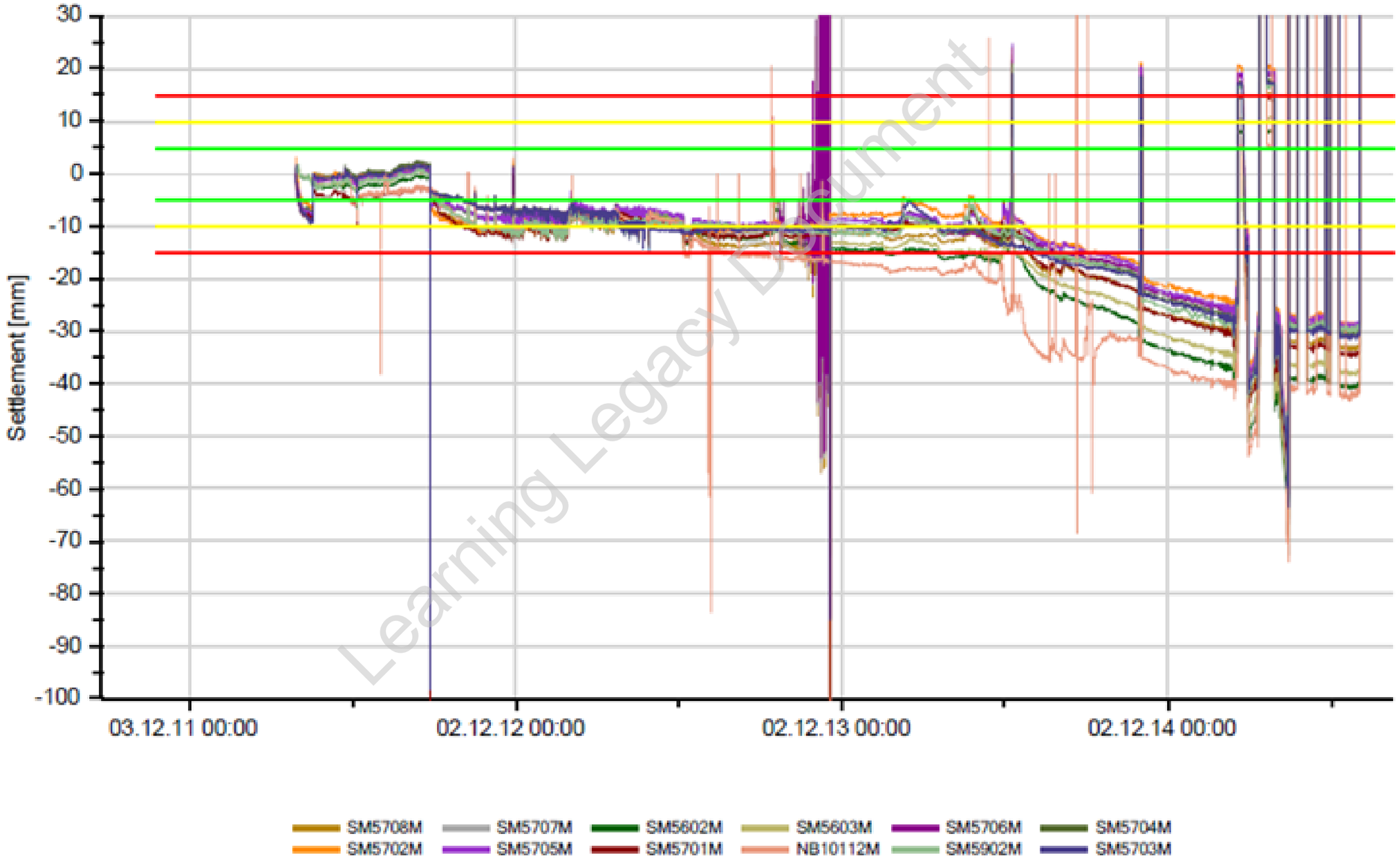
PTE



PTW



South Molton Street East



South Molton Street South