C300/410

Western Tunnels & Caverns Project

Report

Grouting Summary & I&M Close-Out - TCR Grout Shaft 1

CRL Document No. C300-BFK-C4-RGN-CRT00_ST005-51225

Contract MDL reference: C13.016

1. Contractor Document Submittal History

Revision	Date	Prepared by	Checked by	Approved by	Reason for Issue
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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.

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2b. Review by Stakeholder (if required):

Stakeholder Organisation	Job Title	Name	Signature	Date	Acceptance
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3. Acceptance by *Crossrail*:

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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 C122-OVE-Z4-RSP-CR001-00010) and Instrumentation and Monitoring (KX10 KX10 C122-OVE-Z4-RSP-CR001-00007) 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 1 at Tottenham Court Road 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 (C122-OVE-C2-RSP-C125-00001) Clause 3.2.5.1 and 3.2.5.2. A general location plan of the grout shafts at TCR is provided in Figure 1.2.

All low level tunnelling works within the plan extent of the compensation grouting arrays from TCR Station Grout Shaft 1 were completed by May 2014. An abridged version of this report was issued in August 2014 (C300-CCM-08479), about 3 months after the end of tunnelling, to justify de-commissioning of the grout shaft: this report was accepted by CRL (C300-PMC-09405) and the grout shaft was subsequently de-commissioned.

A high level tunnel, VWW, was also required in this area. Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.

This report aims to summarise the relevant construction, compensation grouting and monitoring information for Grout Shaft 1 at TCR Station and includes manual monitoring up to September 2015 when the manual monitoring within the GS1 area was de-scoped under C300-PMI-1858. The purpose of this report is therefore to fully document the justification for the decommissioning of the shaft and also to provide a close-out report for the instrumentation. A separate close out report is provided for the ATS prisms (C300-BFK-C4-RGN-CRT00_ST005-53008).

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

- H&S file – submitted separately for construction and for 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

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

The HLCs have been used for construction control during compensation grouting works and a separate "close out" report is not required. Example plots of HLC data are provided in Appendix B. Other instrumentation within the Grout Shaft 1 area comprises:

- Crackmeters - 22 Great Chapel Street
- Tiltmeters – 88- 89 Dean Street

Data from these instruments is also included in Appendix B.

Figure 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.

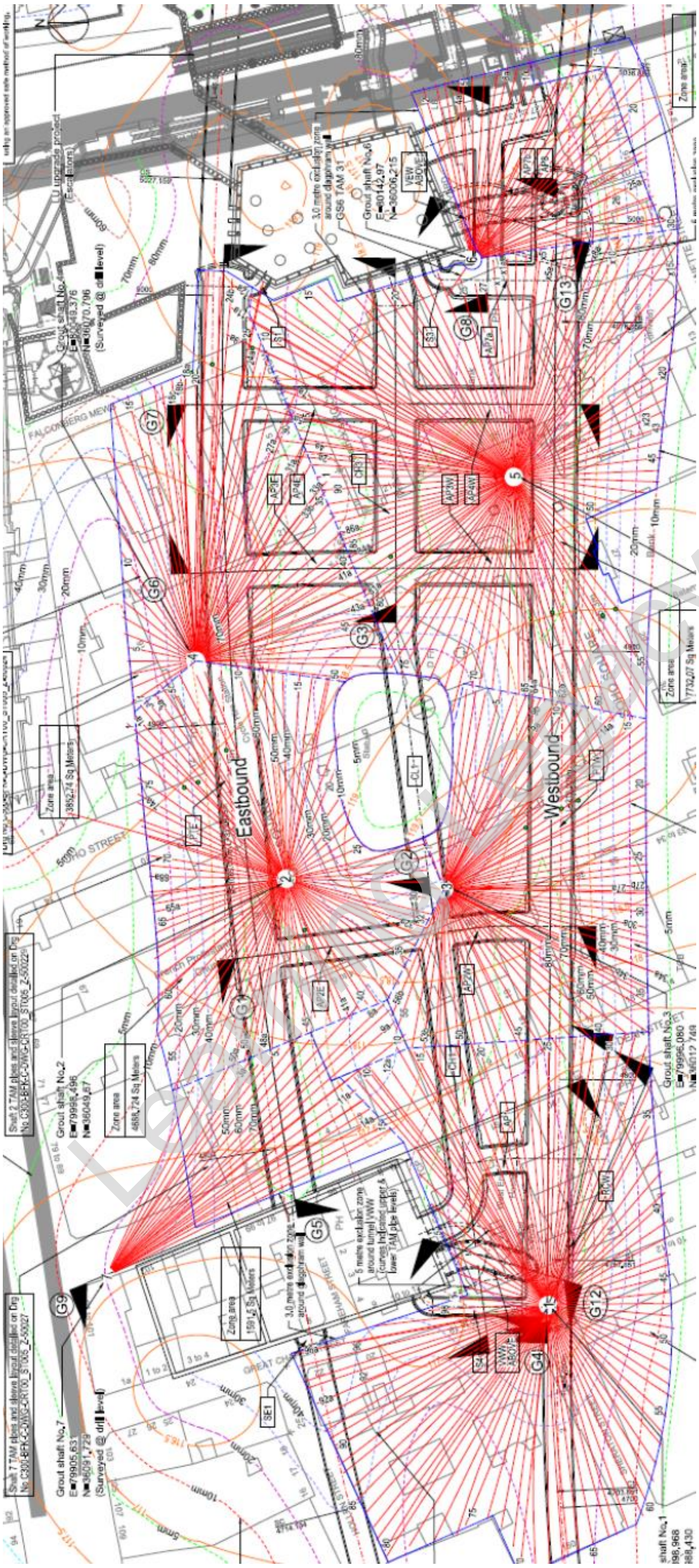
KX10.2113 Final Report

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.

Figure 1.2 General Shafts Location Plan (reproduced from C300-BFK-C-DWG-CRT00_ST005_Z-50020)



2. CONSTRUCTION WORKS PROGRESS

2.1. Tunnels

Table 2.2 and Figure 2.1 show the tunnel construction works undertaken within the footprint of the compensation grouting arrays installed from Grout Shaft 1 at TCR Station. Tunnel excavation commenced with CH1 Pilot in mid February 2013 and was completed in May 2014 for the low level tunnels. Permeation grouting and excavation of VWW was completed in September 2014. To facilitate comparison of monitoring data with construction activities, 7 periods (A to G) have been assigned. Tunnelling was completed in 4 of these periods (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 works at TCR GS1 area

PERIOD	TUNNEL	ABB.	START DATE	END DATE
Period C	CH1 Pilot	CH1P	12/02/2013	27/02/2013
	CH1 Enlargement	CH1E	01/03/2013	23/03/2013
	CH1 Extension	CH1Ext	05/05/2013	21/05/2013
	Access Passage 1	AP1	02/04/2013	25/04/2013
Period D	Westbound Running Tunnel	WBRT	22/05/2013	02/06/2013
	Eastbound Running Tunnel	EBRT	25/07/2013	29/07/2013
Period E	Platform Tunnel Westbound	PTW	04/12/2013	16/12/2013
	Platform Tunnel Westbound 2	PTW 2	22/03/2014	29/04/2014
	Sevices Adit 4	S4	11/05/2014	19/05/2014
Period F	Ventilation Tunnel West Westbound	VWW	30/08/2014	14/09/2014

2.2. Other construction works

Works by BFK prior to the commencement of tunnelling included:

- Sinking of Grout Shaft 1
- Drilling for installation of TaMs
- Pre-treatment grouting
- Excavation of Western Ticket Hall (WTH) south box

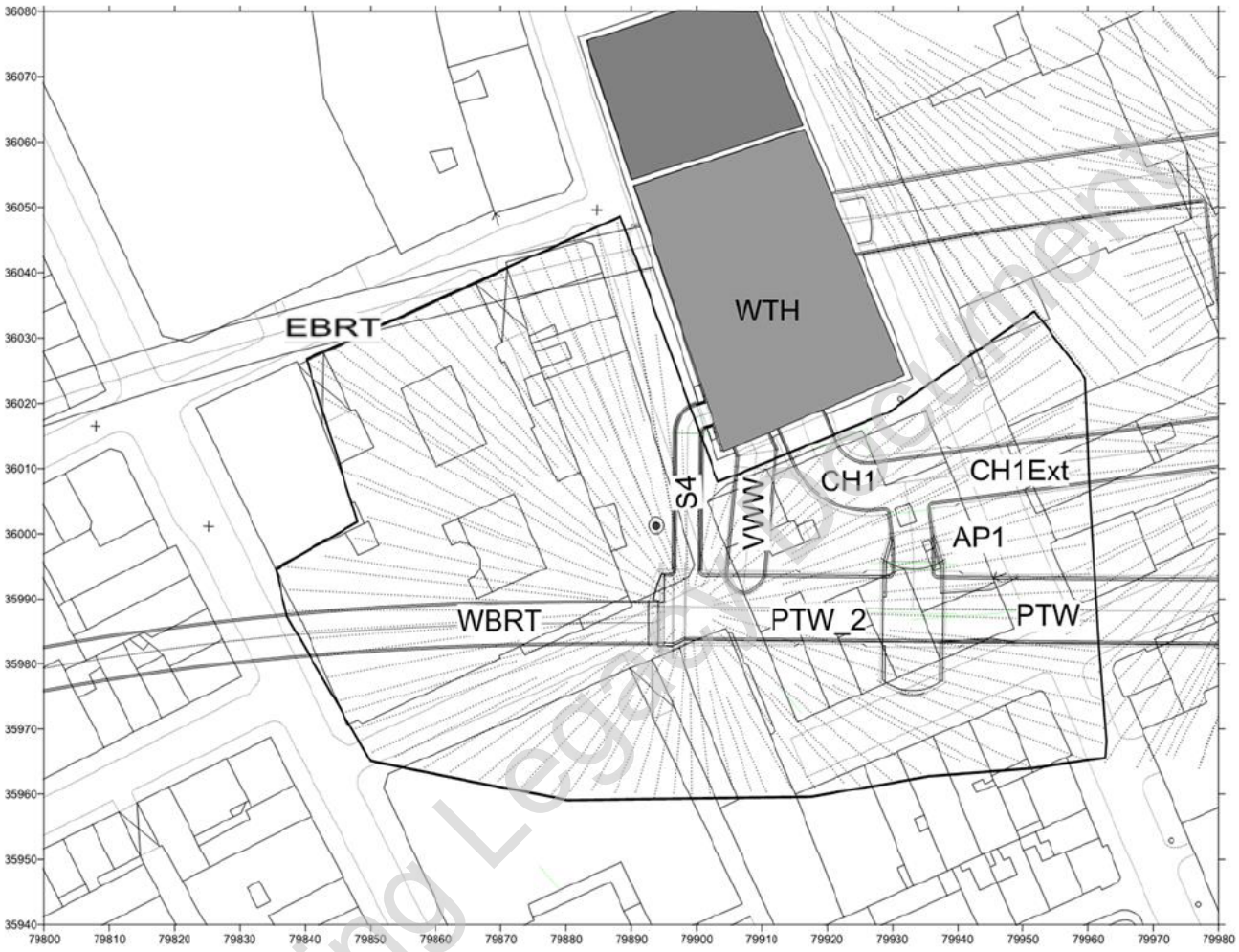
Works by Others prior to the start of tunnelling included:

- Construction of Western Ticket Hall (WTH) diaphragm-walls and piles

Works by Others during and after tunnelling:

- C422 works: construction of permanent internal structure and removal of temporary props in WTH
- Various building re-developments

Figure 2.1. Tunnels within extent of grout array from Grout Shaft 1



2.3. Compensation Grouting

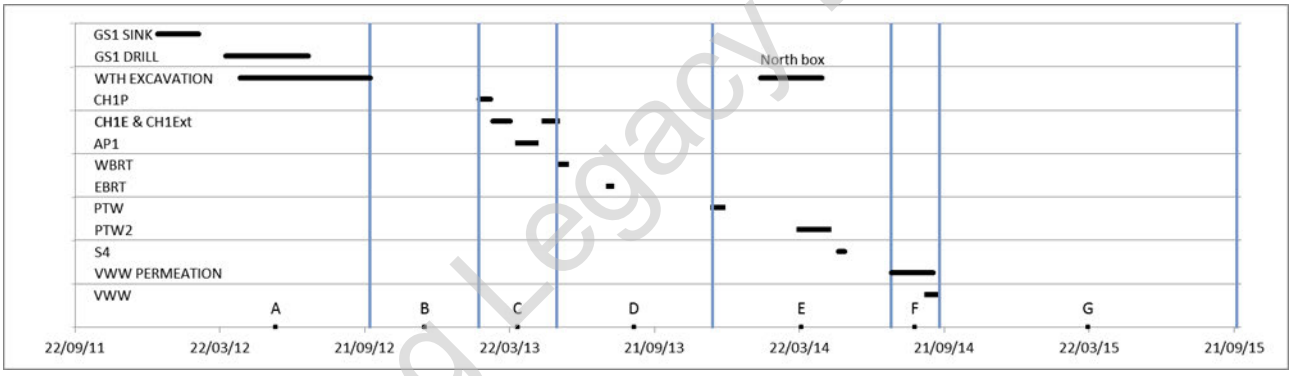
The volume of grout injected from TCR GS1 is plotted against time on Figure 2.2 together with a plot of when each of the tunnels was constructed. Figure 2.2 shows that pre-treatment comprised approximately 50m^3 injected prior to tunnelling, concurrent grouting over 170m^3 and grout jacking almost 40m^3. A VE proposal was implemented to avoid any delays to the running tunnel drive (WBRT) which allowed grouting to be undertaken pre- and post-tunnelling (C300-PMI-00434) – the volume of grout associated with this is included under grout jacking. No concurrent grouting was undertaken with S4 or VWW: the former due to its small diameter and the latter since it is at a higher elevation than the other tunnels and it intercepted a number of the TaMs installed from GS1 adjacent to the WTH wall. Based on an assessment of the expected volume loss settlement from VWW and the settlements recorded prior to its excavation, it was concluded that no grout jacking was required prior to its excavation (C410-RFI-001308).

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 TCR GS1 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.

Table 2.2 Construction Periods for works in TCR GS1 area

Period	Start Date	End Date	Main Works
A	30/09/2011	28/09/2012	GS1 Sink, GS1 TaM installation, WTH excavation, Pre-treatment
B	28/09/2012	12/02/2013	Pre-treatment, Grout Jacking
C	12/02/2013	21/05/2013	CH1P, CH1E, CH1Ext; AP1, concurrent grouting, Grout Jacking
D	21/05/2013	03/12/2013	WBRT, EBRT, Grout Jacking
E	03/12/2013	16/07/2014	PTW, PTW2, S4, WTH north box concurrent grouting, Grout Jacking
F	16/07/2014	15/09/2014	VWW permeation, VWW
G	15/09/2014	30/09/2015	Post Construction

Figure 2.2 Volume of grout injected from TCR GS1 by grouting type.



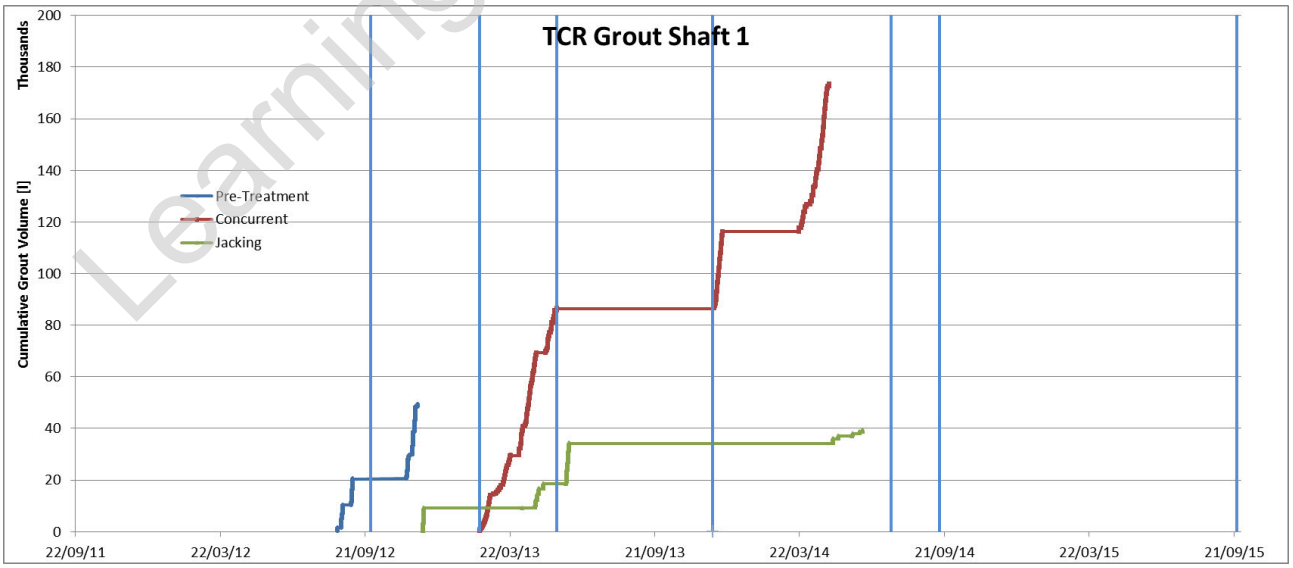


Figure 2.3 Distribution of grout injected from TCR GS1: Pretreatment grouting. Grout Intensity (mm).

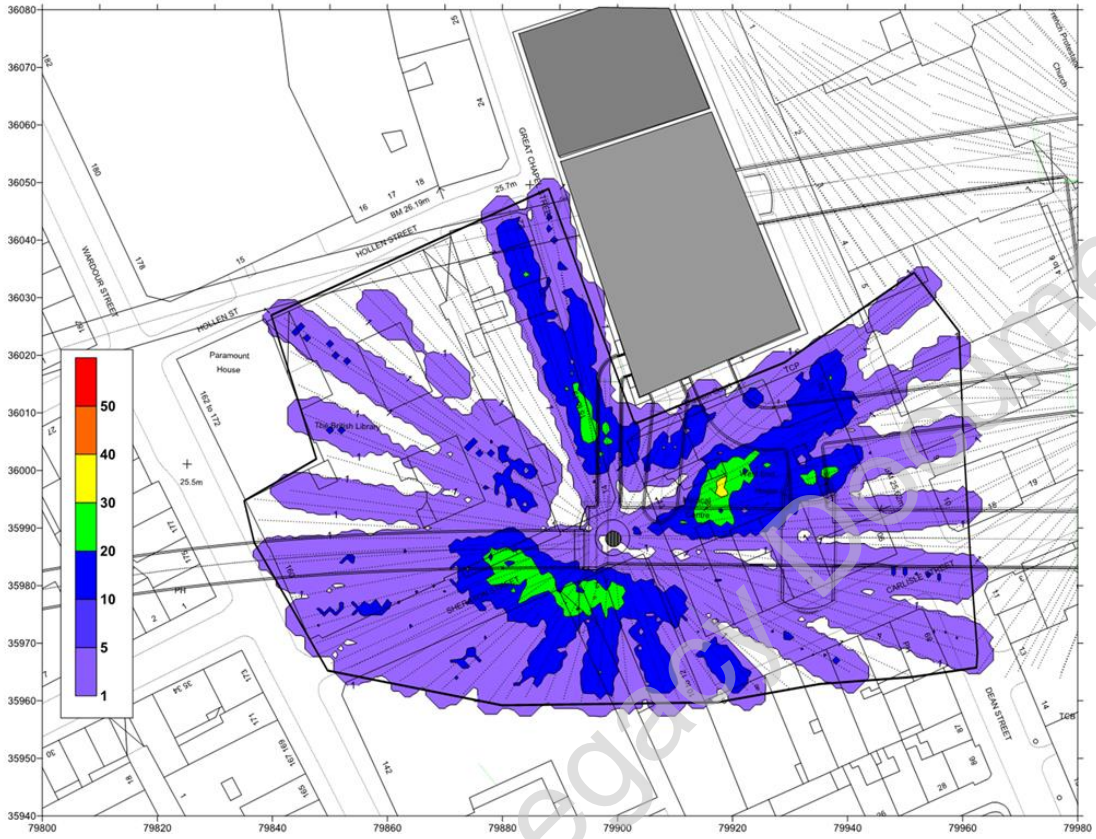


Figure 2.4 Distribution of grout injected from TCR GS1: Concurrent grouting. Grout Intensity (mm).

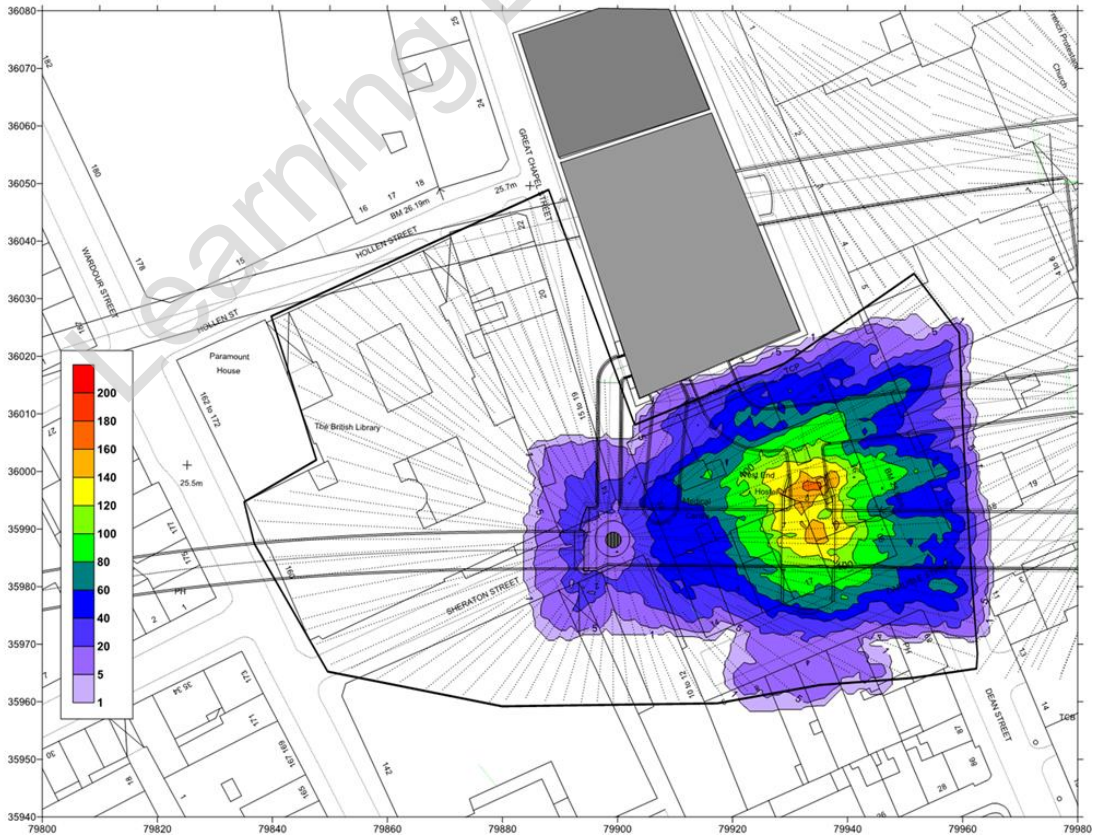


Figure 2.5 Distribution of grout injected from TCR GS1: Jack grouting. Grout Intensity (mm).

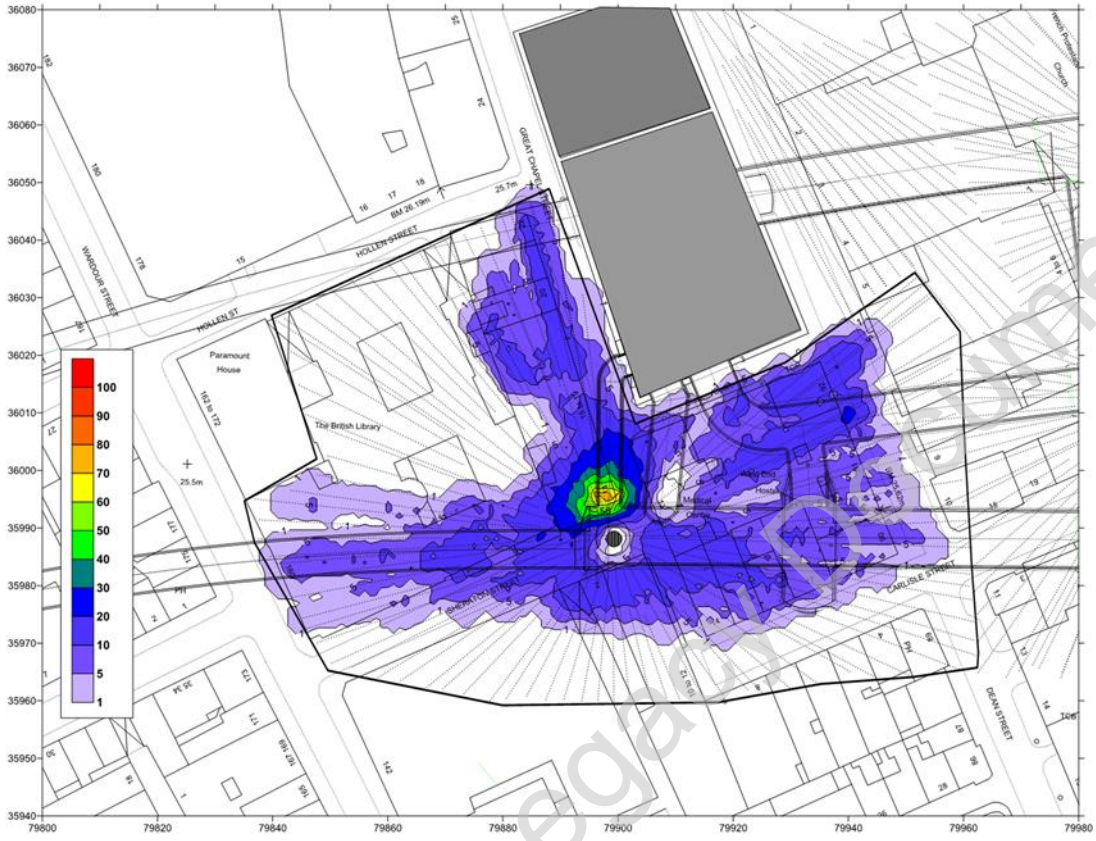
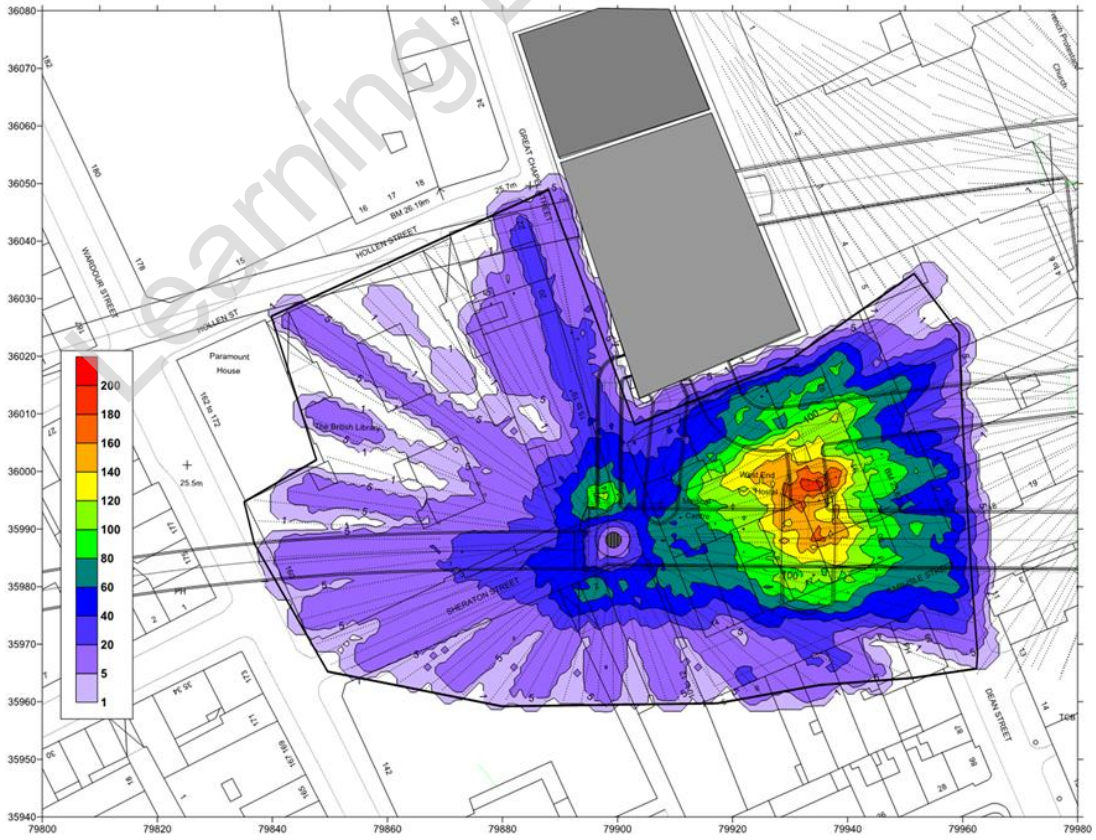


Figure 2.6 Distribution of grout injected from TCR GS1: All grouting. Grout Intensity (mm).



3. COMPARISON OF OBSERVED AND PREDICTED SETTLEMENT

3.1. Settlement Overview

Settlement contours have been generated showing the total settlement at the end of each Construction Period and the change in settlement during the Period. The latter is compared to the calculated volume loss settlement contour generated using the specified maximum values. The effect of the WTH excavation has been calculated using simple empirical methods.

Contours of total predicted short term greenfield settlement (supplied on C122) are shown in Figure 3.1.1. The measured settlement at the end of excavation in September 2014 (Period F), including consolidation settlement during the period of construction, is shown in Figure 3.1.2.

The following points are noted:

- Settlements were generally less than 50% of the predicted values, notwithstanding that the observed movements include the consolidation settlement over the construction period.
- The maximum settlement contour for the observed movements is 30mm compared to a calculated value of 80mm.
- The location of the maximum recorded settlement is similar to that predicted.
- The observed contours are much more widely spaced than predicted, implying slopes have been significantly reduced over the whole area.

Figure 3.1.1 Predicted greenfield settlement contour (supplied by C122)

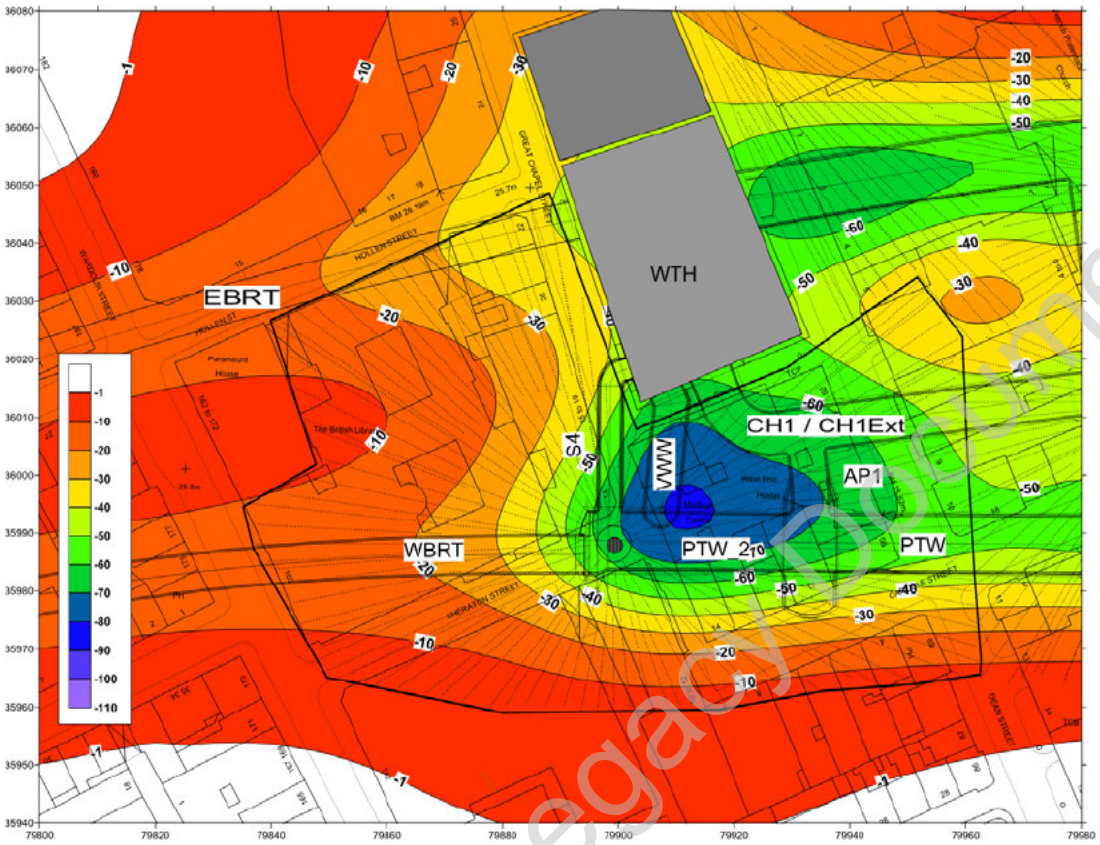
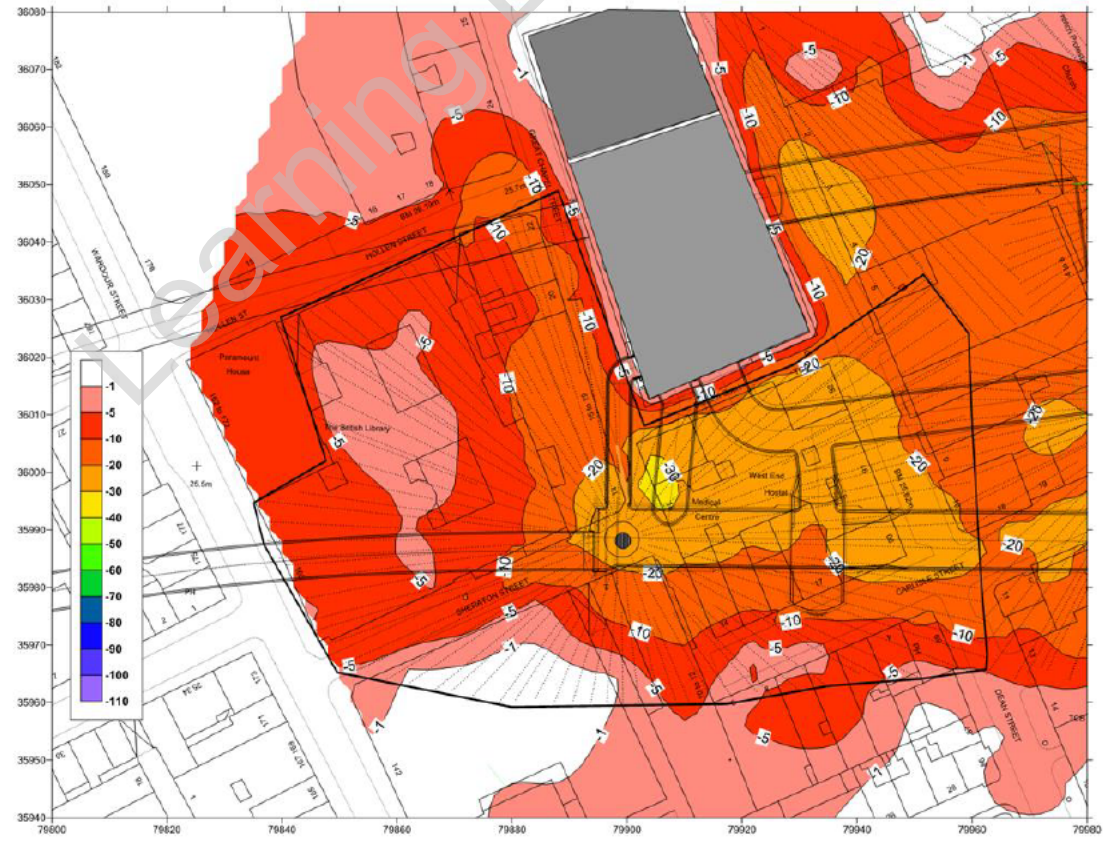


Figure 3.1.2 Observed settlement contour in September 2014 (End of Construction – Period F)



In order to compare the predicted and actual movements at various stages of construction, the overall monitoring period from September 2011 to the cessation of general monitoring (under C300-PMI-01858) in September 2015 has been divided into a number of periods, based largely on tunnel excavation. The dates of construction activities in each period are summarised in Table 2.2.

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

3.2. Period A – 30/09/11 – 28/09/12 GS1 sink, Tam drilling, WTH excavation, Pre-treatment

BFK's preparatory work undertaken in Period A prior to the commencement of tunnelling, comprised GS1 sinking, the drilling and pre-treatment of TaMs from TCR GS1 and excavation of the South Box of the Western Ticket Hall. Adjustments have been applied to the BFK monitoring based on the contour shown in Figure 3.2.1 which shows the settlement recorded by C421 at completion of their works (surveys on 08/02/12 and 09/02/12): the effects within the GS1 area are generally less than 5mm.

The calculated short term movements associated with the wall installation and excavation of the South Box of the Western Ticket Hall are shown in Figure 3.2.2 (as supplied by C122). Greatest settlement is near the WTH d-walls, where ~20mm settlement is indicated.

The observed settlements at the end of Period A (based on data adjusted to allow for movements prior to the start of BFK monitoring) are shown on Figure 3.2.3. Pre-treatment was partly completed in Period A: a grout intensity contour is shown in Figure 3.2.4.

A maximum settlement of 12mm was produced by the end of Period A, lower than the predicted ~20mm settlement for excavation of the South Box.

Figure 3.2.1 Contours of settlement at completion of C421 works (based on C421 surveys 08 & 09/02/12)

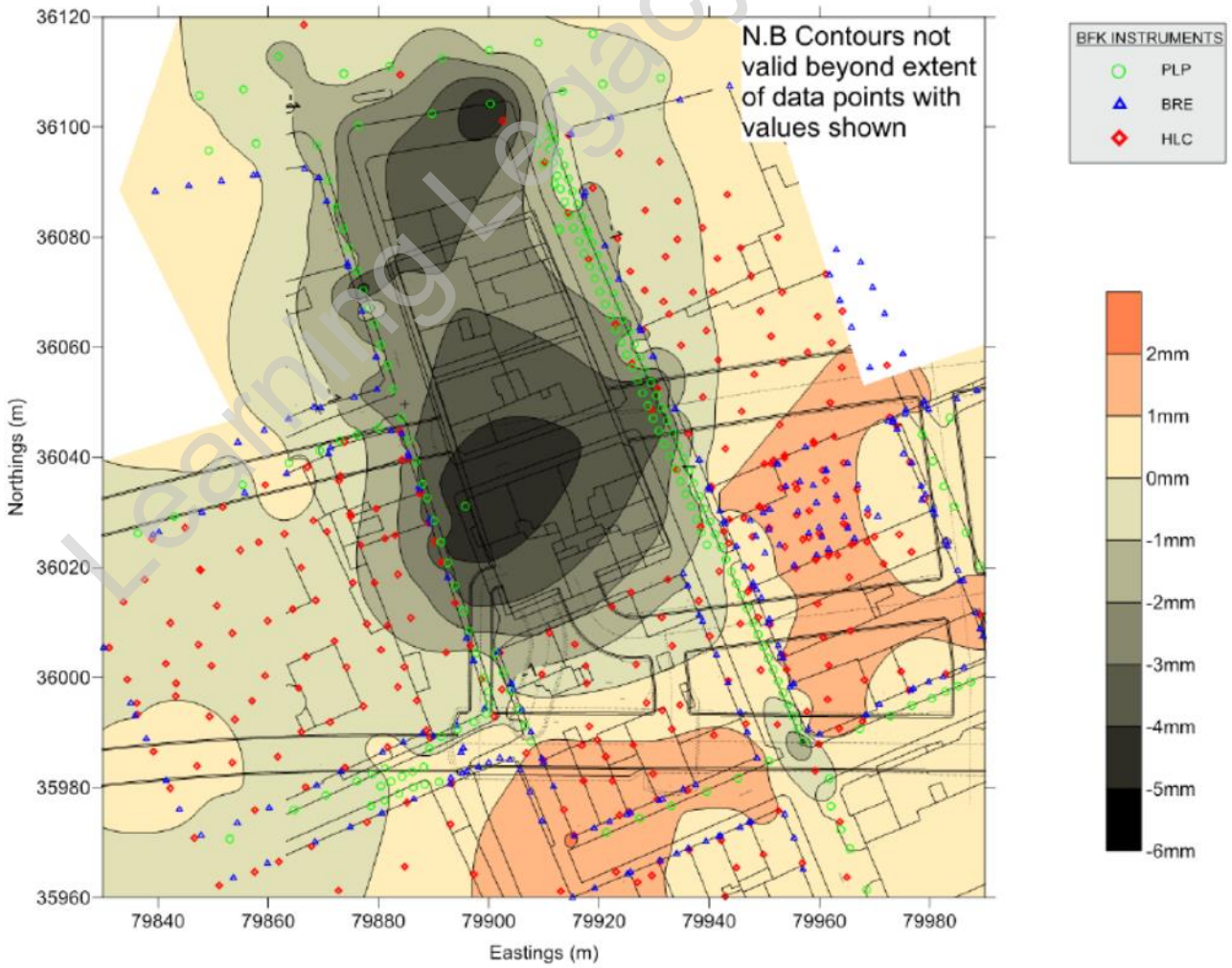


Figure 3.2.2 Period A: Total predicted greenfield settlement (supplied by C122)

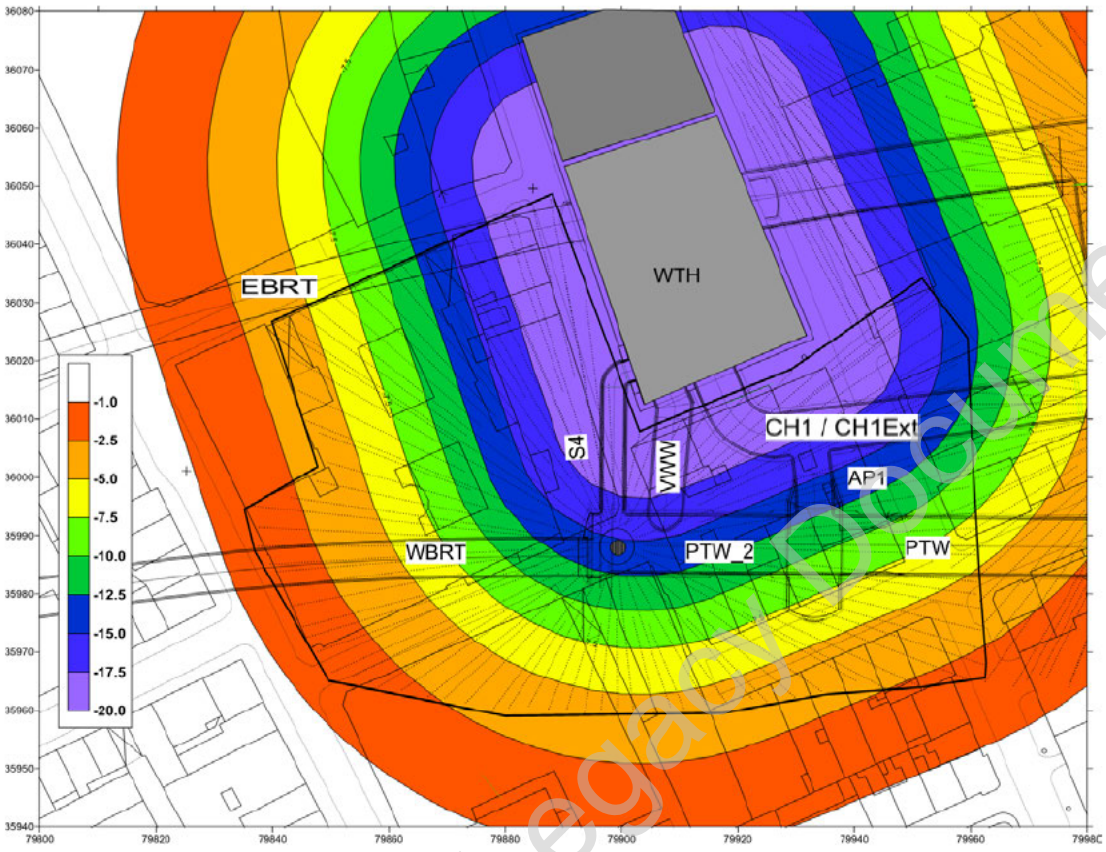


Figure 3.2.3 Period A: Total measured settlement

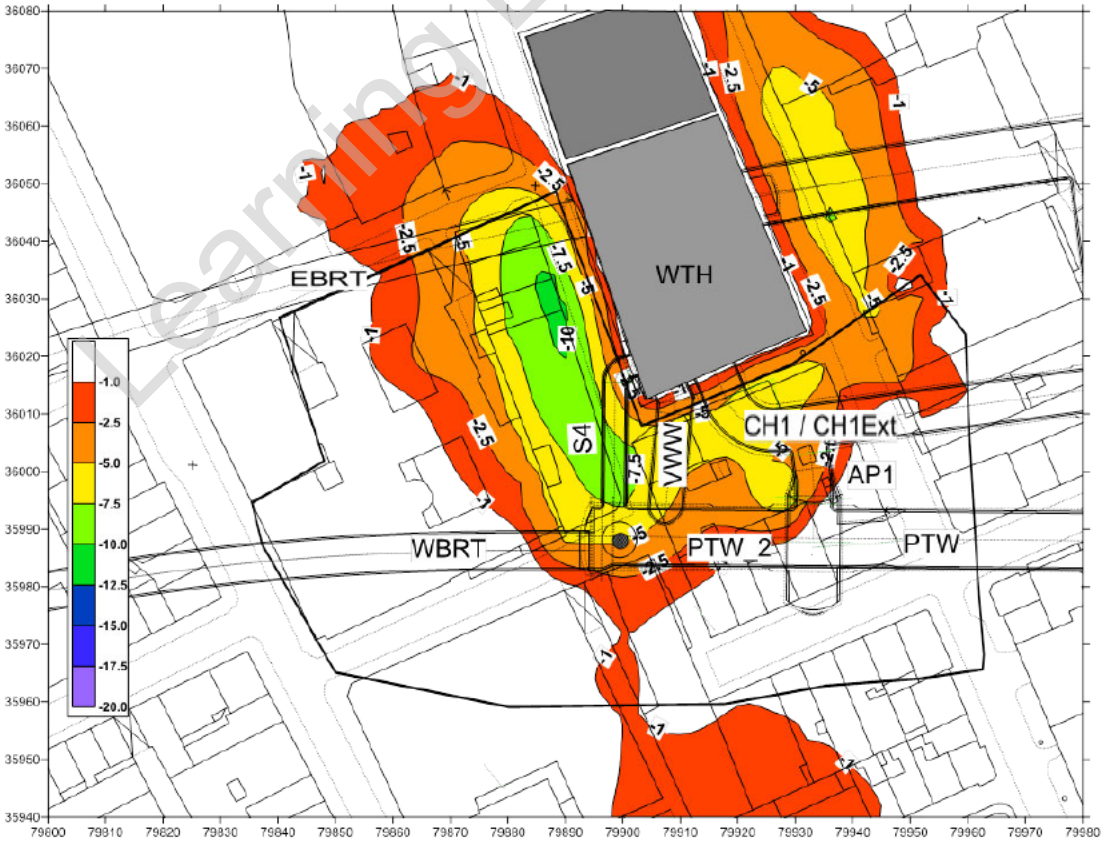
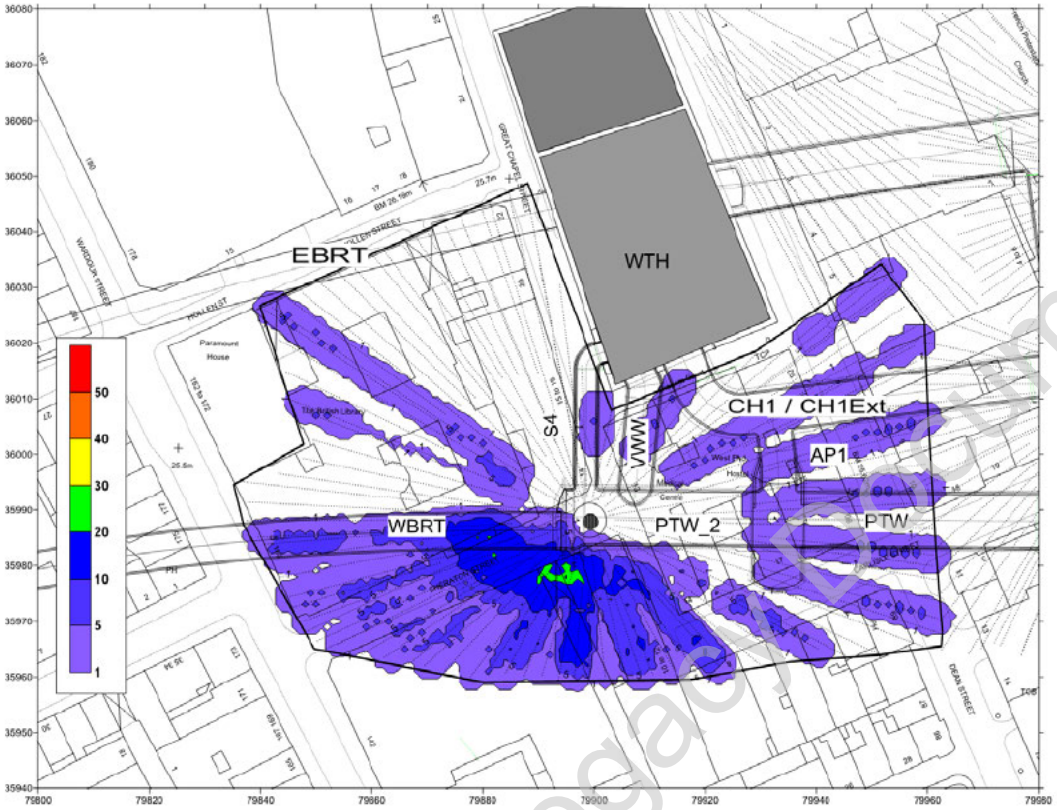
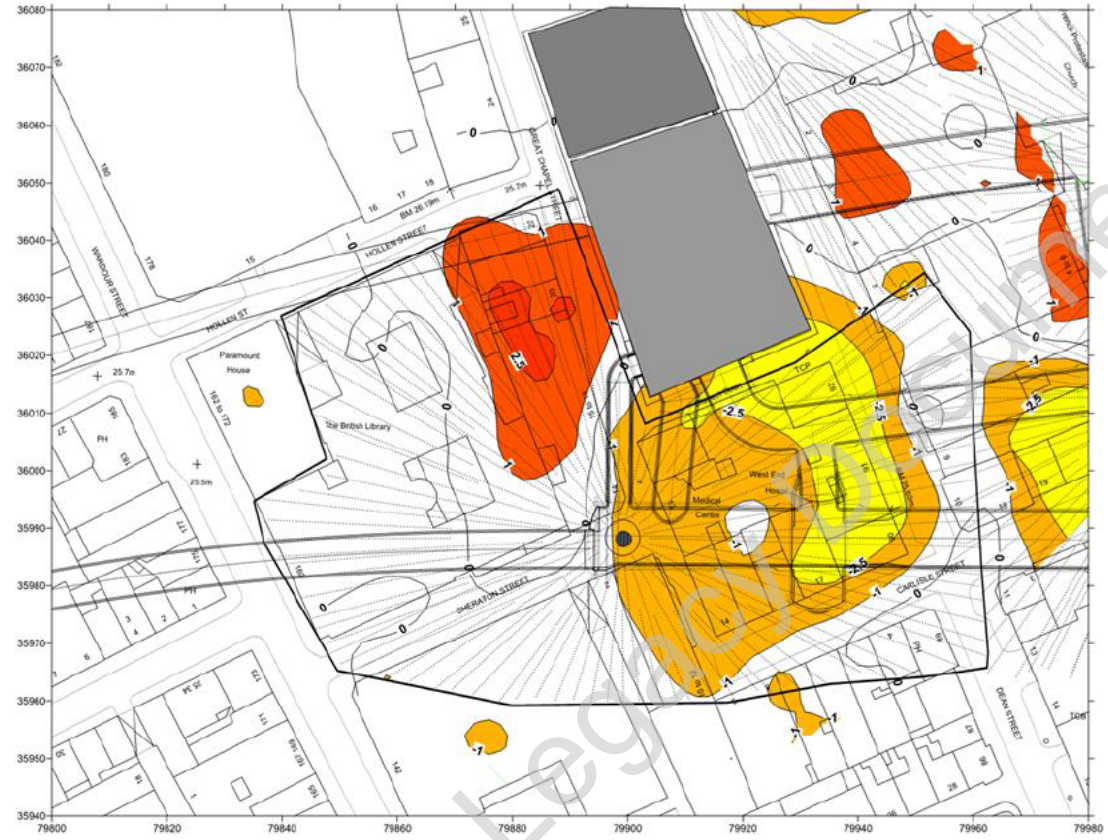


Figure 3.2.4 Distribution of grout injected from TCR GS1 Period A: Pretreatment grouting. Grout Intensity (mm).



3.3. Period B: 28/09/12 – 12/02/13: Pre-treatment, Grout Jacking

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



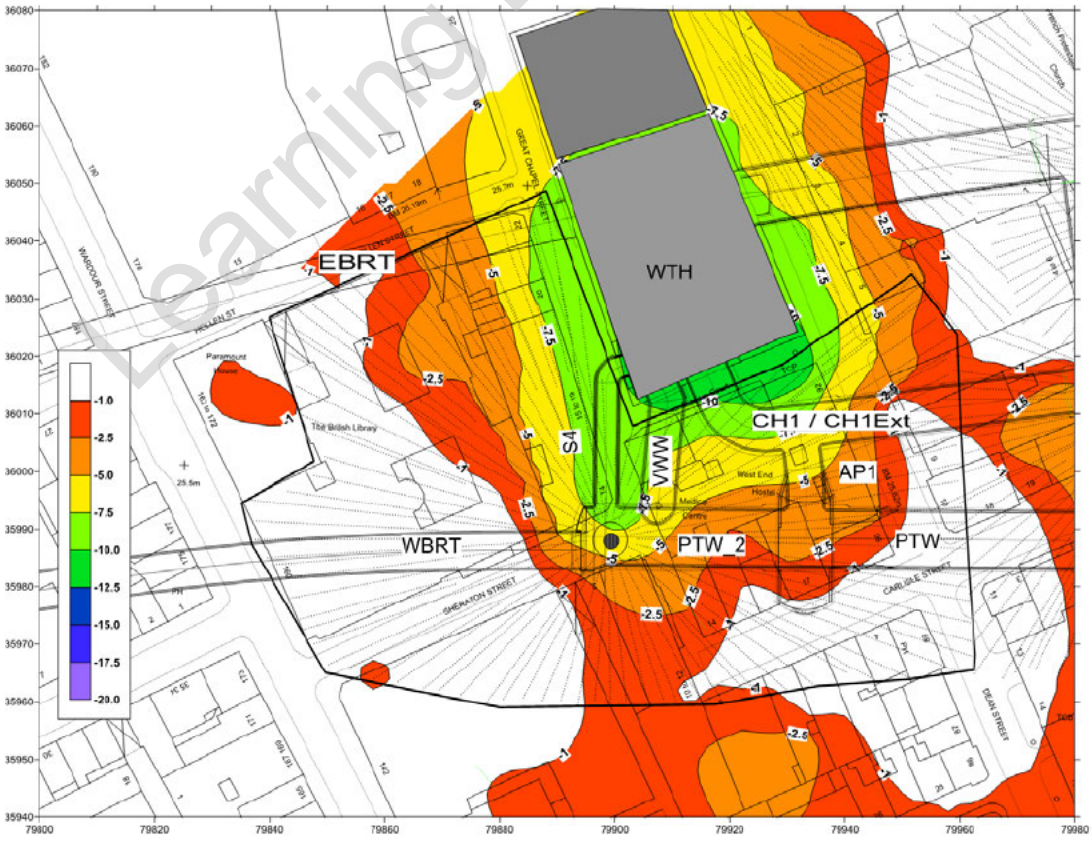


Figure 3.3.2 Period B: Distribution of grout injected from TCR GS1: Pre-treatment grouting. Grout Intensity (mm).

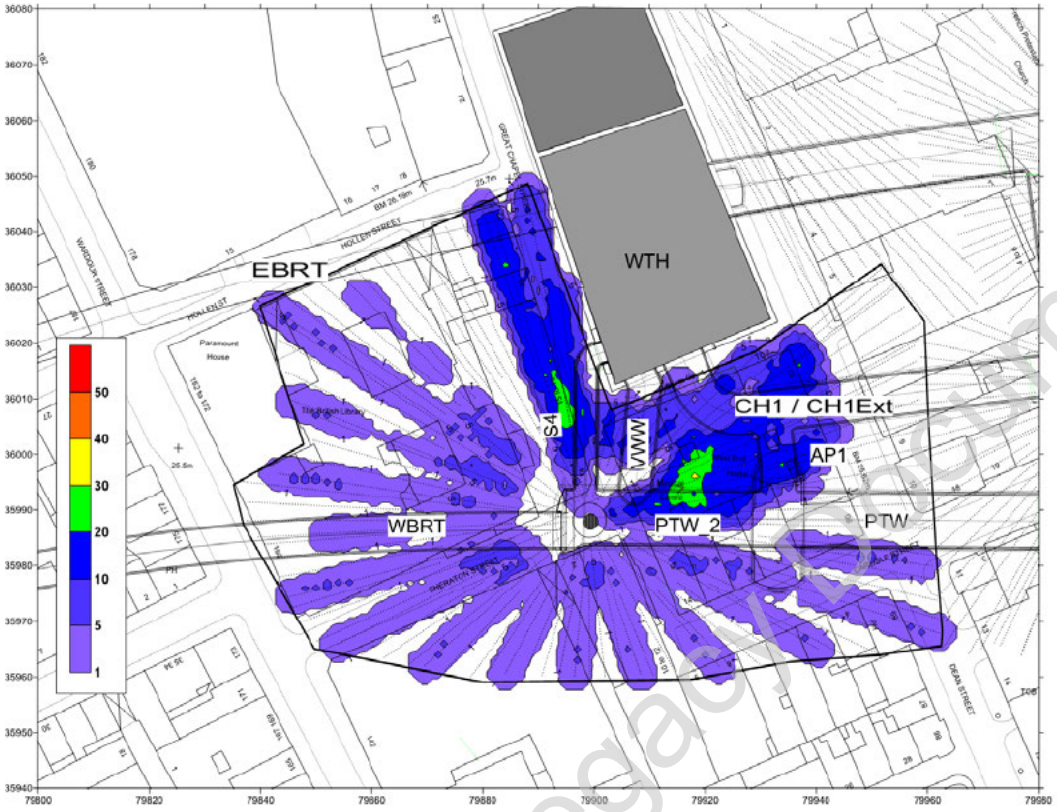


Figure 3.3.3 Period B: Distribution of grout injected from TCR GS1: Grout jacking. Grout Intensity (mm).

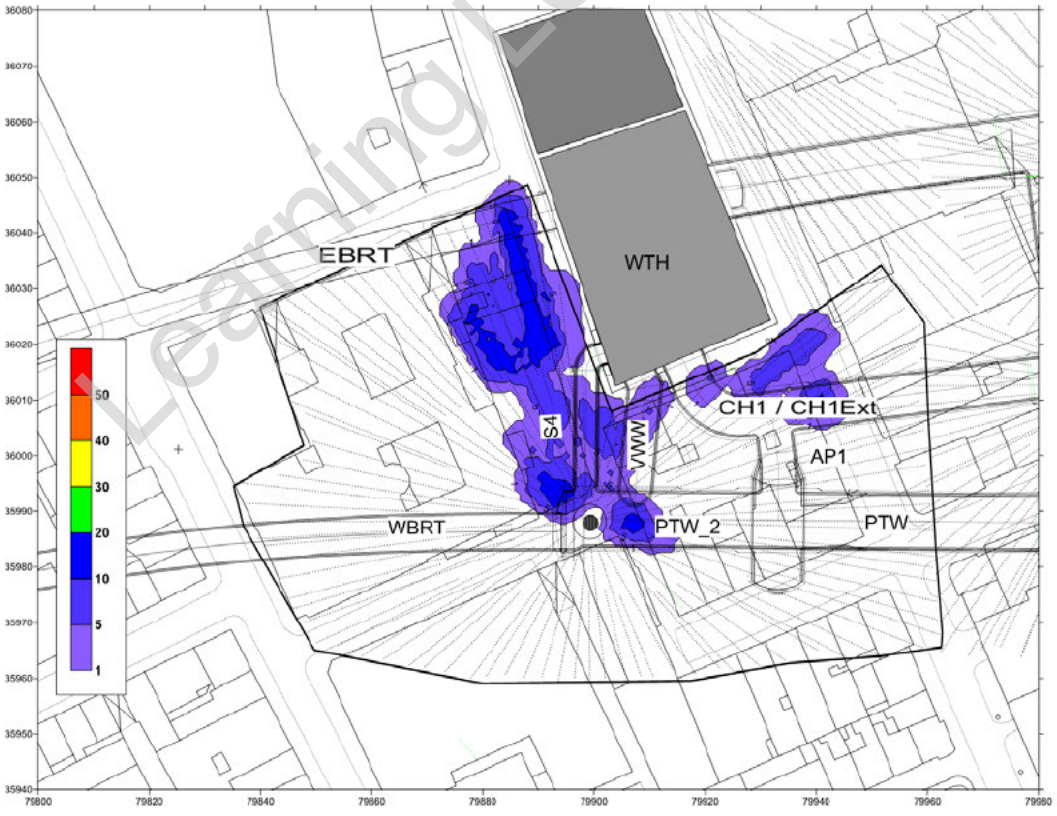


Figure 3.3.1(a) shows that only small movements developed during Period B. Since there was no excavation in Period B, the settlements are most probably due to consolidation. The measured heave resulted from the pre-

treatment and the jack grouting passes carried out during the period. The maximum settlement during the period was about 3mm, the maximum heave was about 3mm.

The total settlement shown in Figure 3.3.1(b) has a similar distribution to that at the end of Period A.

Figures 3.3.2 and 3.3.3 show the pre-treatment and jack grouting undertaken during the period in terms of grout Intensity: the intensity of the pre-treatment was varied to reflect the observed settlements.

3.4. Period C: 12/02/13 – 21/05/13: CH1P, CH1E, CH1Ext, AP1, Concurrent & Grout Jacking

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

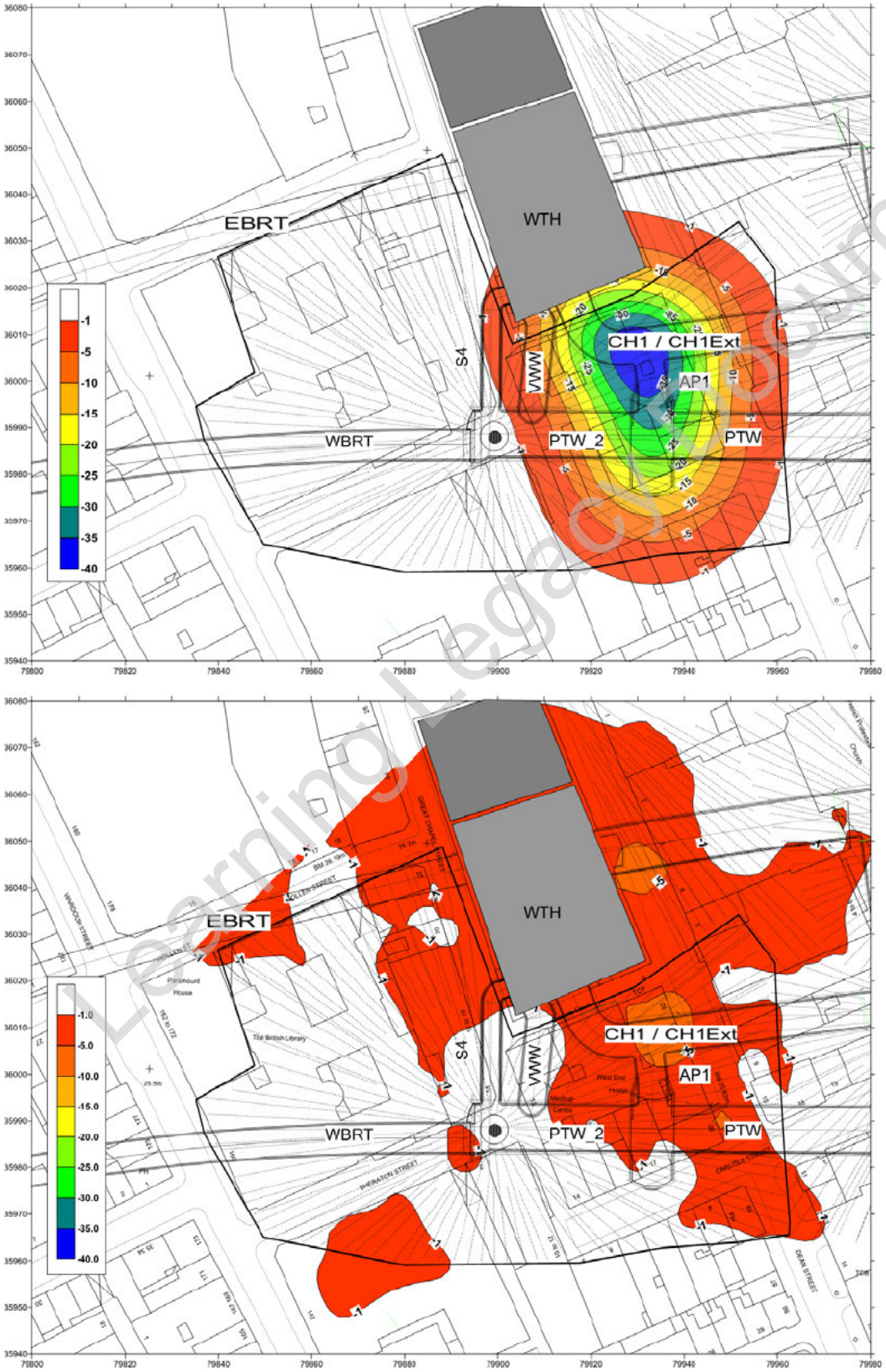


Figure 3.4.2 Period C: Distribution of grout injected from TCR GS1: Concurrent grouting. Grout Intensity (mm).

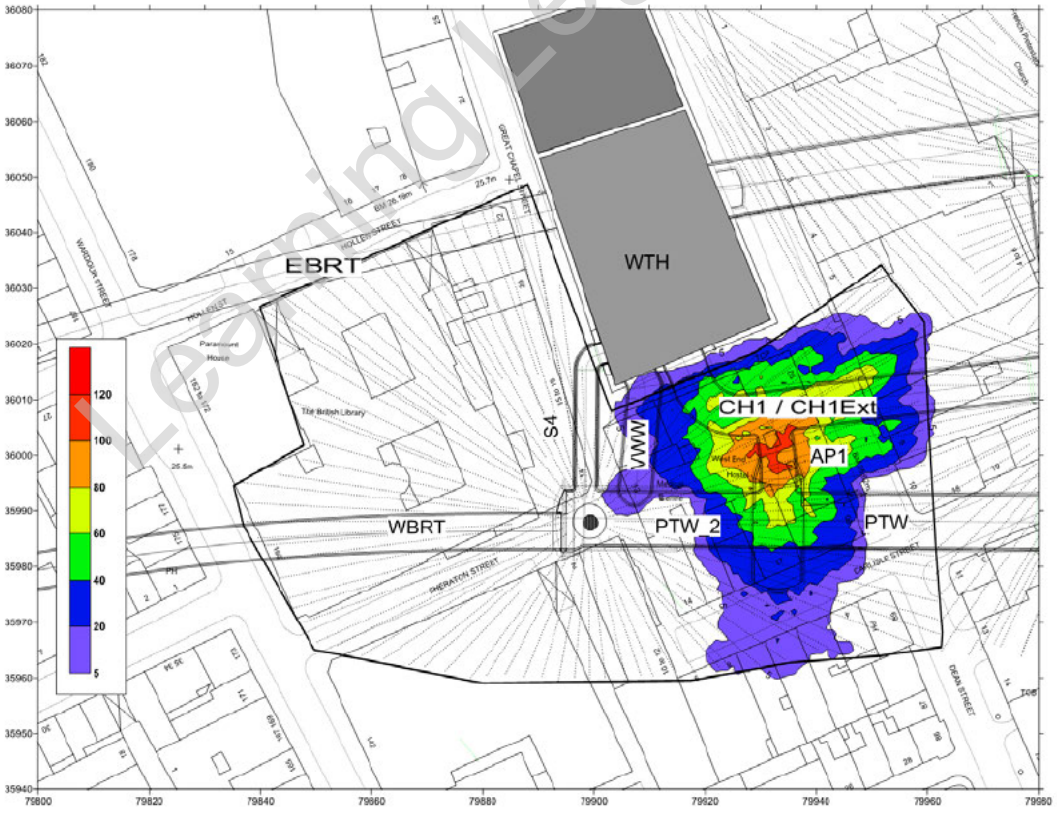


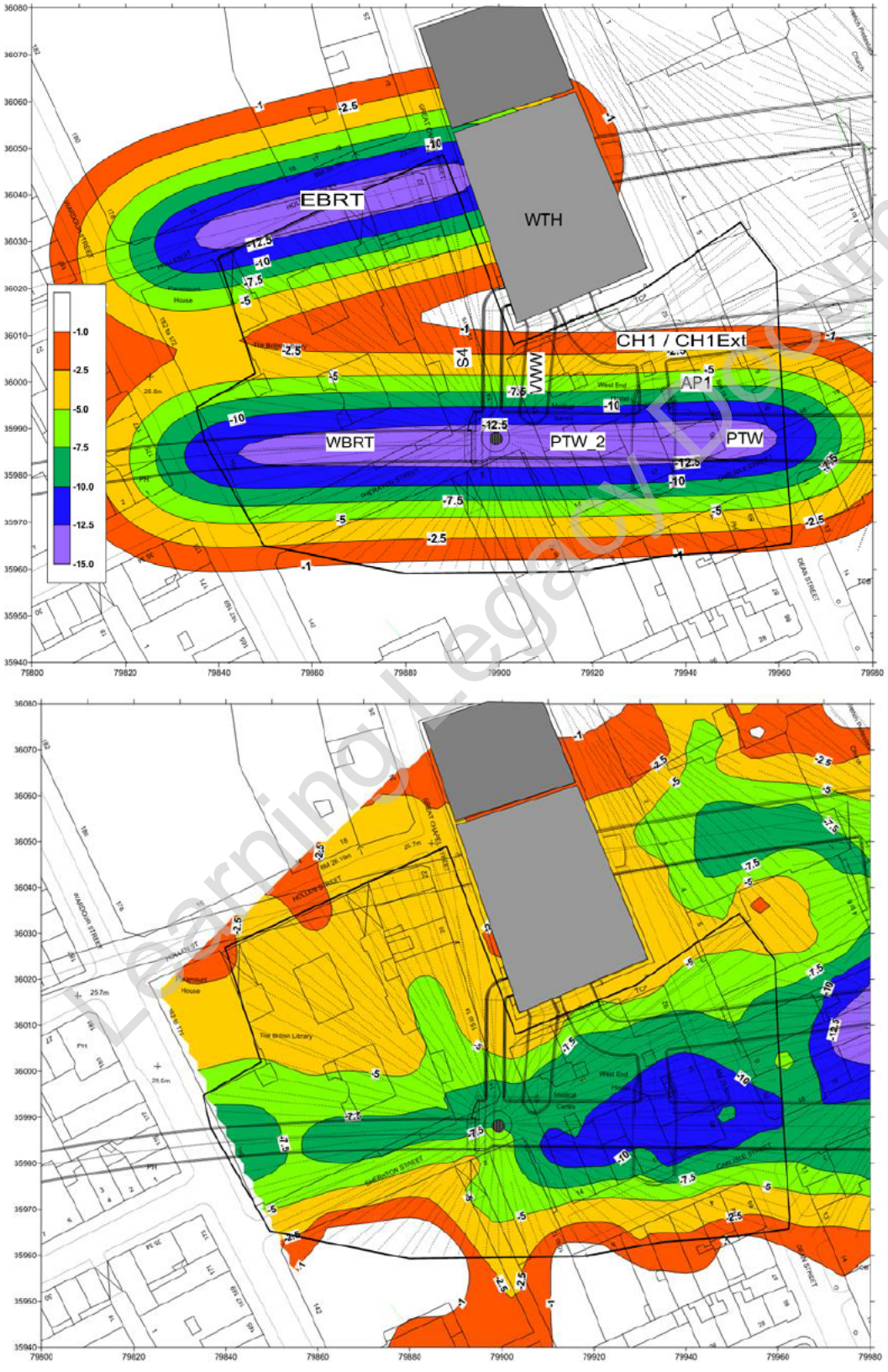
Figure 3.4.3 Period C: Distribution of grout injected from TCR GS1: Grout jacking. Grout Intensity (mm).

Figure 3.4.1(a) shows that up to 40mm volume loss settlement was calcuated from excavation of AP1 and CH1 tunnels.

Figure 3.4.1(b) shows the recorded settlement with a maximum increase of less than 10mm due to the tunnelling works which gave a maximum total settlement contour at the end of Period C of 15mm (Figure 3.4.1(c)). This was a result of the execution of concurrent grouting during tunnelling and a grout jacking episode over the junction between CH1 and AP1 (see Figures 3.4.2 and 3.4.3). Pre-heave grout jacking for the WBRT was also undertaken to the west of the shaft, as shown on Figure 3.4.3.

3.5. Period D: 21/05/13 – 03/12/13: WBRT, EBRT, Grout Jacking

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



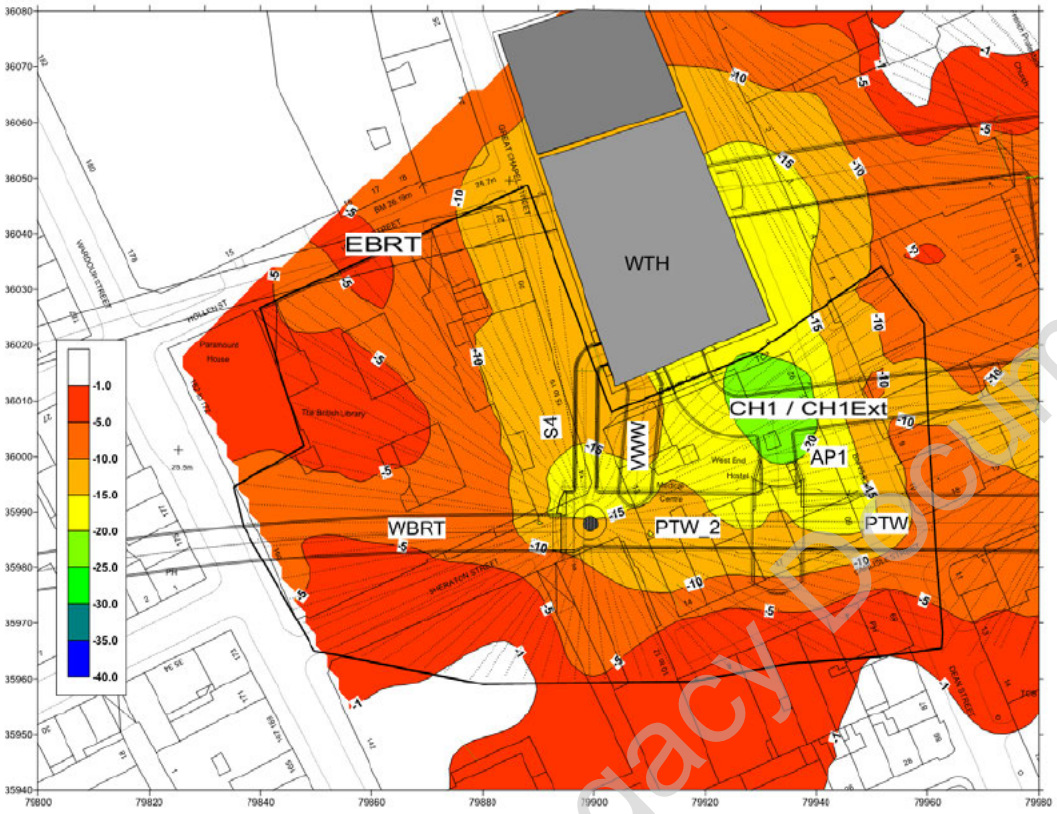
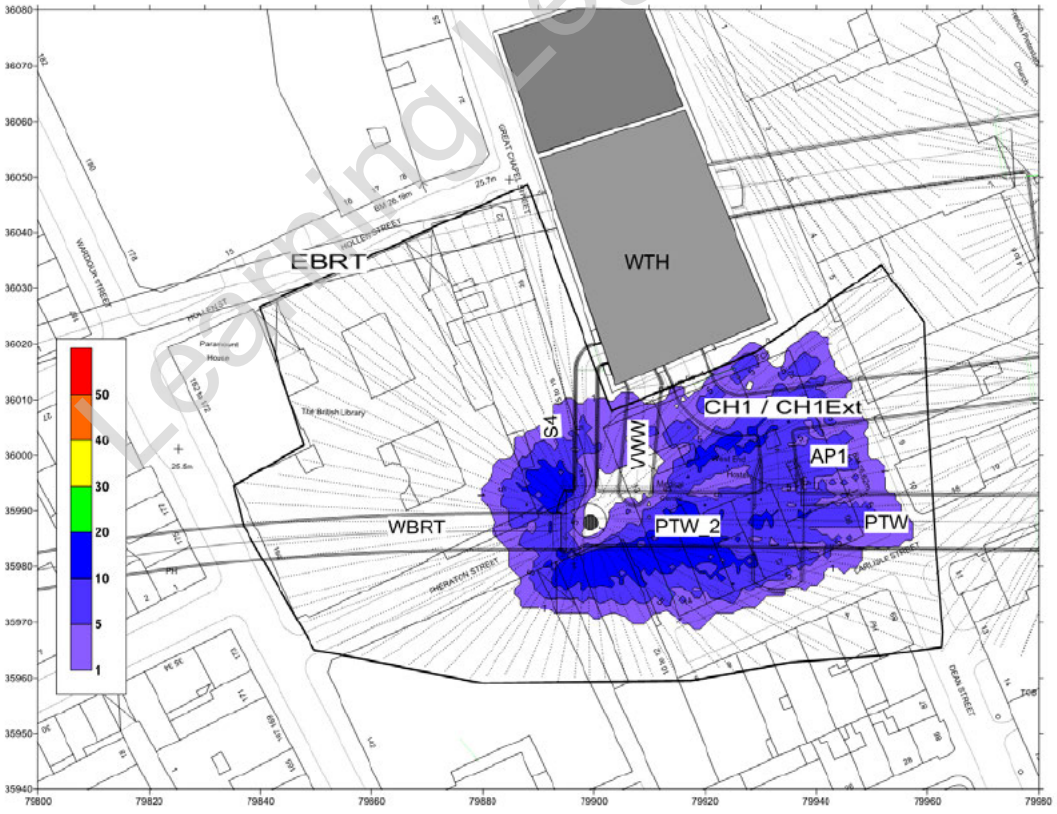


Figure 3.5.2 Period D: Distribution of grout injected from TCR GS1: Grout jacking. Grout Intensity (mm).



Both WBRT and EBRT drives progressed into the TCR station area during Period D. The WBRT and the EBRT had maximum predicted volume loss settlement (C122) within the GS1 area of about 14mm. The maximum measured settlement in Period D was about 11mm over the WBRT in proximity to the previously constructed SCL tunnels. The WBRT was constructed through the GS1 area over about 10 days at the start if Period D and, consequently, the movements shown include consolidation over the remaining 6 months of Period D.

Over the remainder of the WBRT settlement was less than 10mm and over the EBRT settlement was less than 5mm.

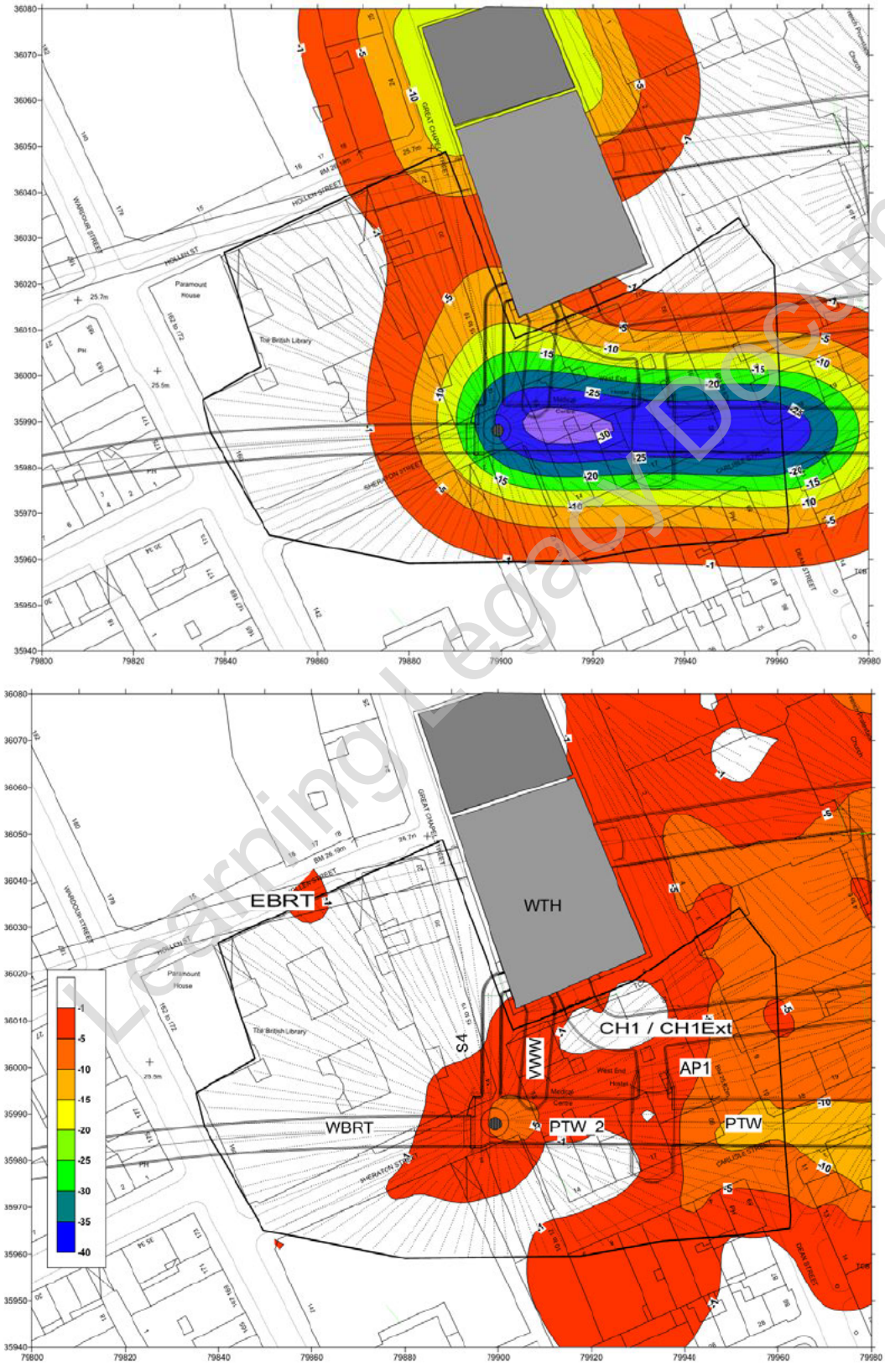
The maximum measured absolute settlement at the end of Period D was about 22mm, centred over the junction between CH1 and AP1 as shown in Figure 3.5.1(c).

No concurrent grouting was carried out during the WBRT or EBRT drives.

A grout jacking episode was undertaken following the WBRT drive which was targeted at the areas of maximum settlement as shown in Figure 3.5.2.

3.6. Period E: 03/12/13 – 16/07/14: PTW, PTW2, S4, North Box, Concurrent & Grout Jacking

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



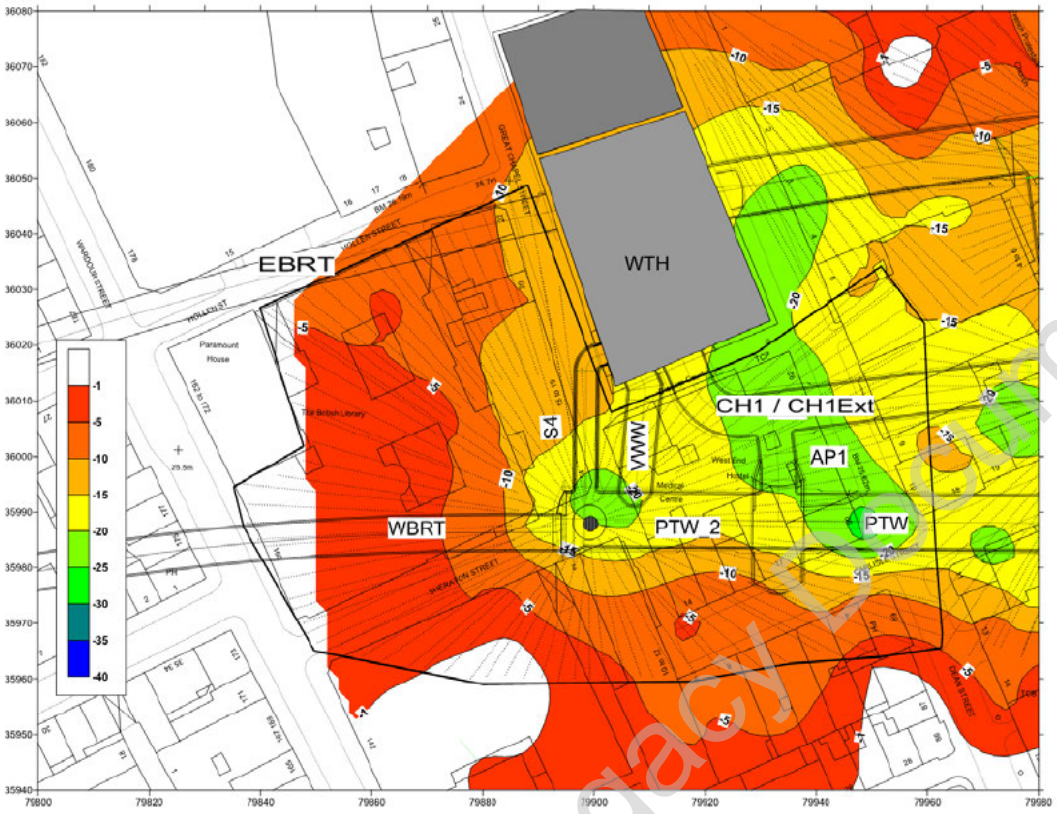


Figure 3.6.2 Period E: Distribution of grout injected from TCR GS1: Concurrent Grouting. Grout Intensity (mm).

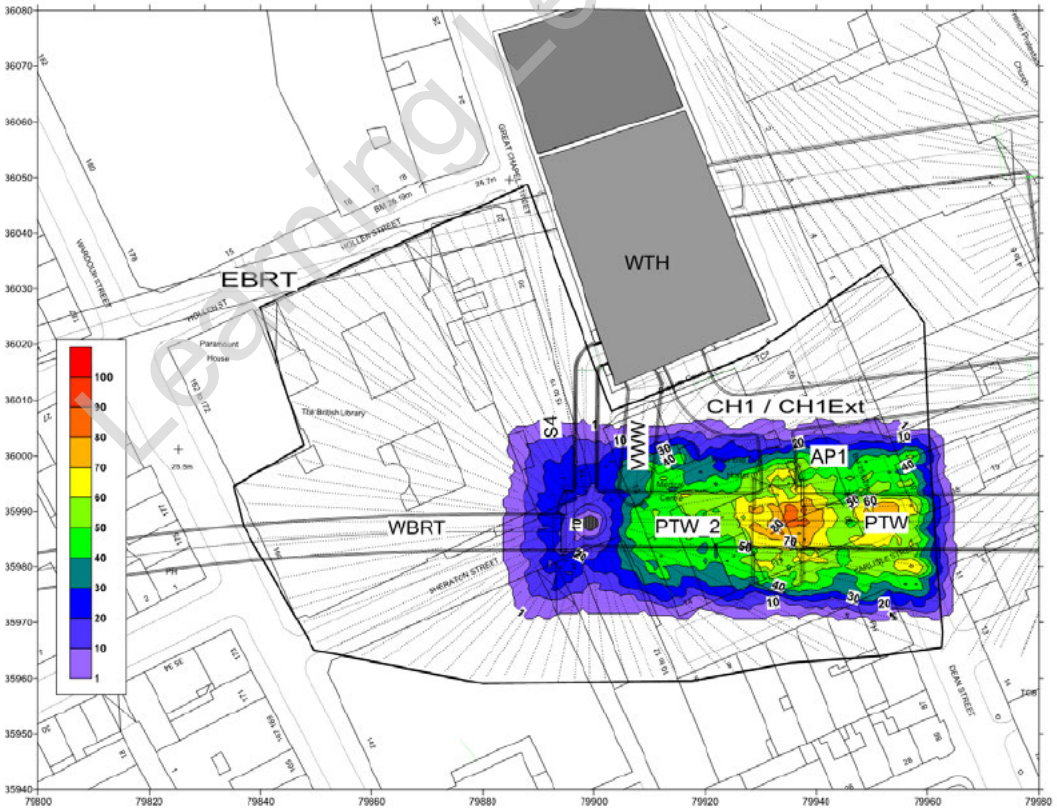


Figure 3.6.3 Period E: Distribution of grout injected from TCR GS1: Grout jacking. Grout Intensity (mm).

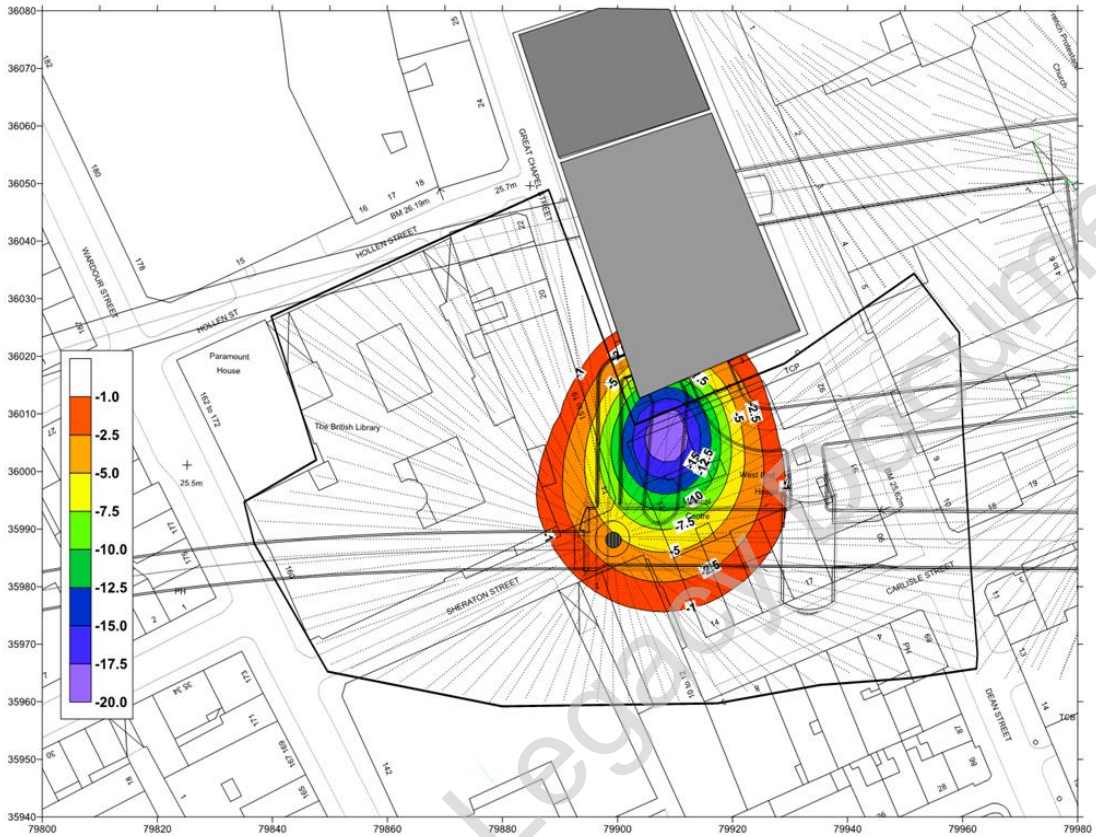
The predicted maximum displacement from volume loss calculation was over 30mm for PTW2, with up to 10mm at the north extremity of the GS1 arrays due to the WTH north box. However, as shown on Figure 3.6.1(b), the maximum displacement recorded due to the SCL tunnelling activities during Period E was ~12mm over PTW at the east end of the GS1 area. No impact is evident in Figure 3.6.1(b) from the WTH north box excavation.

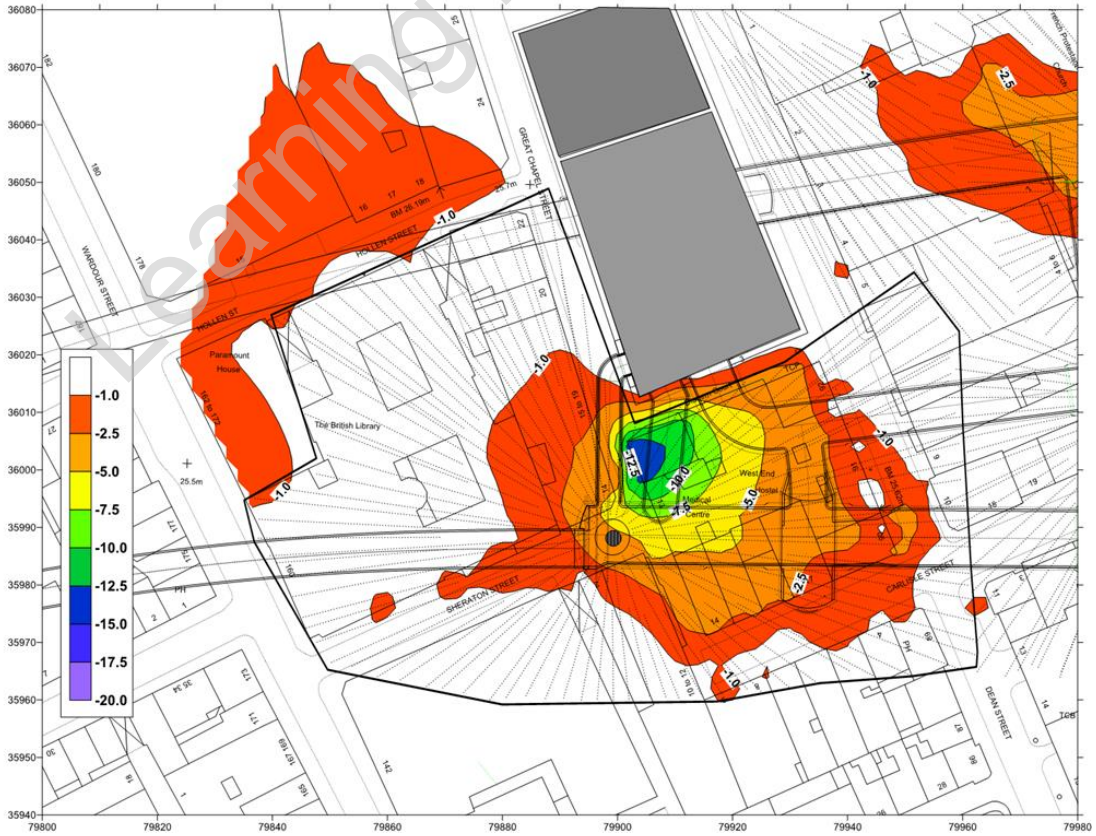
The maximum measured total settlement at the end of Period E within TCR GS1 area was ~26mm.

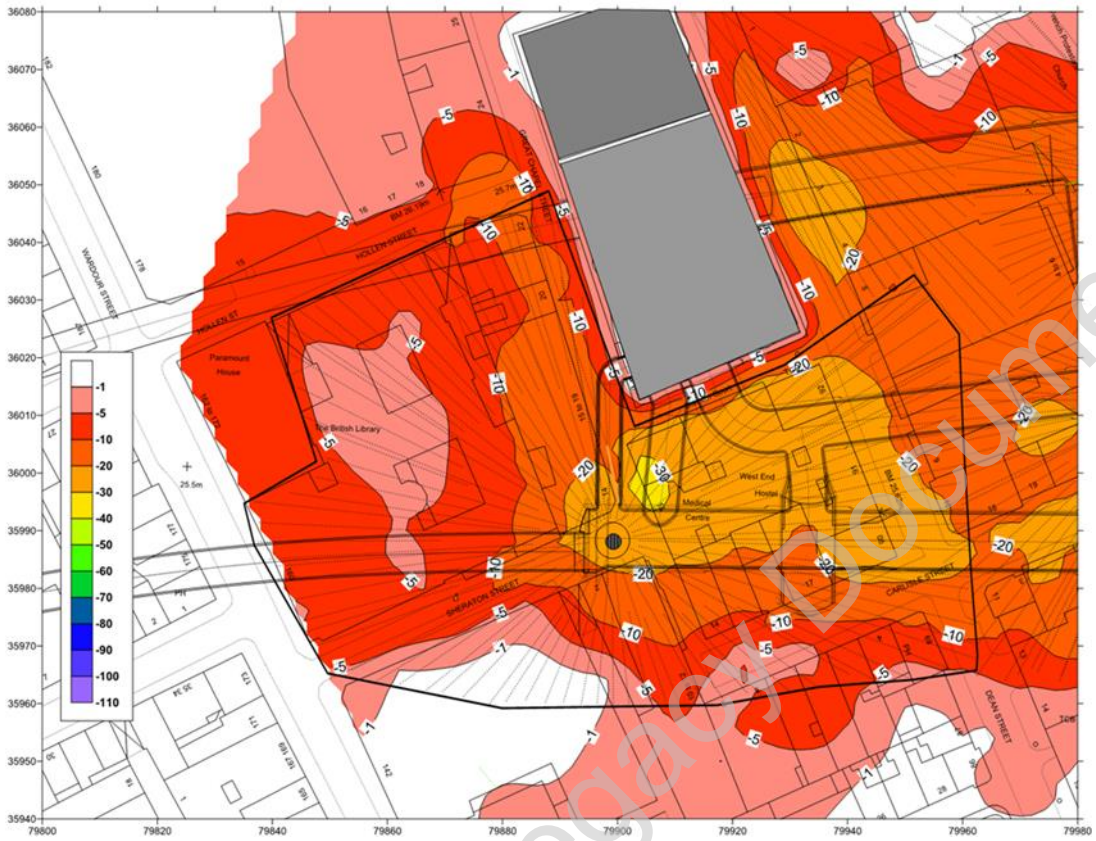
The concurrent grouting carried out with PTW and PTW2 (Figure 3.6.2) was successful in reducing volume loss settlement substantially. Grout jacking episodes were carried out during Period E over S4 (Figure 3.6.3), before and after its excavation due to the minor impact expected from this small diameter tunnel.

3.7. Period F: 16/07/14 – 15/09/14: Permeation grouting, VWW

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







Predicted volume loss settlement from VWW amounted to 20mm with the width of zone of influence reducing to the north, reflecting the inclination of the tunnel (Figure 3.7.1(a)). Concurrent grouting was not possible since the TaMs were located at an elevation very close to the crown of the tunnel at its junction with the WTH.

An assessment of the impact of the combined effect of the existing settlements and the volume loss movements from VWW was undertaken and it was concluded that no grout jacking was necessary prior to tunnelling, although it was expected that the Amber trigger on slope would be exceeded in a number of locations (C410-RFI-001308).

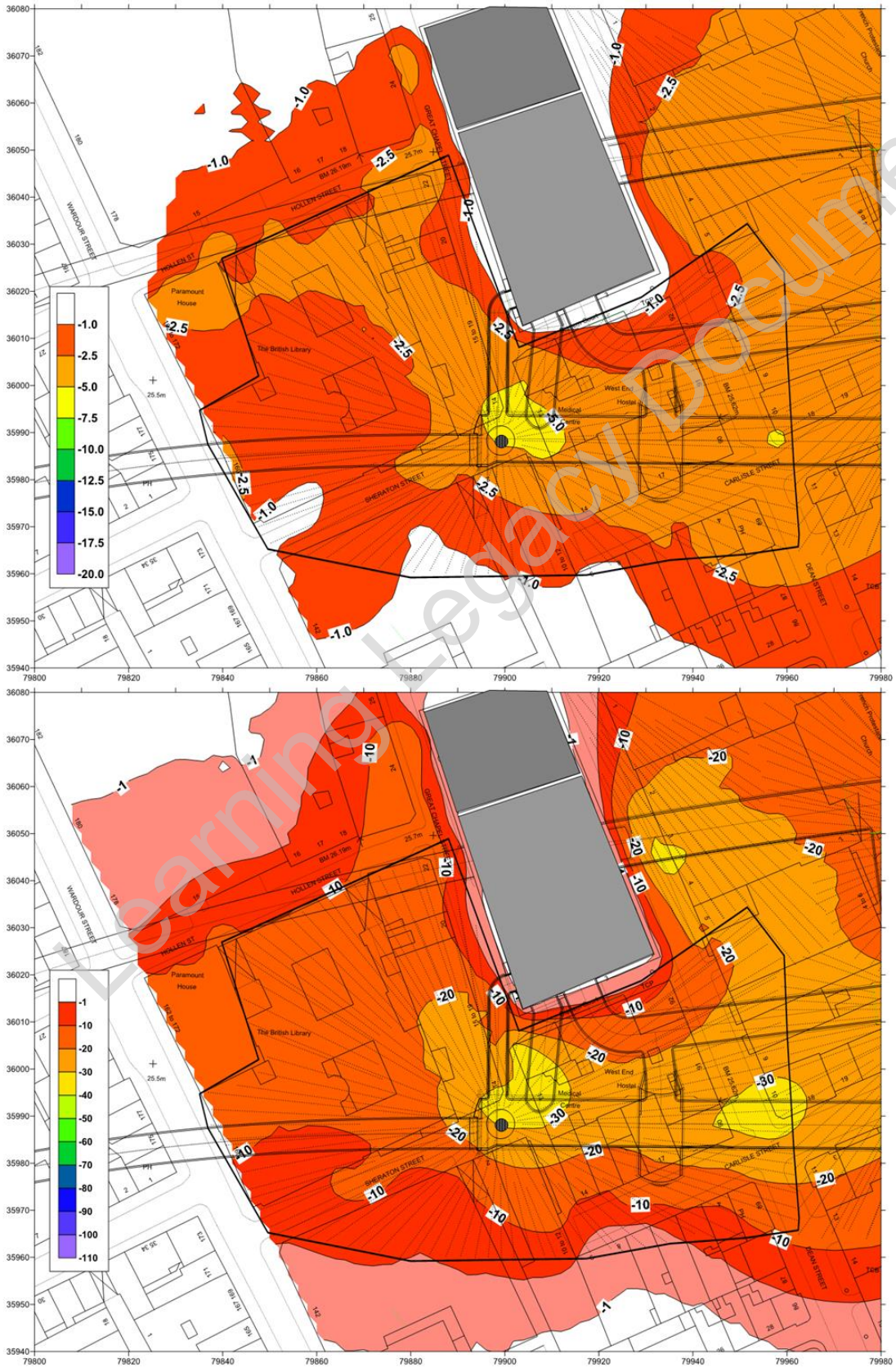
The clay cover at the north end of the tunnel was ~2m which was deemed insufficient for safe excavation. Permeation grouting of the River Terrace Deposits was required which was achieved by de-commissioning the compensation grouting TaMs and drilling an array of inclined TaMs at a higher elevation from GS1.

The observed maximum settlement (~15mm) was less than the calculated volume loss value but the form of the settlement contours (Figure 3.7.1(b)) suggests that the stiffness of the overlying buildings modified the distribution and widened the zone of influence.

The maximum settlement at the end of construction was locally ~30mm, as shown in Figure 3.6.1(c).

3.8. Period G. 15/09/14 – 30/09/15: Post Construction

Figure 3.8.1 Period G: (a) Contour of observed settlement during Period G-(b) Settlement at end of Period G



Monitoring was continued for ~1 year after the end of excavation. The maximum increase in settlement was ~5mm and the distribution of the post construction increase in settlement was closely related to the distribution of the total observed movements at the end of construction, as evidenced by the similarity in the pattern of the contours presented in Figures 3.8.1(a) and 3.8.1(b).

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. A larger version of Figure 4.1.1 is included in Appendix C. Details of trigger breaches are given in Table 4.1. By inspection, there have been no Deflection Ratio trigger breaches.

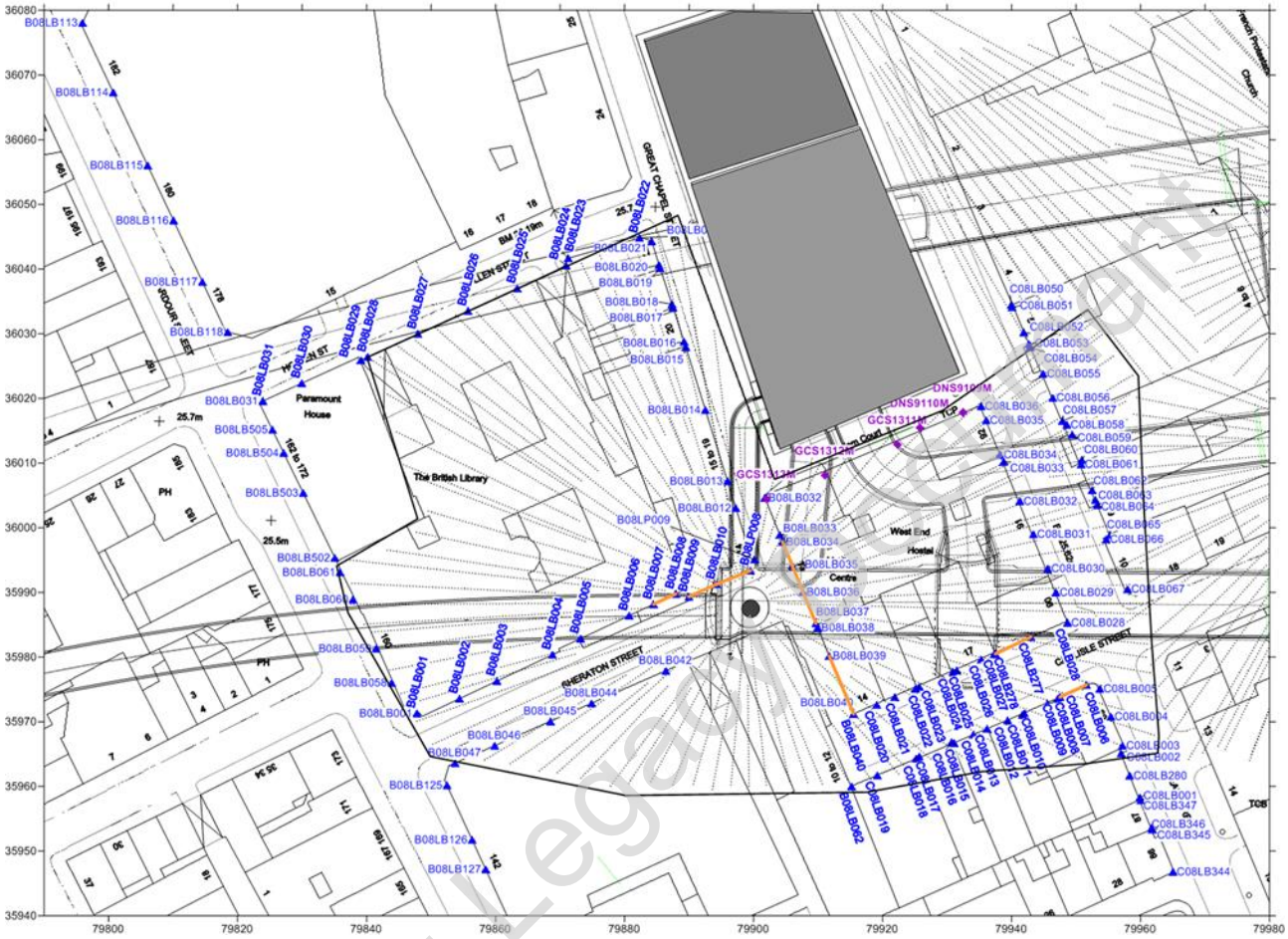
Slope triggers are as follows:

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

Table 4.1 Details of Amber trigger breaches on BREs

BUILDING FACADES		Comment	Date exceeded	Maximum (mm/m)	Final (mm/m)
Hollen Street South: NONE					
Sheraton Street North					
B08LB007 - B08LB008	Amber	Associated with VWW works after GS1 de-commissioned	08/09/14	1.25	1.16
B08LB009 - B08LB010	Amber	Initial values >1 post S4 in Period E (max 1.12, mean 0.96). Increase due to VWW works after GS1 de-commissioned	03/05/14	1.54	1.54
B08LP008 - B08LB010	Amber	Associated with VWW works after GS1 de-commissioned. PLP used at corner of Sheraton St.	16/12/14	1.34	1.34
Sheraton Street South: NONE					
Wardour Street East: NONE					
Great Chapel Street East					
B08LB034 – B08LB035	Amber	Transitory breach associated with WBRT. Corrected by grout jacking by 26/05/13	23/05/13	1.11	0.64
B08LB035 – B08LB036	Amber	Associated with VWW works after GS1 de-commissioned.	07/09/14	1.25	1.20
B08LB036 – B08LB037	Amber	Associated with VWW works after GS1 de-commissioned.	11/08/14	1.48	1.23
B08LB038 – B08LB039	Amber	Associated with VWW works after GS1 de-commissioned.	12/09/14	1.04	1.02
B08LB039 – B08LB040	Amber	Associated with VWW works after GS1 de-commissioned.	04/09/14	1.26	1.15
Great Chapel Street West					
B08LP009 – B08LB012	Amber	PLP used at corner of Sheraton St. 5mm settlement between 2 readings in post construction period	06/05/15	1.26	1.25
Diadem Court (HLC): NONE					
Carlisle Street West North:					
C08LB027 – C08LB277	Amber	Trigger with PTW. Mean value in Period G = 1.02	29/03/14	1.33	1.22
Carlisle Street West South					
C08LB007 – C08LB006	Amber	Trigger with PTW. Value at end of Period F = 1.02	16/04/14	1.26	1.26
Dean Street West: NONE					
Dean Street East: NONE					

Figure 4.1.1 Locations where building slope triggers have been exceeded.

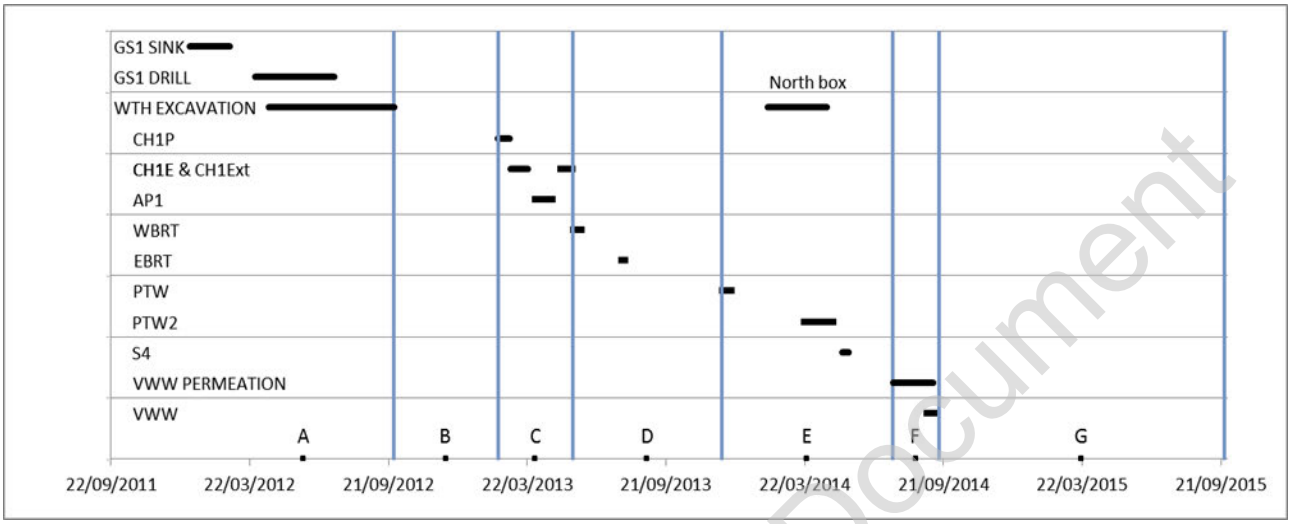


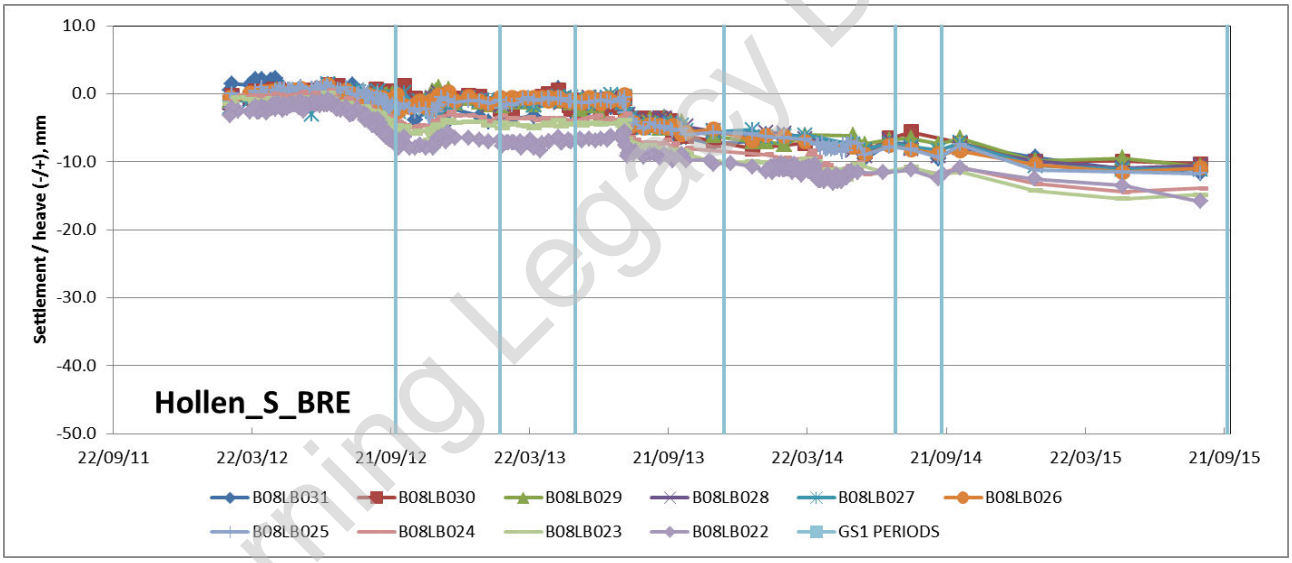
BRE monitoring data from the facades within the footprint of GS1 are presented in the following sections, namely Hollen Street south, Sheraton Street north and south, Wardour Street east, Great Chapel Street east and west, Carlisle Street north and south and Dean Street east and west. HLC data are presented for Diadem Court since there was no access for manual monitoring. The HLC data presented is based on daily means.

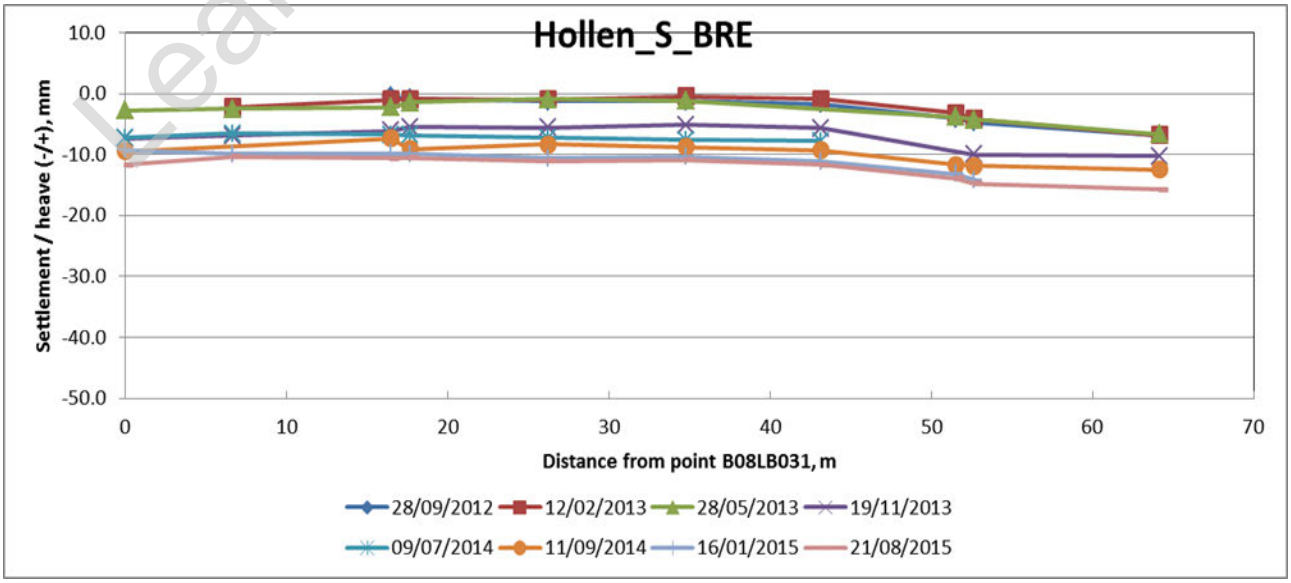
The plots presented for each comprise, as appropriate:

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.

4.2. Hollen Street – South



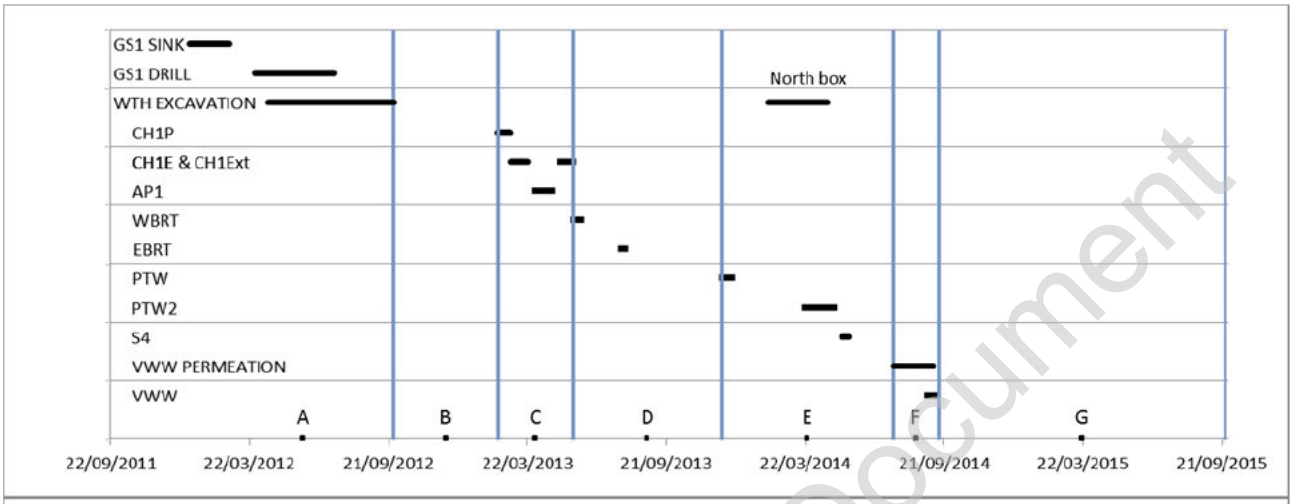


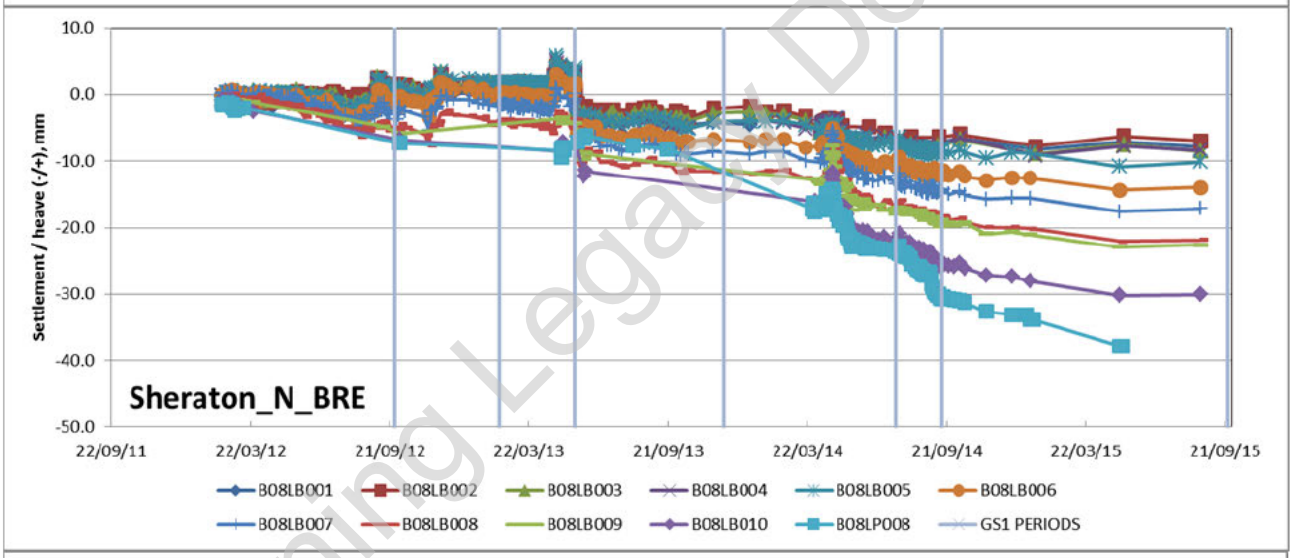


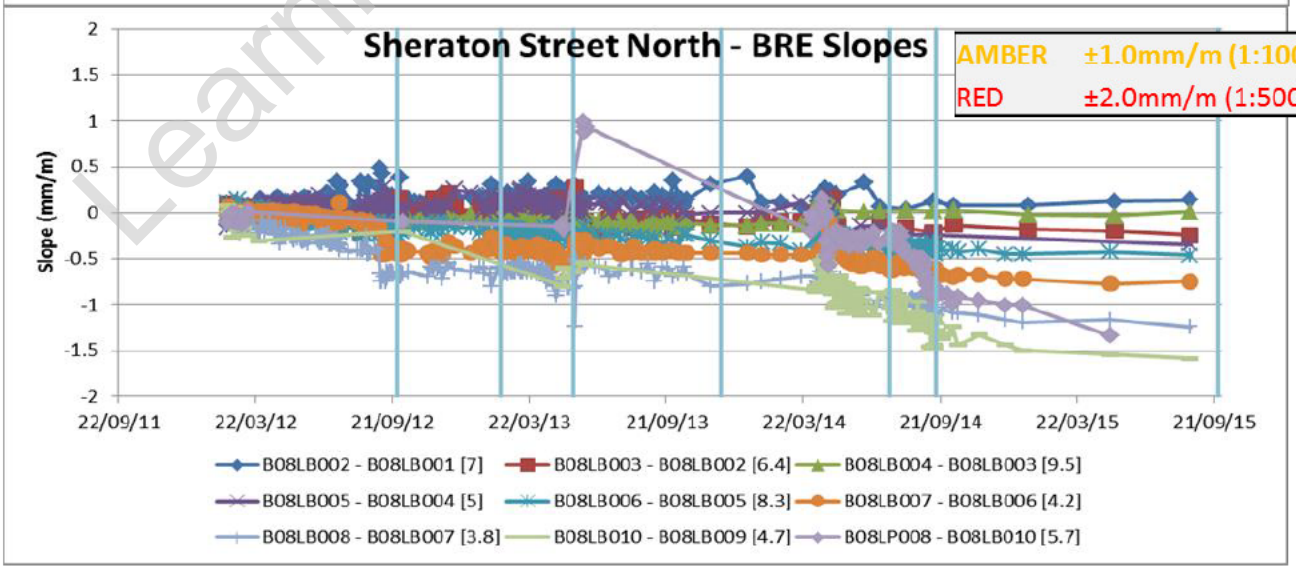
The following points are noted:

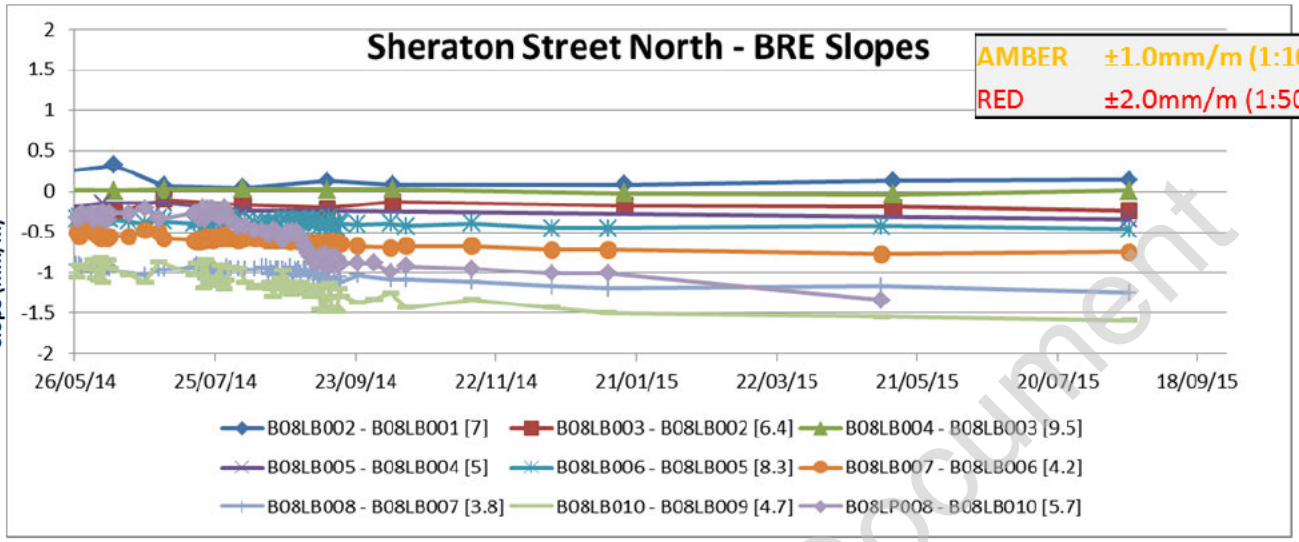
- The building façade on the south side of Hollen Street is at the periphery of the GS1 arrays.
- The key events were the WTH excavation in Period A and the EBRT in Period D. It is noted that at the end of these activities the maximum settlement was about 10mm. At the end of Period A, the settlement had reached 8mm primarily due to the WTH excavation and in Period D the EBRT produced less than 5mm settlement.
- The profile plot confirms that settlement was nearly uniform over the full profile and, by inspection, the resulting change in slopes were not significant.

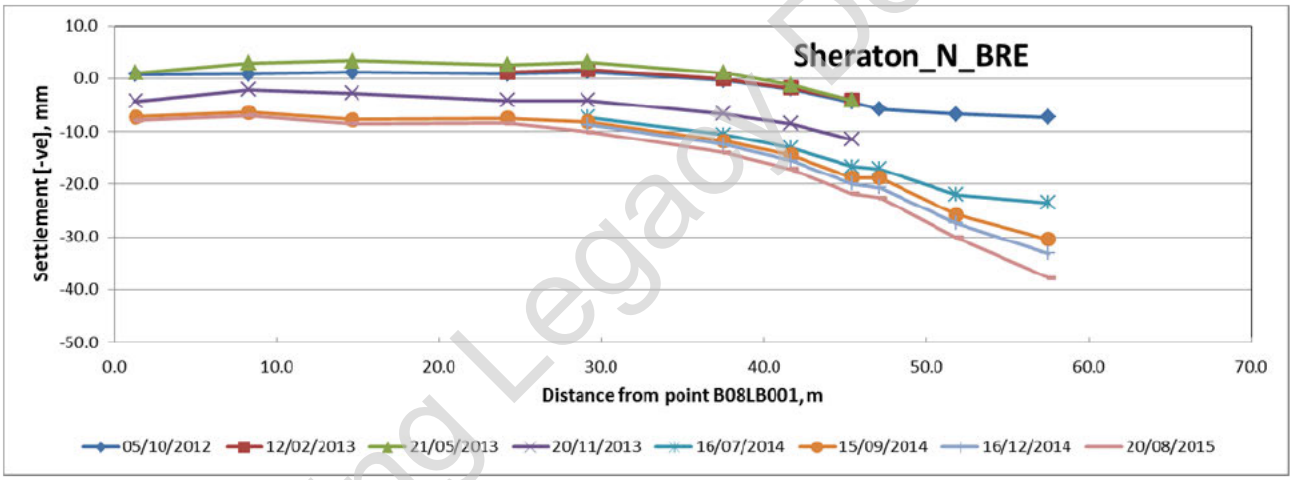
4.3. Sheraton Street – North











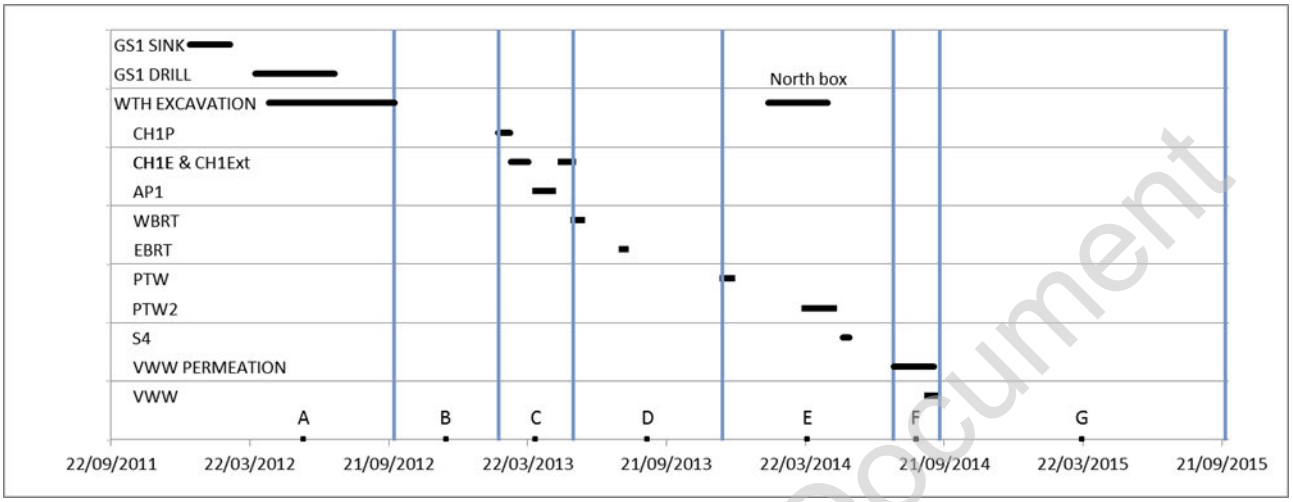
The following points are noted:

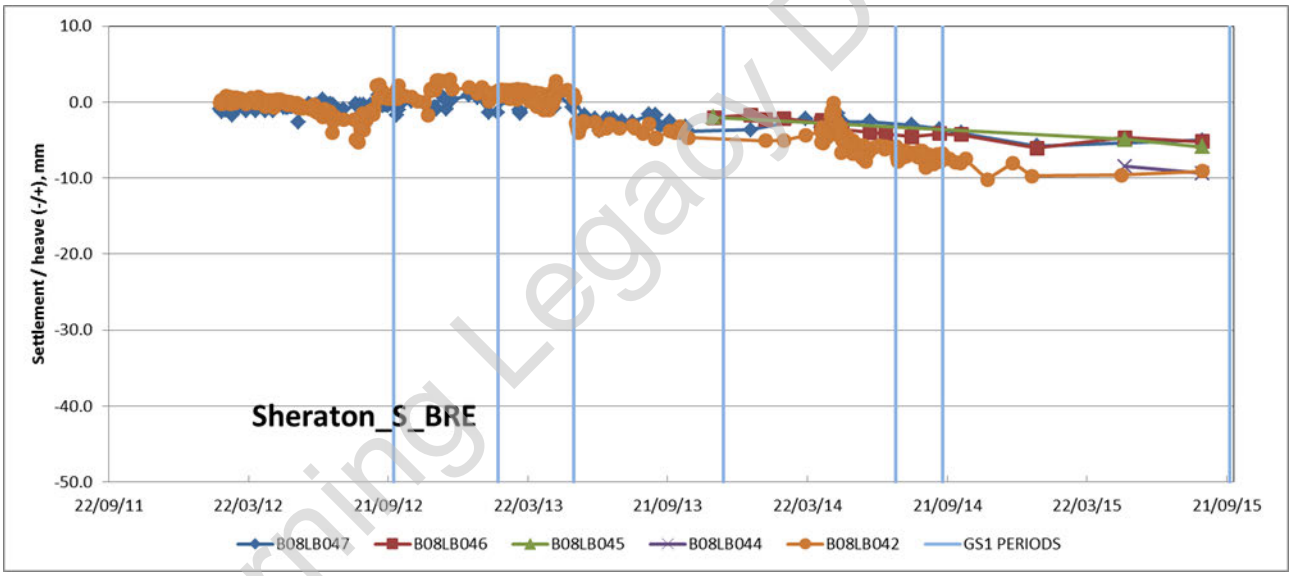
- GS1 was located at the east end of Sheraton Street and part of the façade was close to the 3m exclusion zone around the shaft. The whole of the façade is within the plan extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), the WBRT (Period D), PTW2 and S4 (Period E) and the VWW permeation grouting and excavation in Period F. Heave associated with pre-treatment and grout jacking maintained settlement to ~12mm at the end of Period D.
- A key activity in Period E was the PTW2 which passed directly below GS1 and no grouting was possible within a 5m radius of the shaft centre. An increase in settlement of about 8mm (to 22mm) was recorded at the corner of Sheraton Street and Great Chapel Street which resulted in an Amber trigger being reached between points B08LB009 and B08LB010, on 14 Great Chapel Street.
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the

appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.

- The permeation grouting continued after the start of excavation of VWW. The combined effect of the grouting and tunnelling was a further increase in settlement of 8mm to (30mm) and an associated increase in maximum slope to ~1.3mm/m. A second Amber trigger developed between points B08LB007 and B08LP008, also on 14 Great Chapel Street (N.B. a PLP has been used because no BRE could be installed on the corner of Sheraton Street and Gt. Chapel Street).
- The maximum increase in post construction settlement in Period G was approximately 4mm on BRE and 7mm on the PLP (B08LP008). The maximum slope increased to 1.5mm/m but, by inspection of the profile plot, no Deflection Ratio triggers were breached.

4.4. Sheraton Street - South

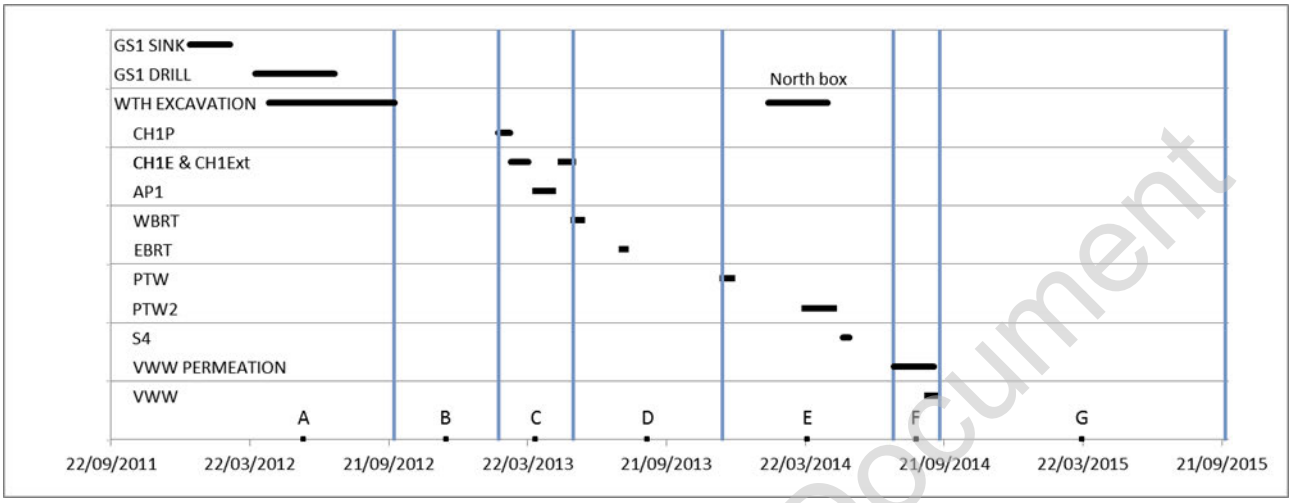


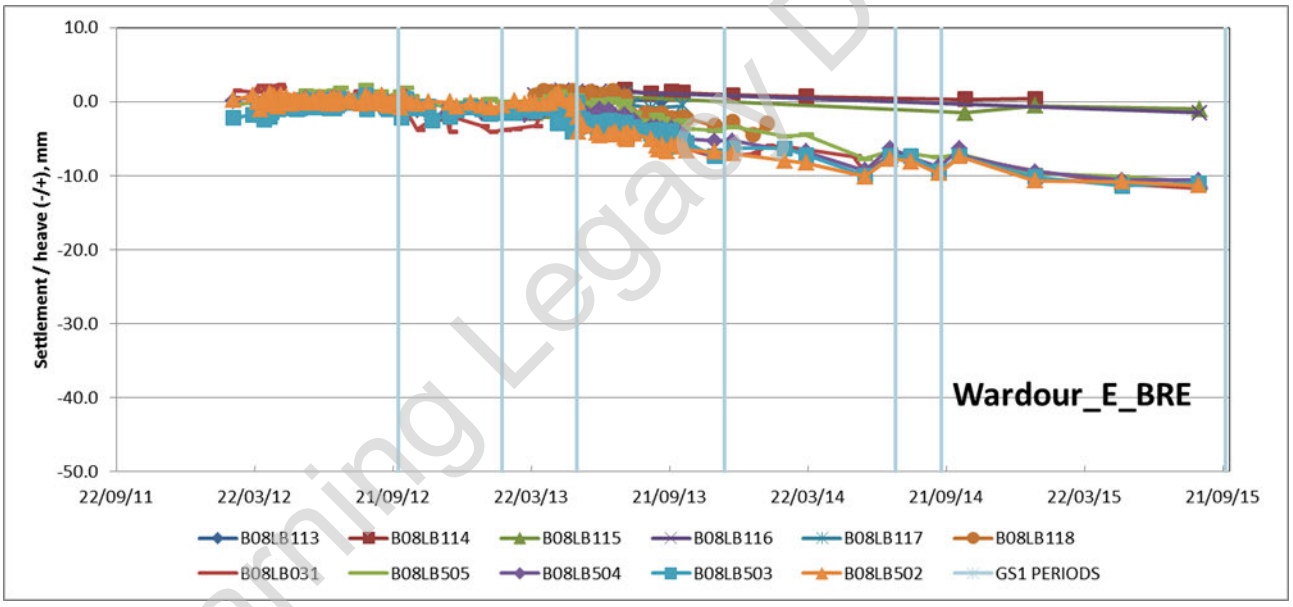


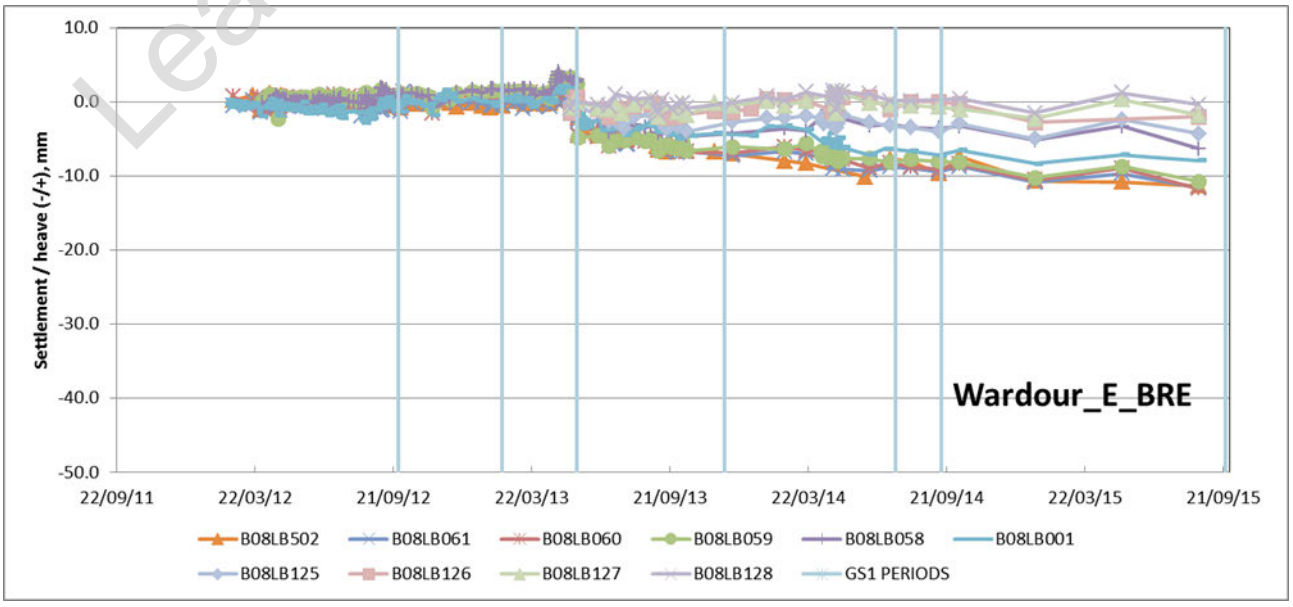
The following points are noted:

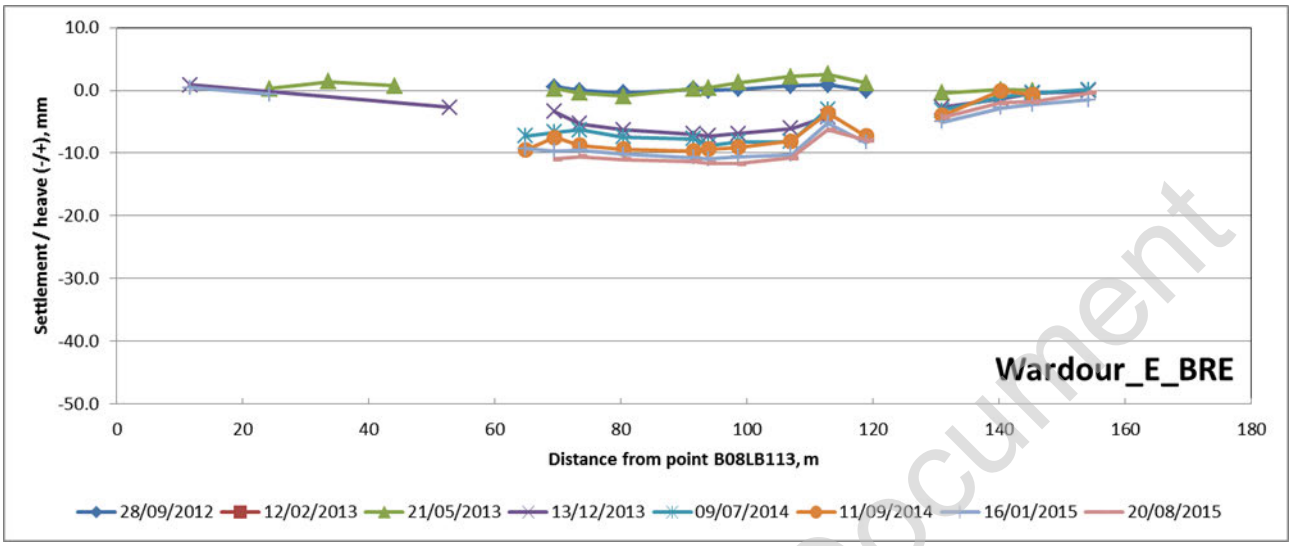
- Monitoring on the south façade of Sheraton Street was very limited due to access difficulties, however, the maximum recorded settlement was less than 10mm.

4.5. Wardour Street - East





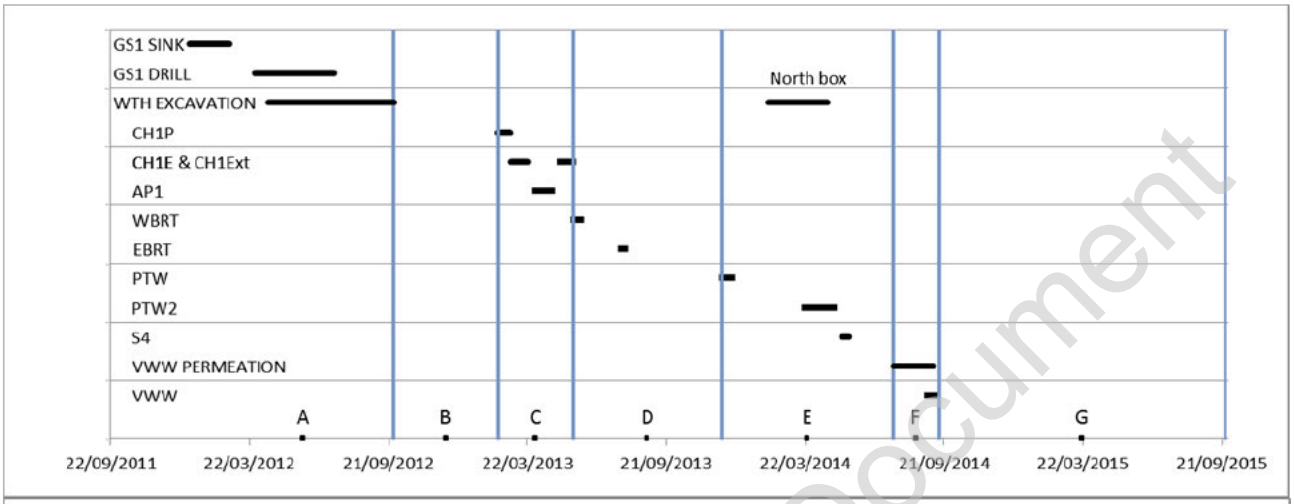


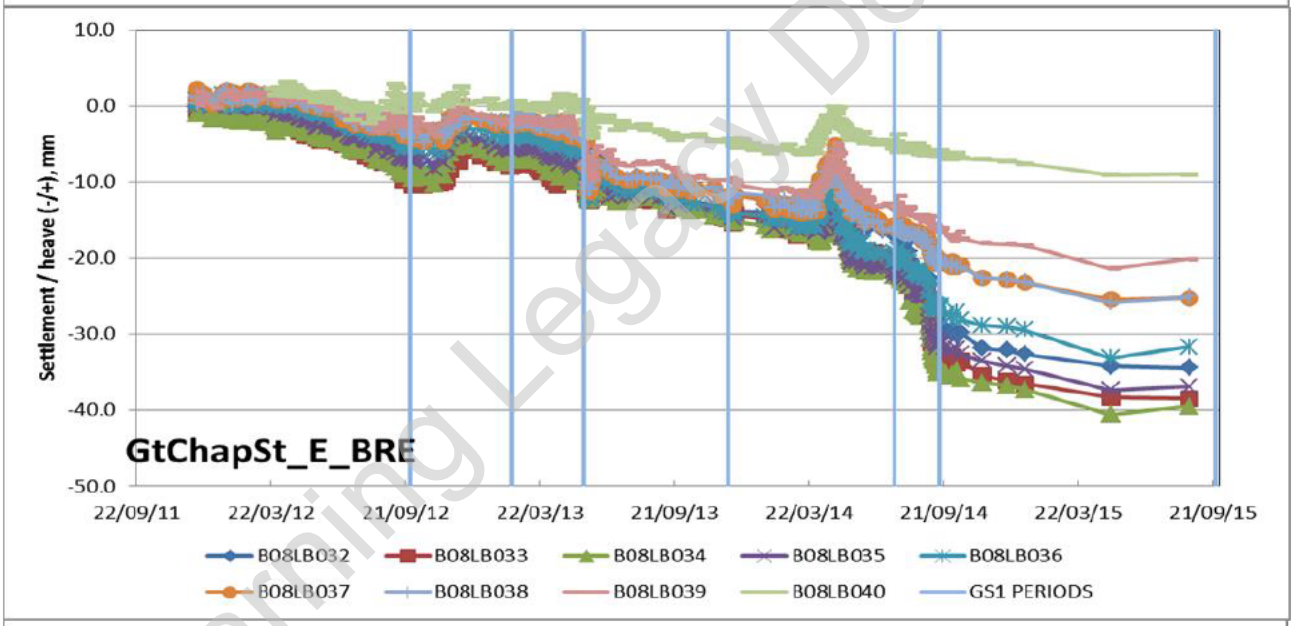


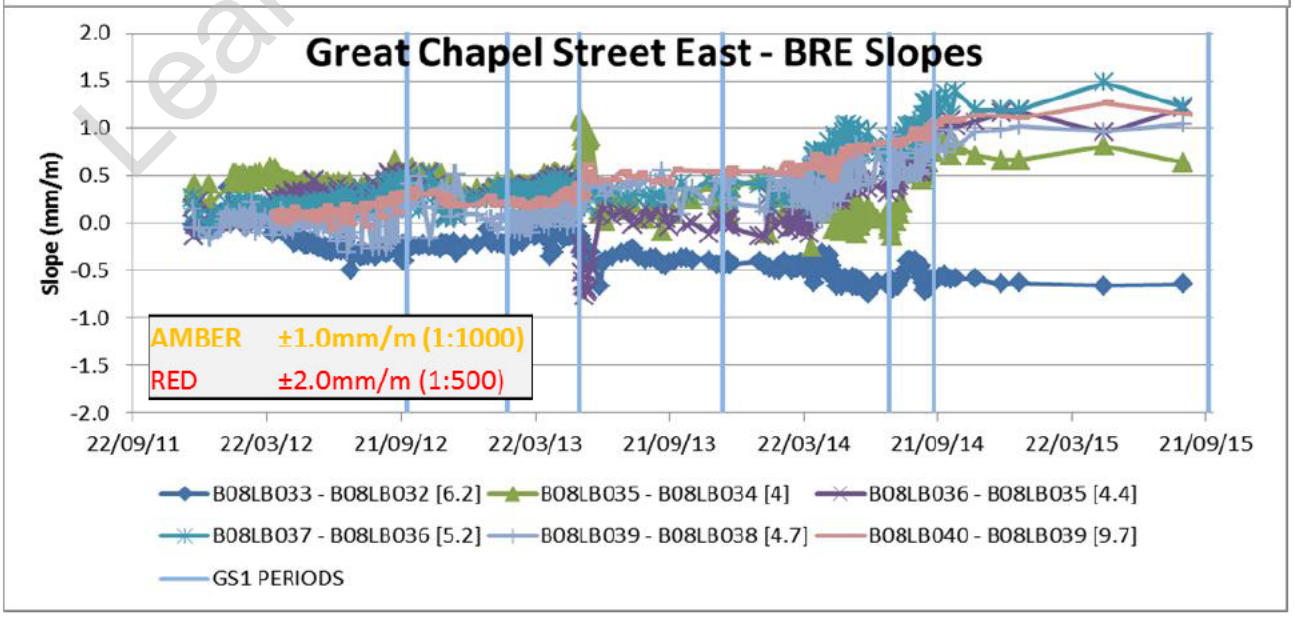
The following points are noted:

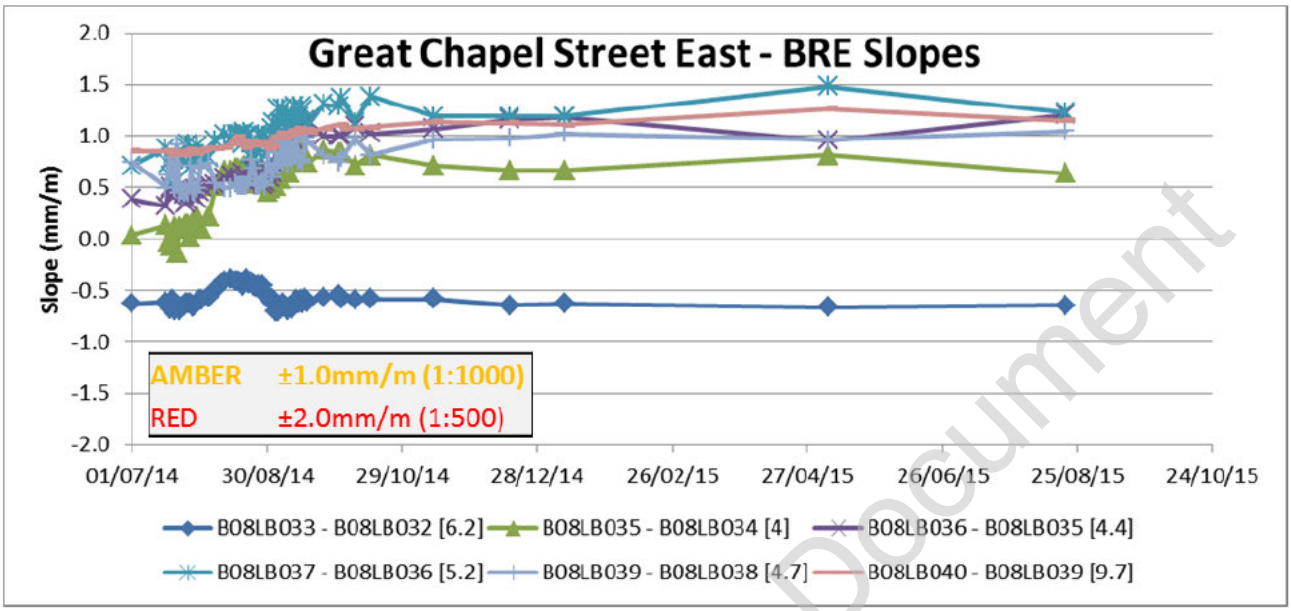
- The building façade on the east side of Wardour Street is at the western periphery of the GS1 arrays.
- The key events were the WBRT and EBRT drives in Period D. It is noted that at the end of these activities the maximum settlement was about 8mm.
- The profile plot confirms that the settlement was nearly uniform over the full profile and, by inspection, the resulting change in slopes were not significant.
- The maximum settlement increased from 8mm at the end of Period D to 12mm at the end of Period G. The increase in settlement in Period G was ~2mm.

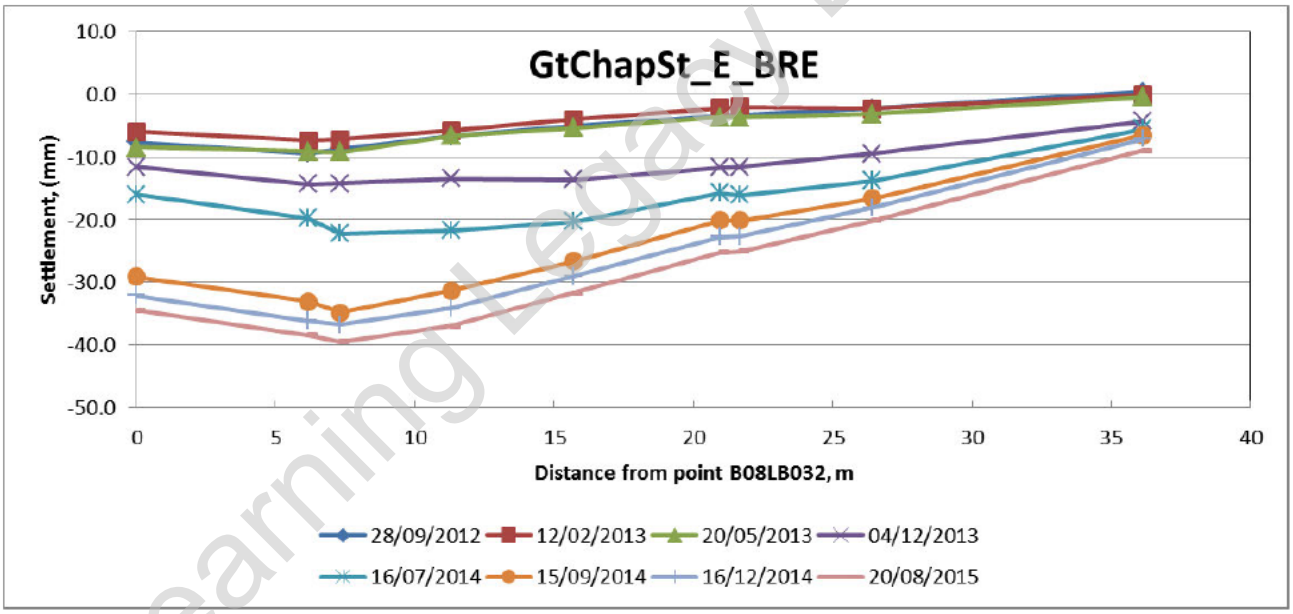
4.6. Great Chapel Street - East









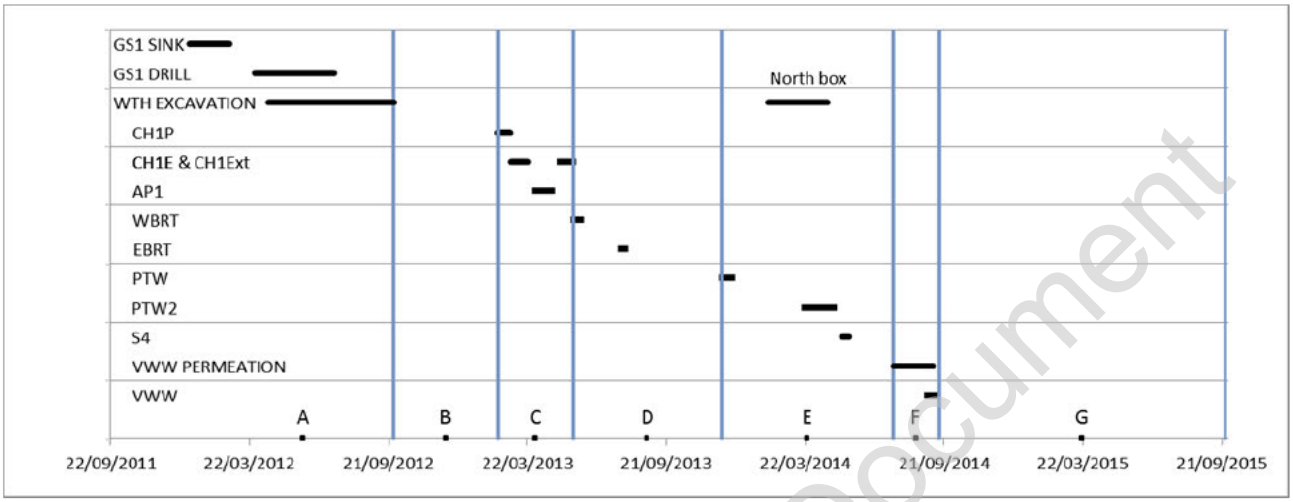


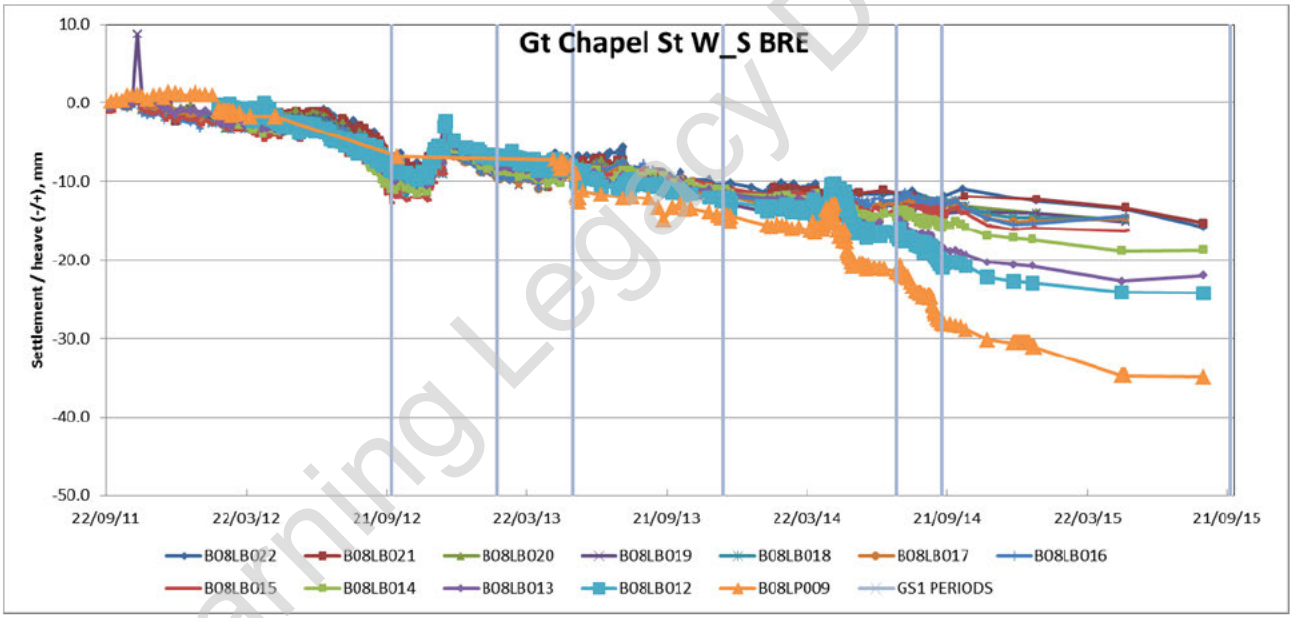
The following points are noted:

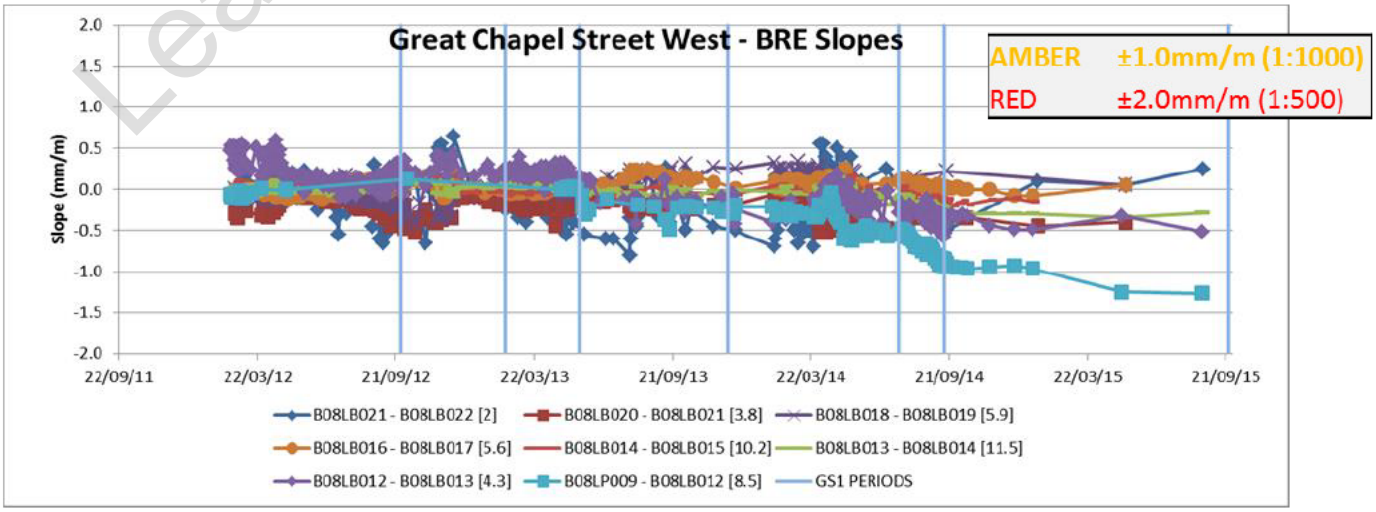
- The Great Chapel Street east façade between Diadem Court and Carlisle Street is located fully within the extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), the WBRT (Period D), PTW2 and S4 (Period E) and the VWW permeation grouting and excavation in Period F. Uplift due to grout jacking is evident in Period B, prior to the start of tunnelling, in Period D following the WBRT and in Period E prior to and during PTW2 excavation.
- Settlement reached ~10mm due to the WTH excavation (Period A), but was reduced by up to 5mm by grouting in Period B. A transitory Amber trigger occurred at the start of Period D (B08LB035 – B08LB034) associated with WBRT without concurrent grouting. The slope was rapidly reduced below the trigger level by grout jacking. Settlement then increased gradually to 18mm ahead of PTW2.

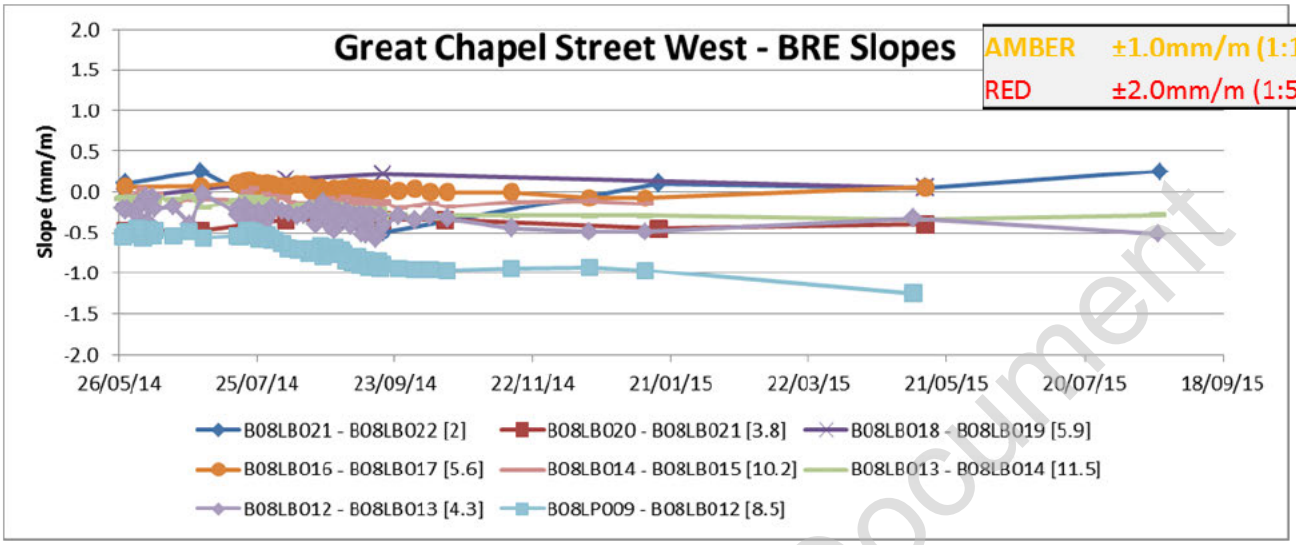
- PTW2 was a key activity: An increase in settlement of about 5mm (to 23mm) was recorded which caused an Amber trigger to be approached between points B08LB036 and B08LB037, on 13 Great Chapel Street. Three non-consecutive readings gave slope >1.0mm/m (maximum 1.04mm/m) but a breach was not confirmed by the subsequent readings.
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.
- The permeation grouting continued after the start of excavation of VWW. The combined effect of the grouting and tunnelling was a further increase in settlement of 13mm to (36mm) and an associated increase in maximum slope to ~1.3mm/m. A second Amber trigger developed between points B08LB040 and B08LB039, also on 13 Great Chapel Street. The maximum Deflection Ratio was 1:2600.
- The increase in settlement in Period G was ~5mm.

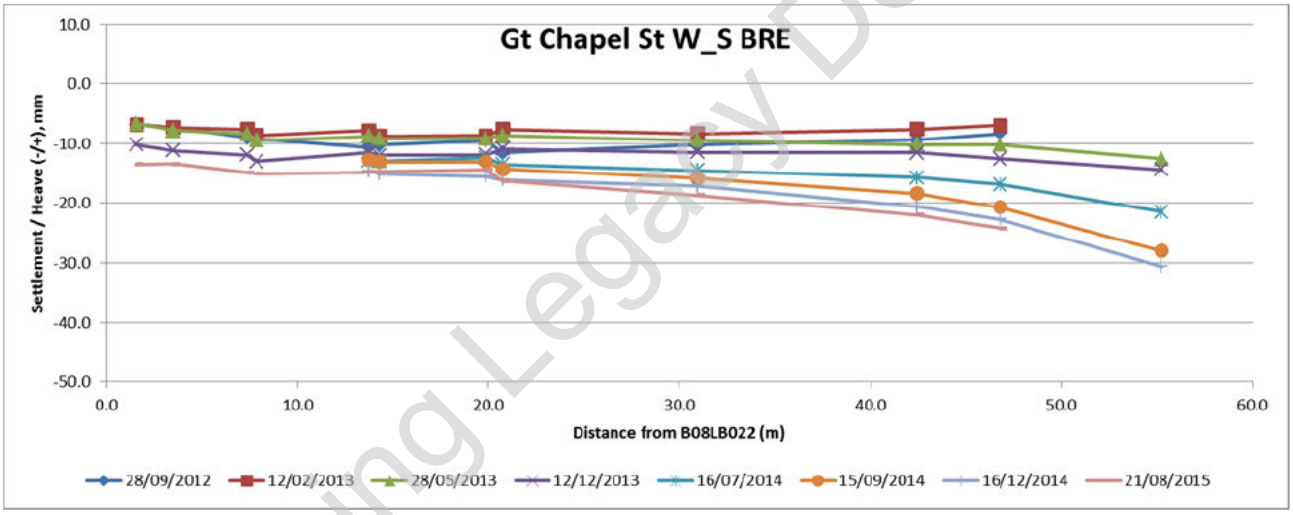
4.7. Great Chapel Street – West









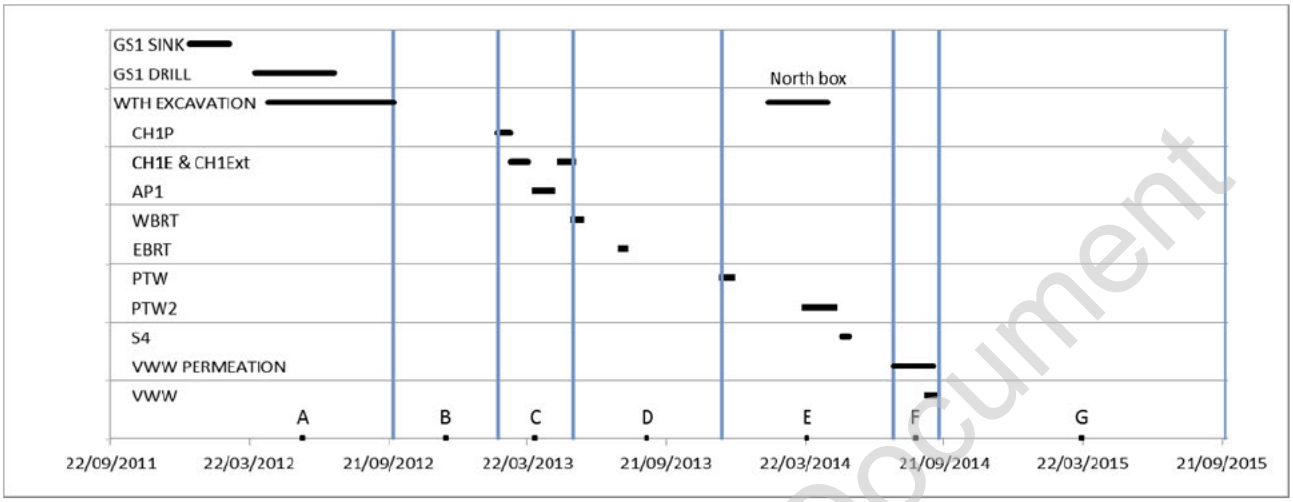


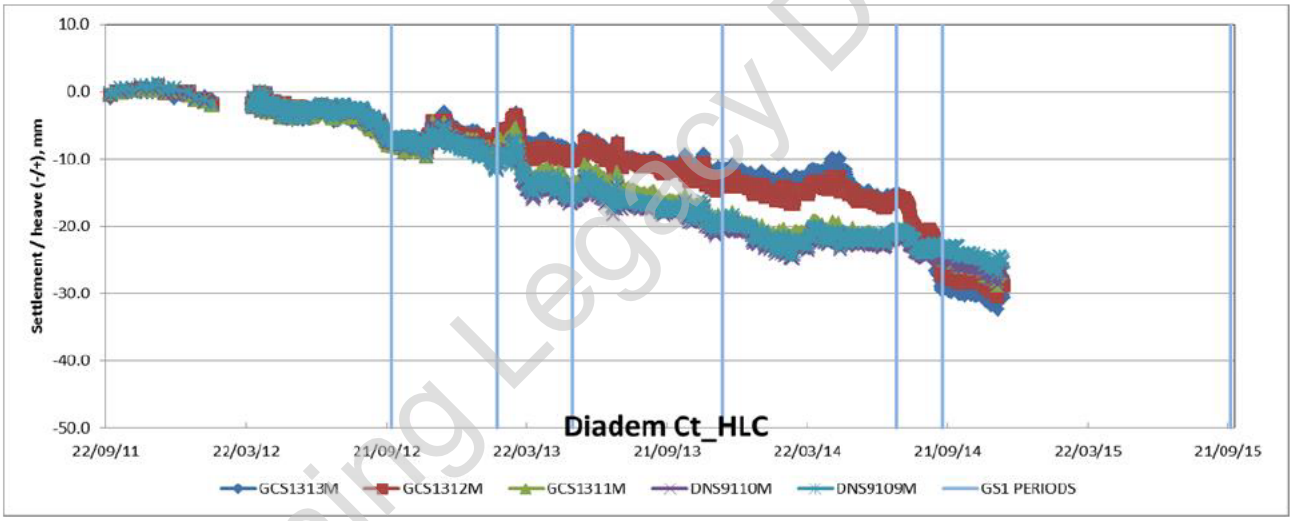
The following points are noted:

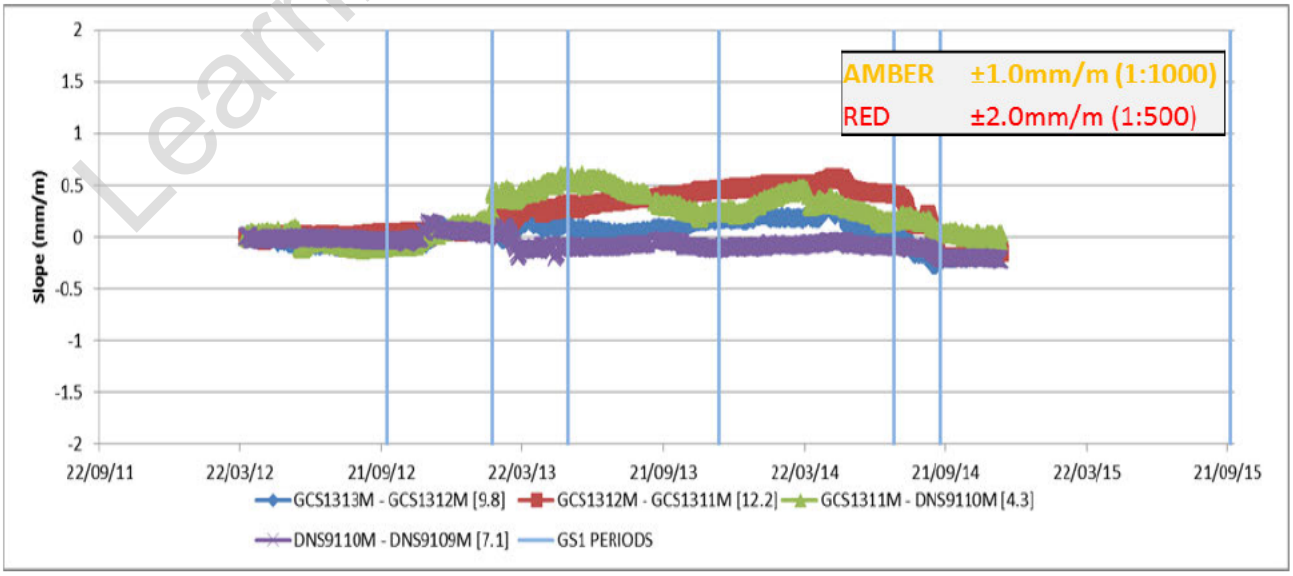
- The Great Chapel Street west façade between Sheraton Street and Hollen Street is located fully within the extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), PTW2 and S4 (Period E) and the VWW permeation grouting and excavation in Period F. Very minor effects were recorded from the WBRT and EBRT drives in Period D. Uplift due to grout jacking is evident in Period B, prior to the start of tunnelling, and in Period E prior to and during PTW2 excavation.
- Settlement reached ~10mm due to the WTH excavation (Period A), but was reduced by up to 5mm by grouting in Period B. Settlement then increased gradually to 17mm ahead of PTW2 which resulted in a further increase in settlement of about 5mm (to 22mm).
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.

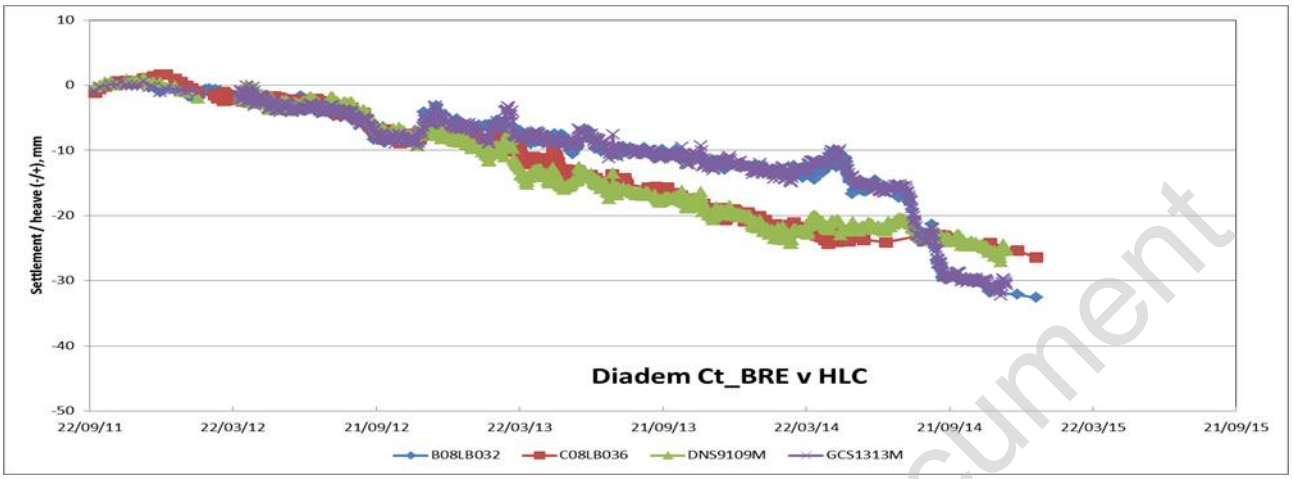
- The permeation grouting continued after the start of excavation of VWW. The combined effect of the grouting and tunnelling was a further increase in settlement of 7mm to (29mm) and an associated increase in maximum slope to just below the Amber trigger ~0.95mm/m between B08LP009 and B08LB012 (N.B. a PLP has been used because no BRE could be installed on the corner of Sheraton Street and Gt. Chapel Street).
- The maximum increase in post construction settlement in Period G was approximately 4mm on BRE and 7mm on the PLP (B08LP008). The final reading indicates an Amber trigger between points B08LP009 and B08LB012 as a result of the larger movement recorded on the PLP.

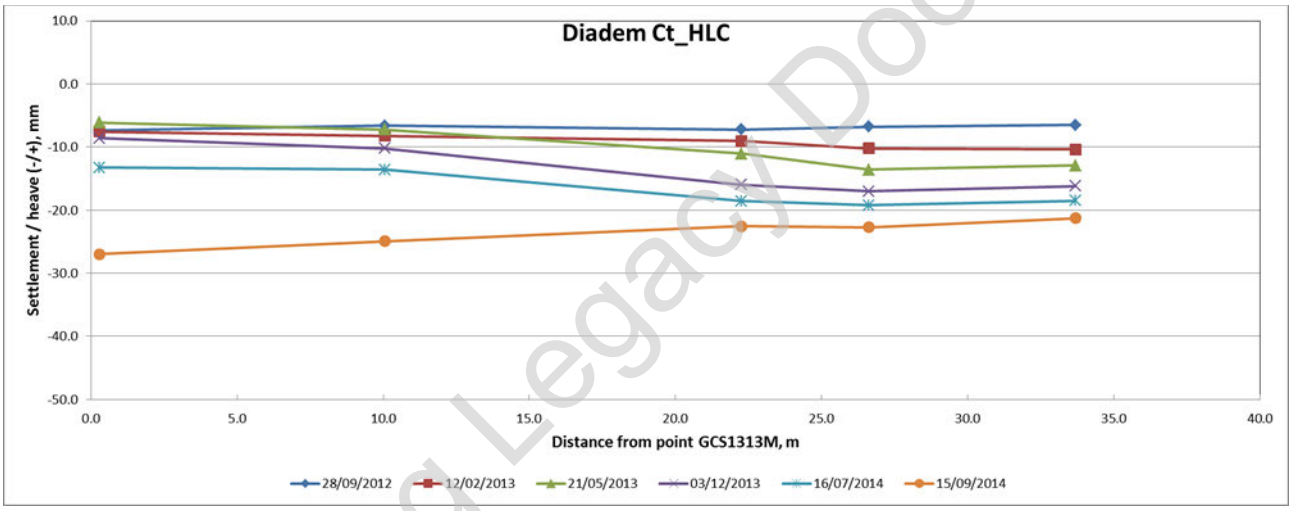
4.8. Diadem Court











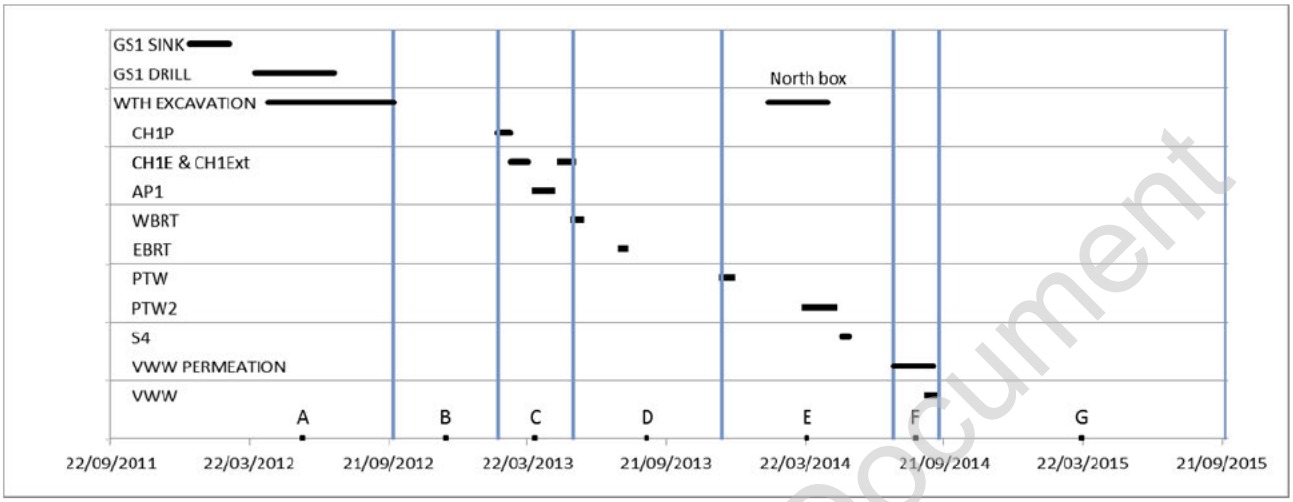
The following points are noted:

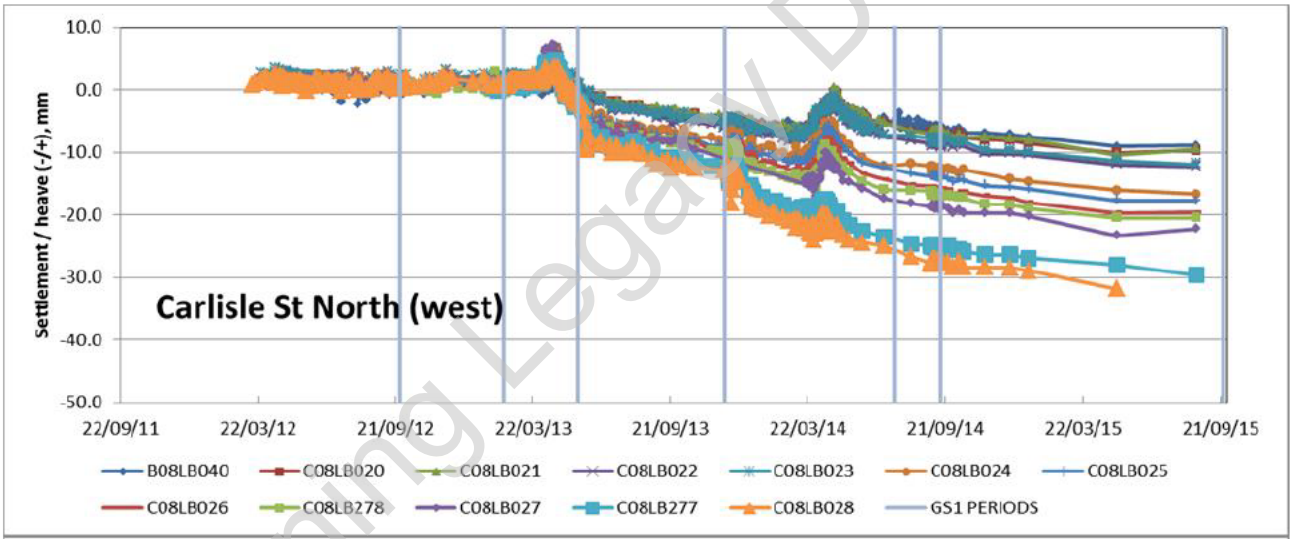
- The Diadem Court façade is located fully within the extent of the GS1 array. Since access was not available for manual survey, data from HLC is presented.
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), the CH1P, CH1E and AP1 (Period C), S4 (Period E) and the VWW permeation grouting and excavation in Period F. Uplift due to grout jacking is evident in Period B, prior to the start of tunnelling, and in Period C during CH1E excavation, in Period D due to post –WBRT jack grouting and in Period E as a result of concurrent grouting with PTW2.
- Settlement reached ~8mm due to the WTH excavation (Period A), and increased to 10mm during Period B despite uplift of up to 3mm generated by grouting. Settlement then increased gradually to 15mm due to tunnelling with concurrent grouting during Period C.
- No significant increase in settlement was recorded for either the WBRT (Period D) or the PTW2 (Period E) but settlement had reached 22mm by the end of Period E.
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the

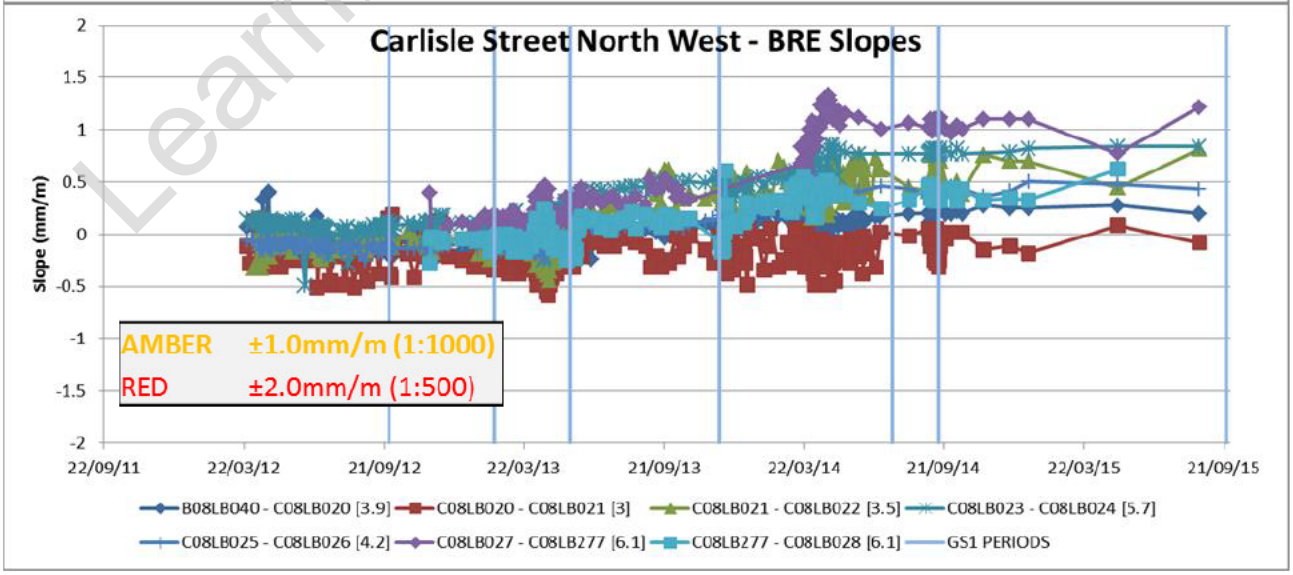
appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.

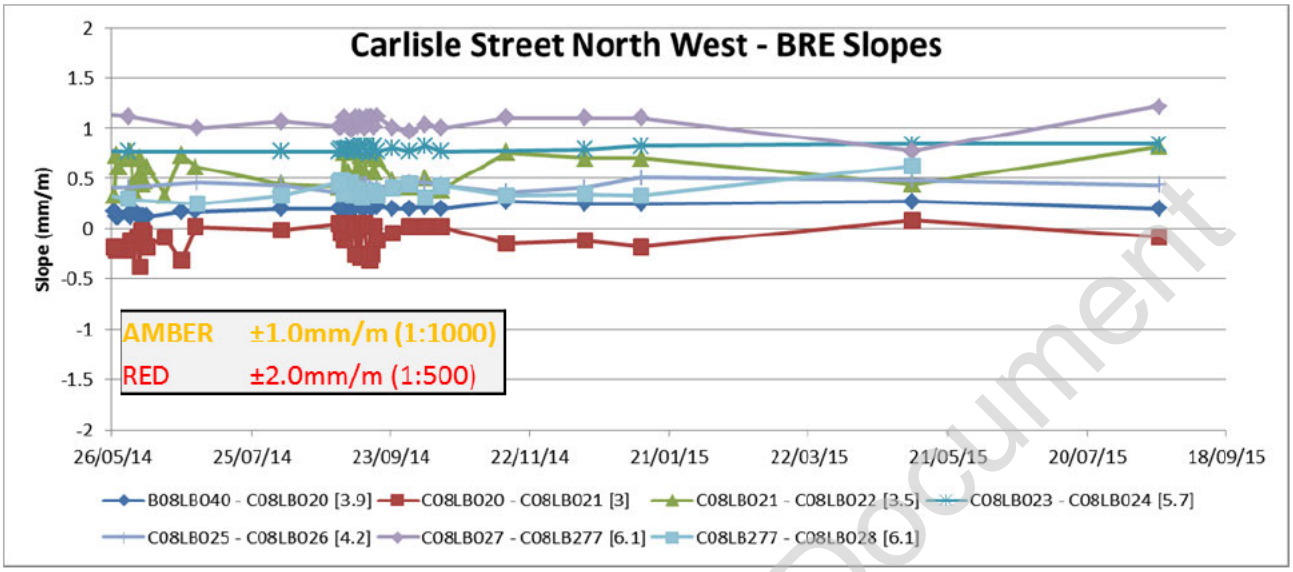
- The permeation grouting continued after the start of excavation of VWW. The combined effect of the grouting and tunnelling was a further increase in the maximum settlement of 8mm to 30mm. No slope triggers were recorded.
- The HLC data at either end of Diadem Court are compared with the adjacent BREs on Great Chapel Street and Dean Street – good agreement is shown over the full monitoring duration of over 3 years.
- HLC monitoring was terminated soon after the end of construction when the grout shaft was de-commissioned (see C410-RFI-001471).

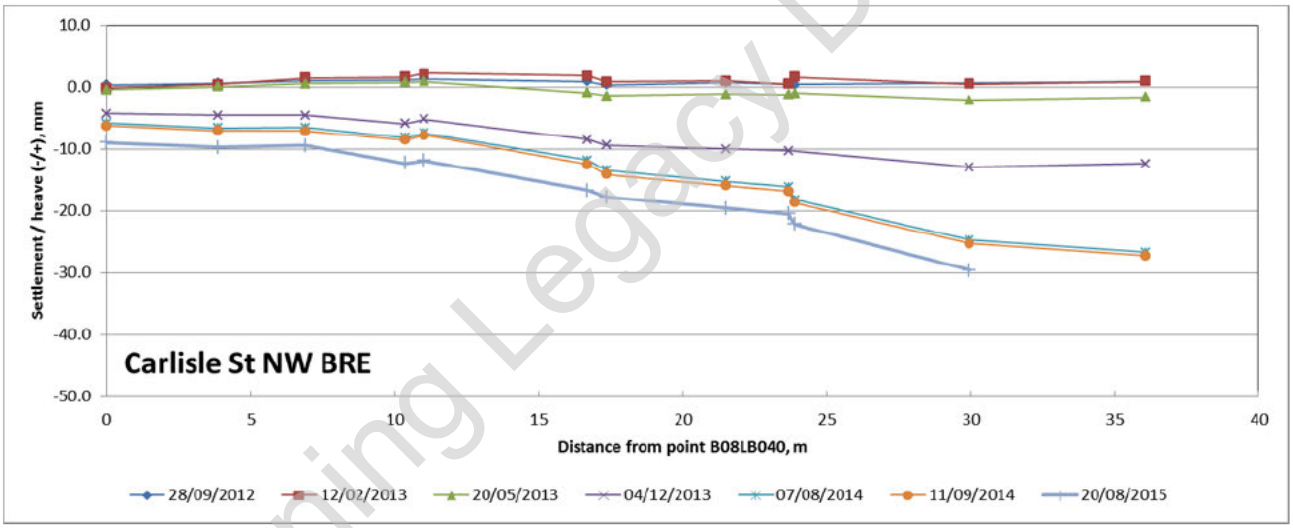
4.9. Carlisle Street - North









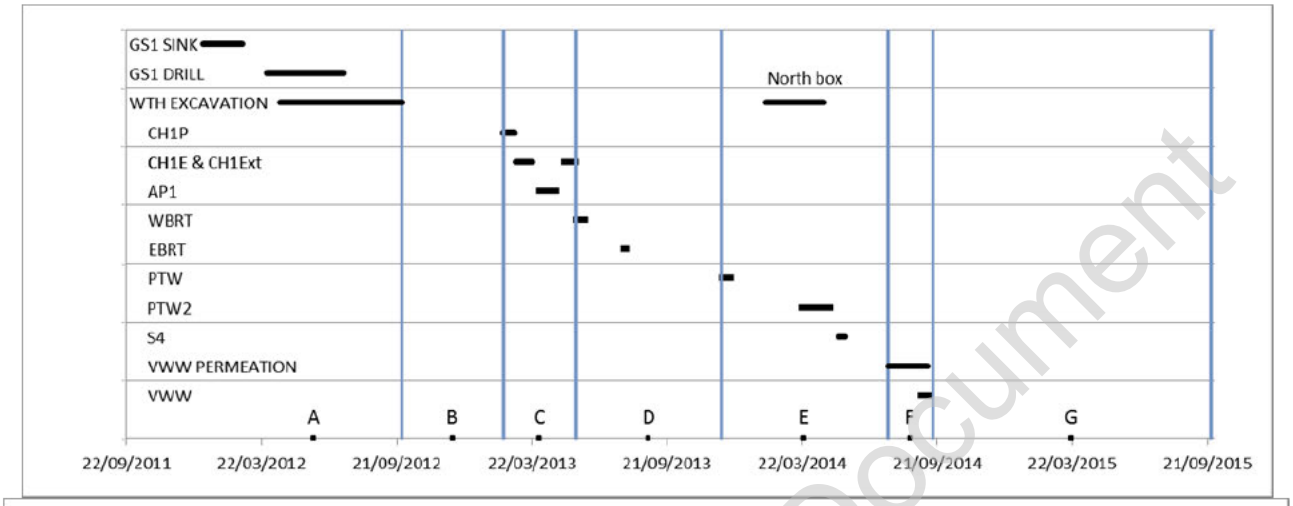


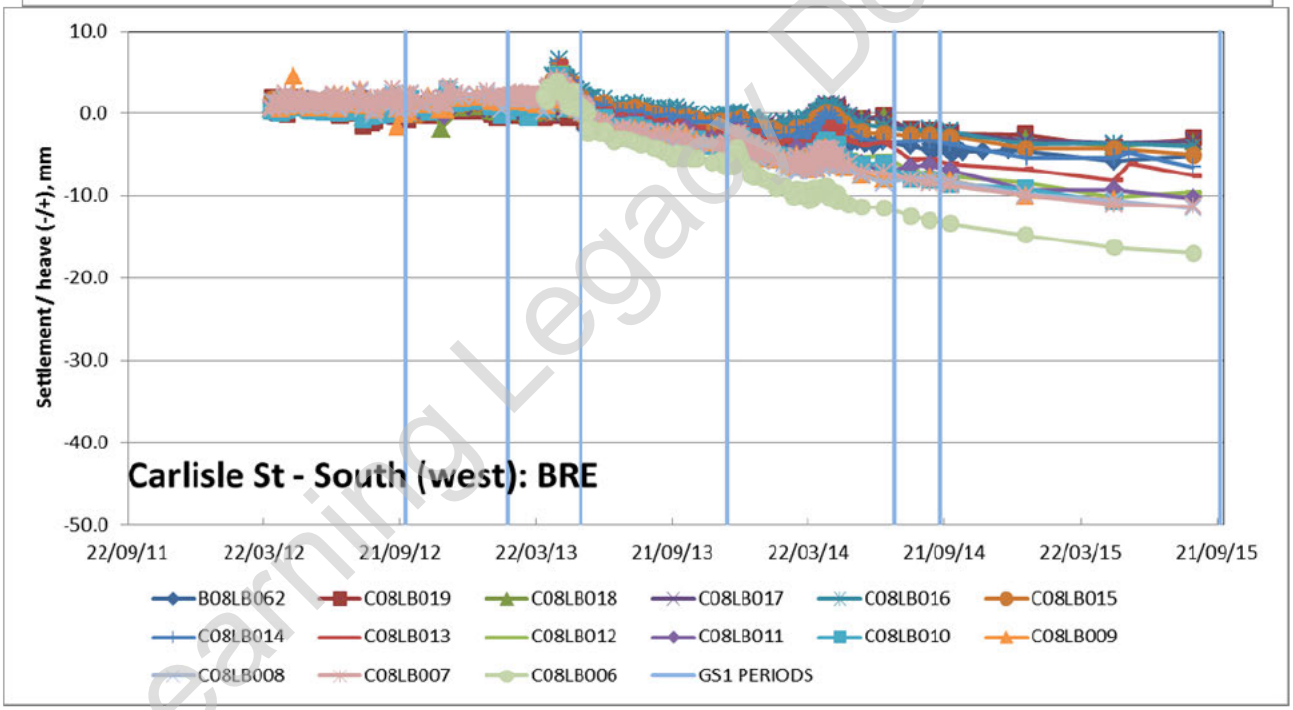
The following points are noted:

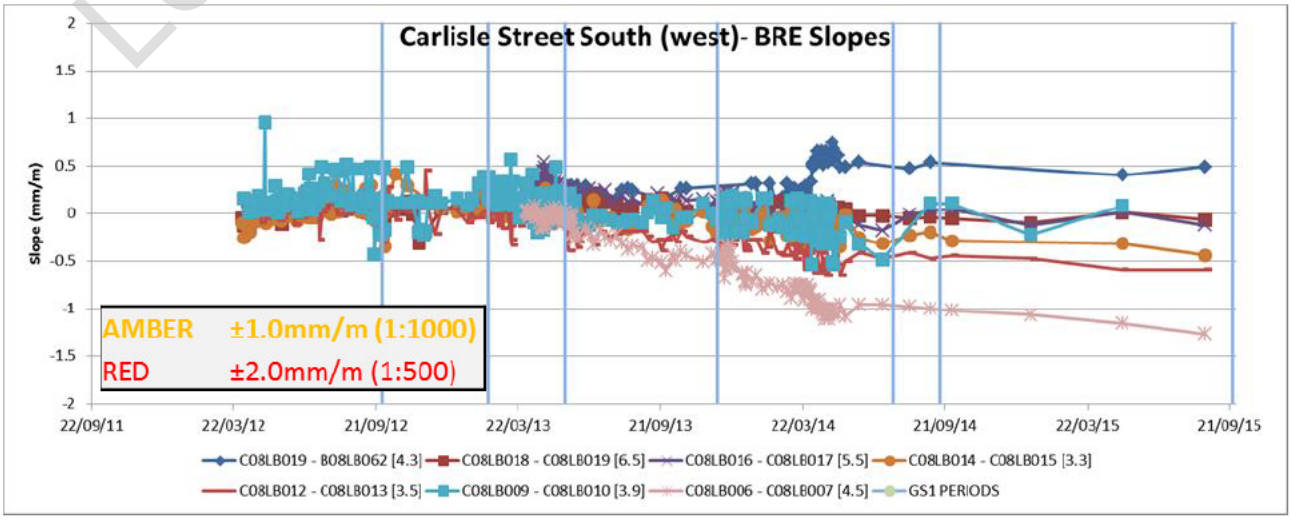
- The Carlisle Street north façade to the west of Dean Street is located fully within the extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the AP1 (Period C), WBRT (Period D) and PTW and PTW2 (Period E). Uplift due to grout jacking is evident in Period C and in Period E associated with grouting for AP1 and PTW / PTW2 excavations respectively.
- There was negligible effect from the WTH excavation (Period A). Heave was generated with concurrent grouting with CH1P, CH1E and AP1 followed by settlement giving a small net settlement (~5mm) at the end of Period C. There was about 5mm settlement from the WBRT and a further 2-3mm during the remainder of Period D giving a total of about 12mm. Settlement during tunnelling for PTW and PTW2 was controlled to small values but post-construction movements in Period E occurred at an increased rate, giving 25mm total at the end of the Period. One Amber slope triggers occurred between C08LB027 and C08LB277.

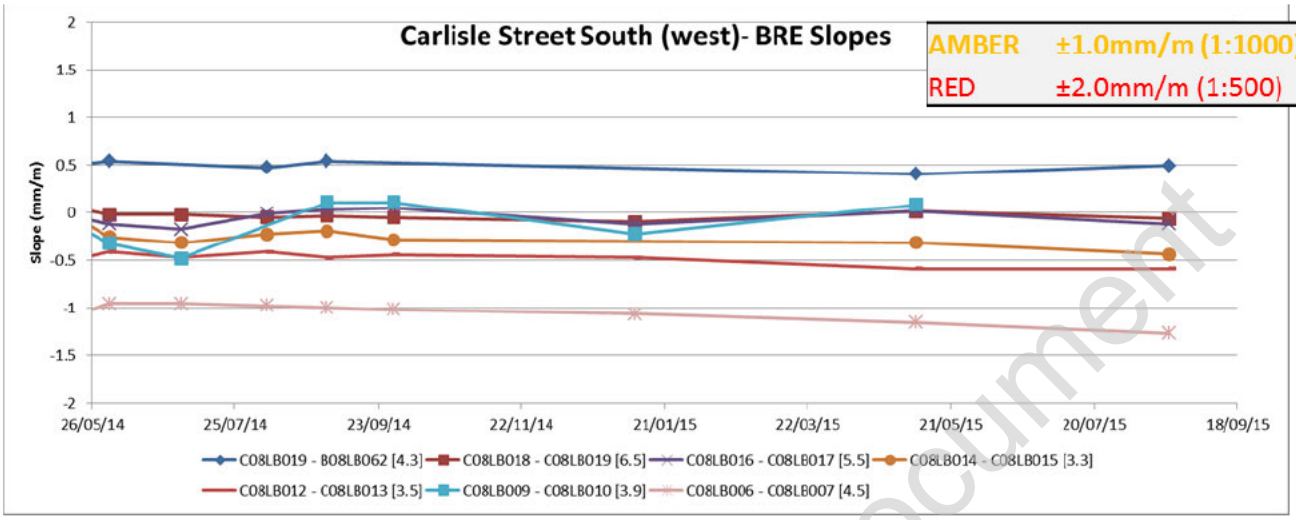
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone. However, there was no discernible effect from VWW works on the Carlisle Street façade.
- Post construction settlement increased by ~4mm to 32mm in Period G.

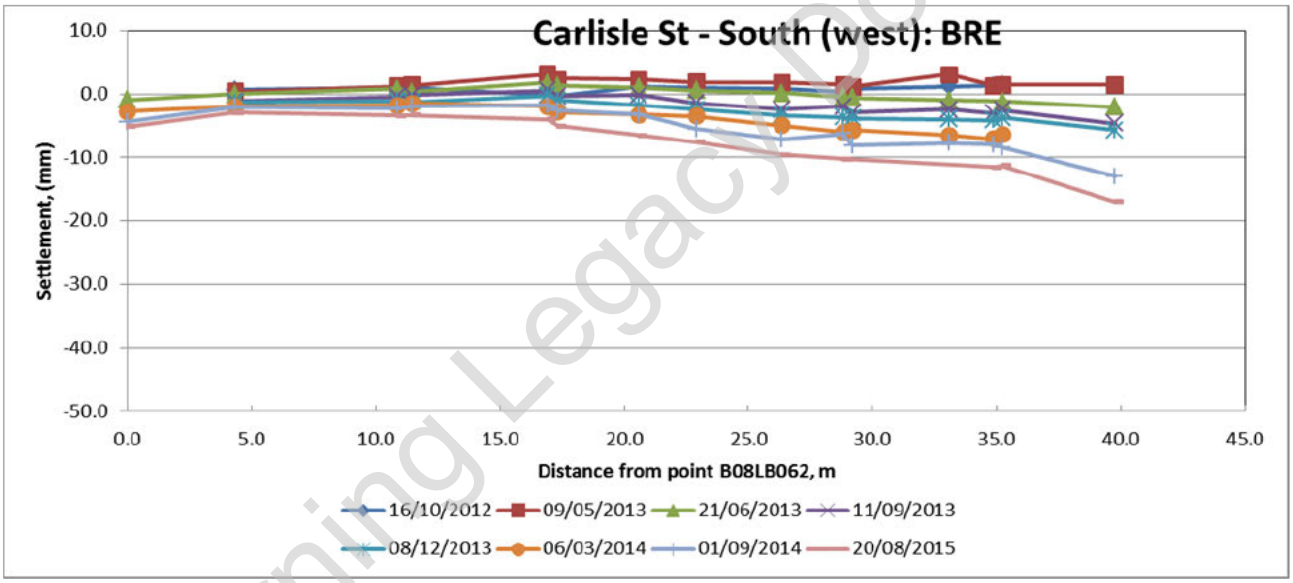
4.10. Carlisle Street - South











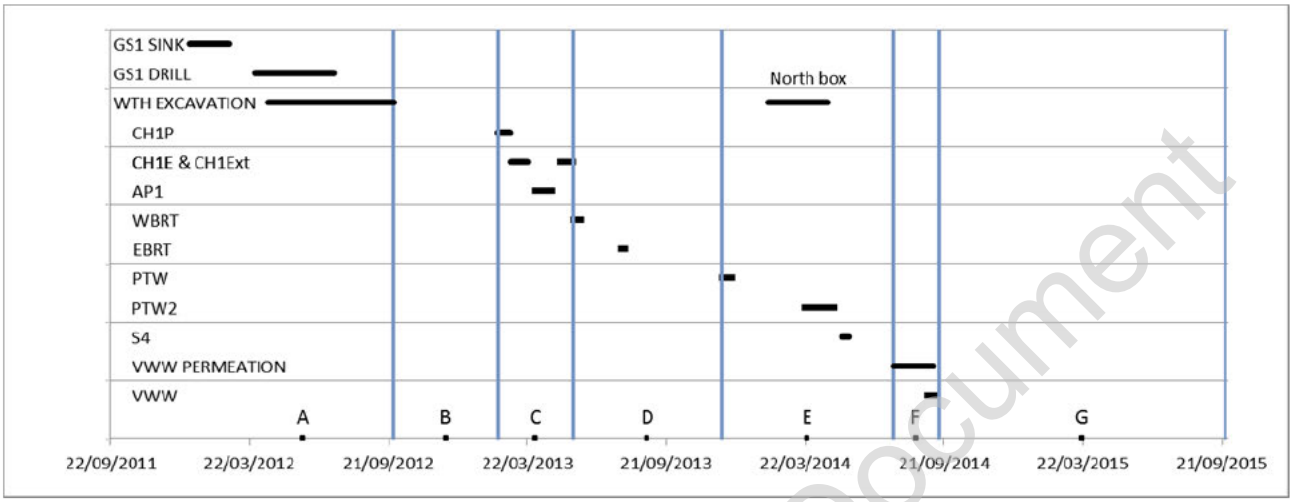
The following points are noted:

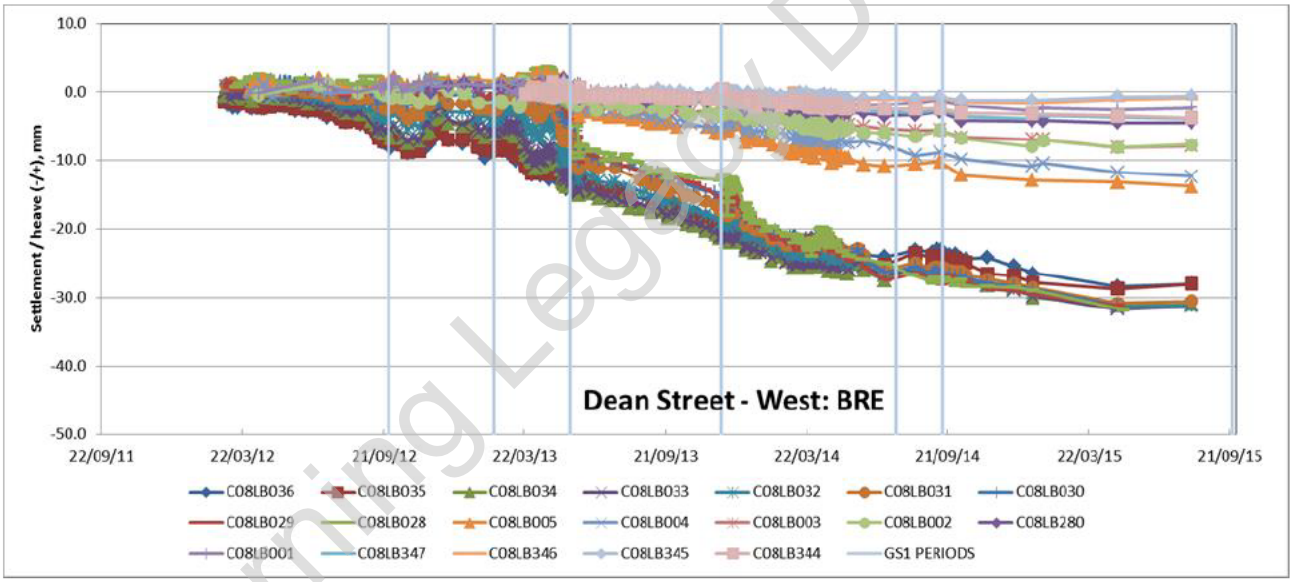
- The Carlisle Street south façade to the west of Dean Street is located fully within the extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the AP1 (Period C), WBRT (Period D) and PTW and PTW2 (Period E). Uplift due to grout jacking is evident in Period C and again in Period E albeit this is associated with concurrent grouting for AP1 and PTW / PTW2 excavations respectively. The net movement from each of these tunnels was very small.
- There was negligible effect from the WTH excavation (Period A). Heave was generated with concurrent grouting with CH1P, CH1E and AP1 followed by settlement giving no net settlement at the end of Period C. There was about 2mm settlement from the WBRT and a further 3-4mm during the remainder of Period D giving a total of about 6mm. Settlement during tunnelling for PTW and PTW2 was controlled to small values but post-construction movements in Period E occurred at an increased rate, giving 12mm total at the end of the Period. An Amber slope trigger

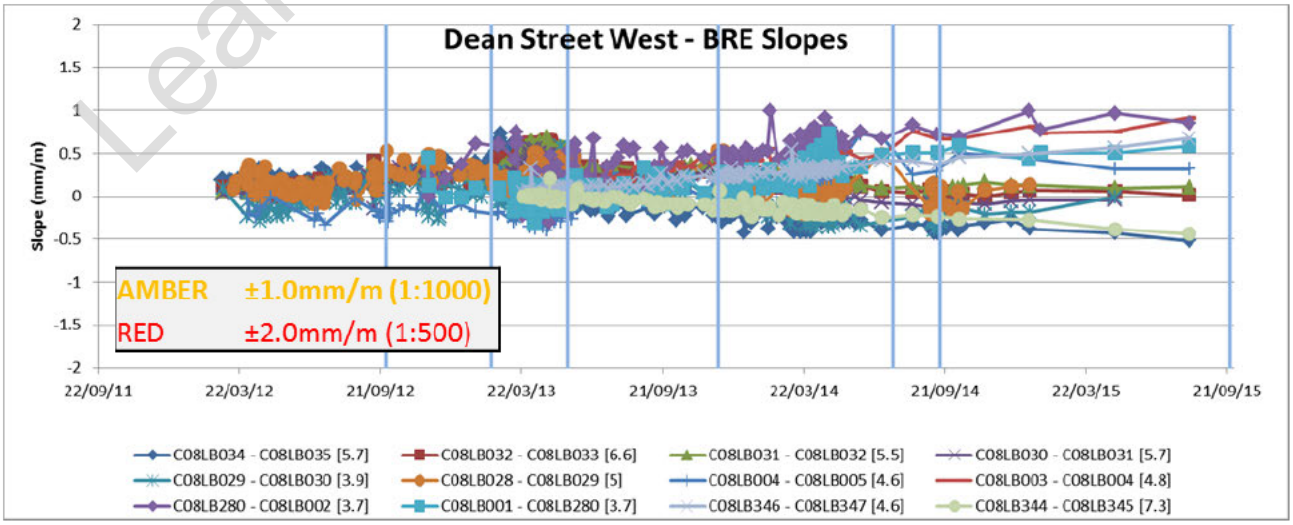
occurred between C08LB006 and C08LB007, albeit it reduced to <1.0mm/m before the end of the Period.

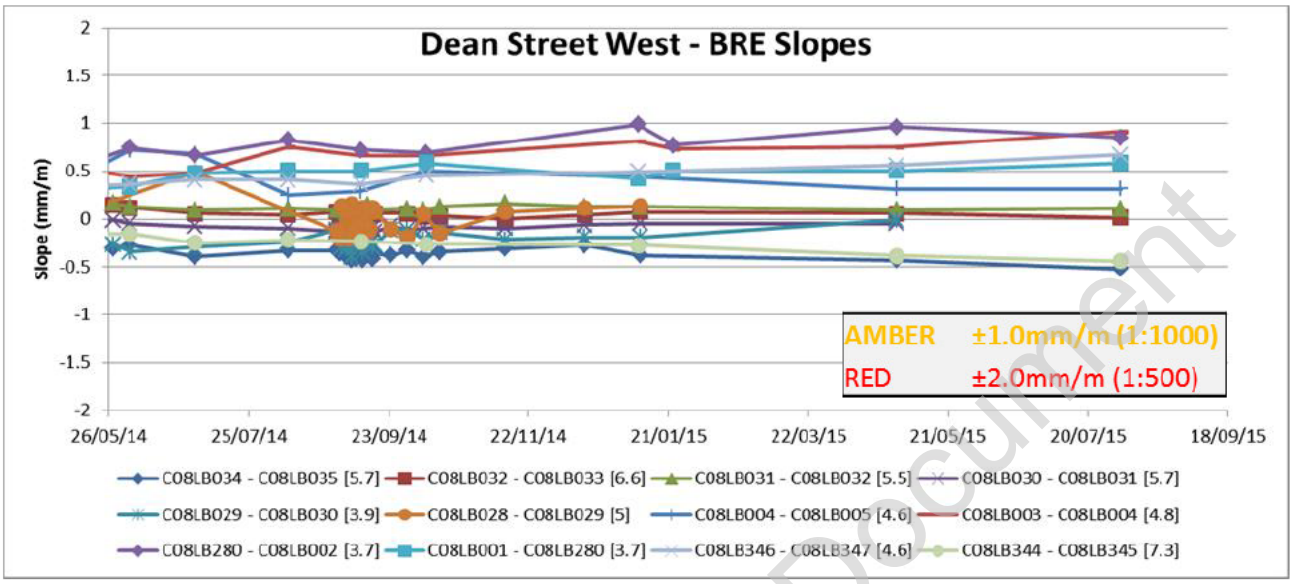
- Post construction settlement increased by up to 5mm in Period G. The post-construction readings indicate that Amber trigger between points C08LB006 and C08LB007 re-occurred.

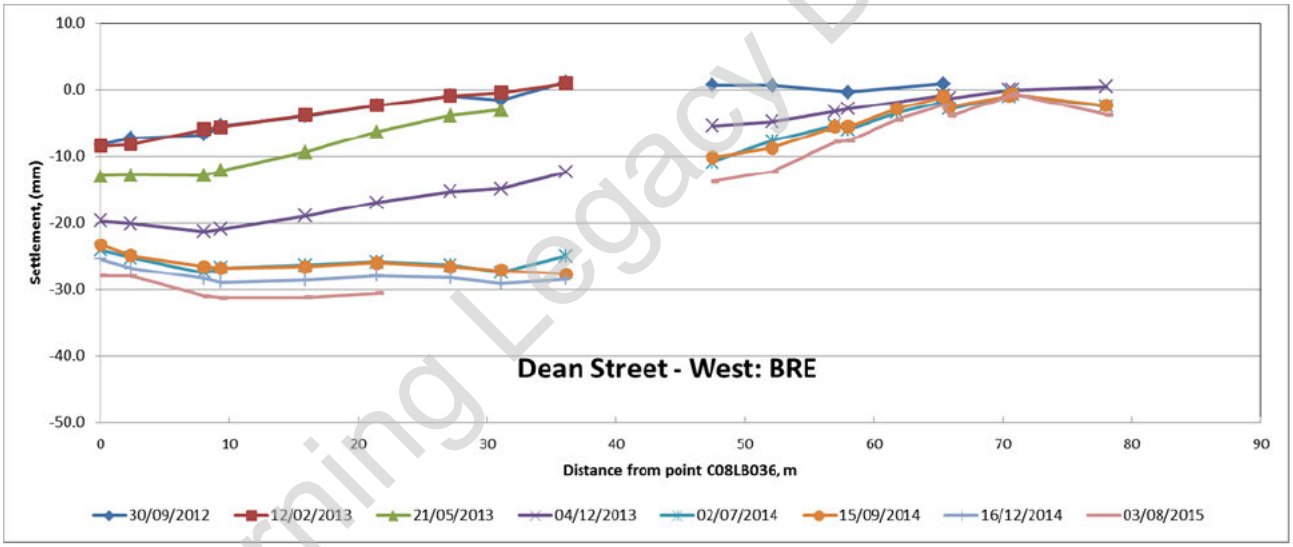
4.11. Dean Street - West











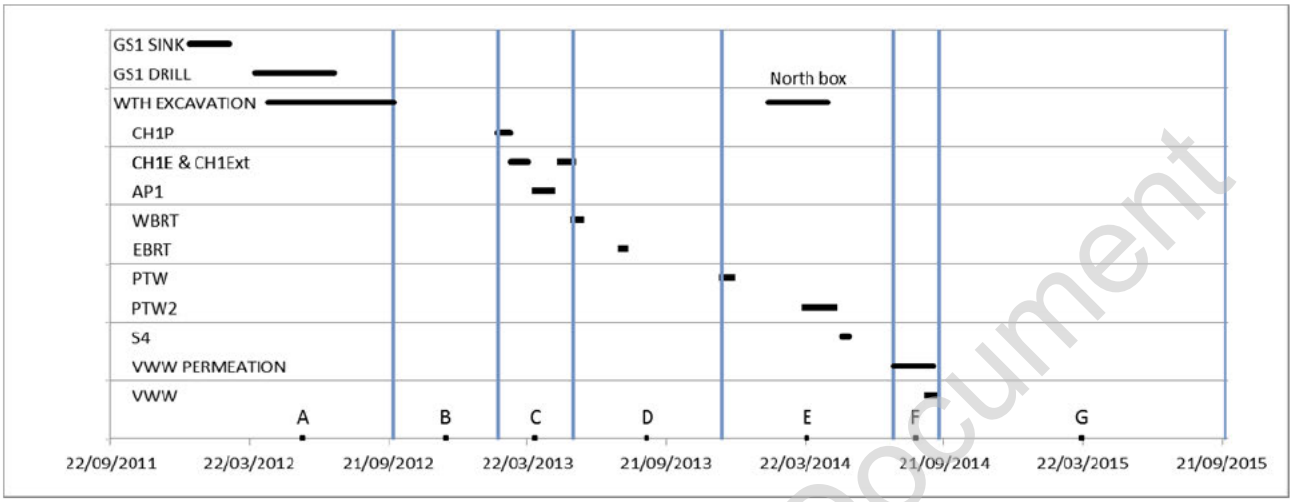
The following points are noted:

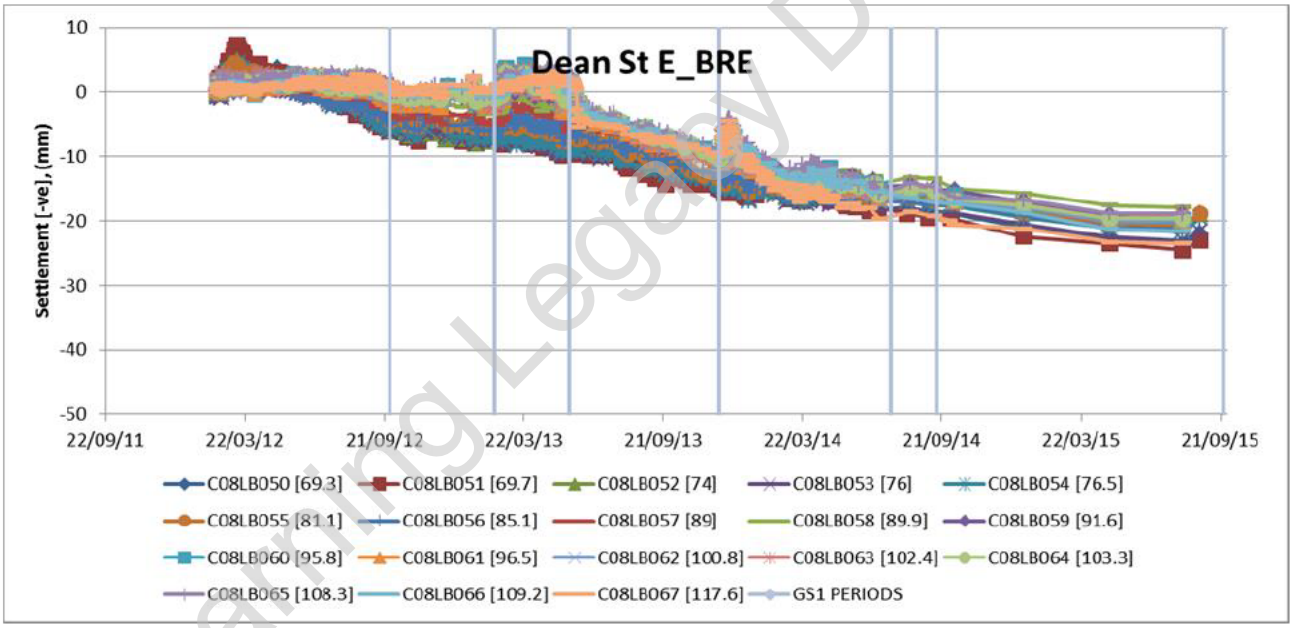
- The Dean Street west façade is located within the extent of the GS1 array as far as 89 Dean Street (distance 59m on the profile plot).
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), the CH1E / AP1 (Period C) and PTW (Period E), albeit the effects are small and the overall trend is characterised by gradual post tunnelling increases. Uplift due to grout jacking is evident in Period B, prior to the start of tunnelling and during Period C following the completion of CH1E.
- Settlement reached ~8mm due to the WTH excavation (Period A), was reduced by up to 3mm by grouting in Period B. Settlement then increased gradually to 27mm at the end of Period E.
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the appropriate level for drilling. No compensation grouting was required (or possible) since the

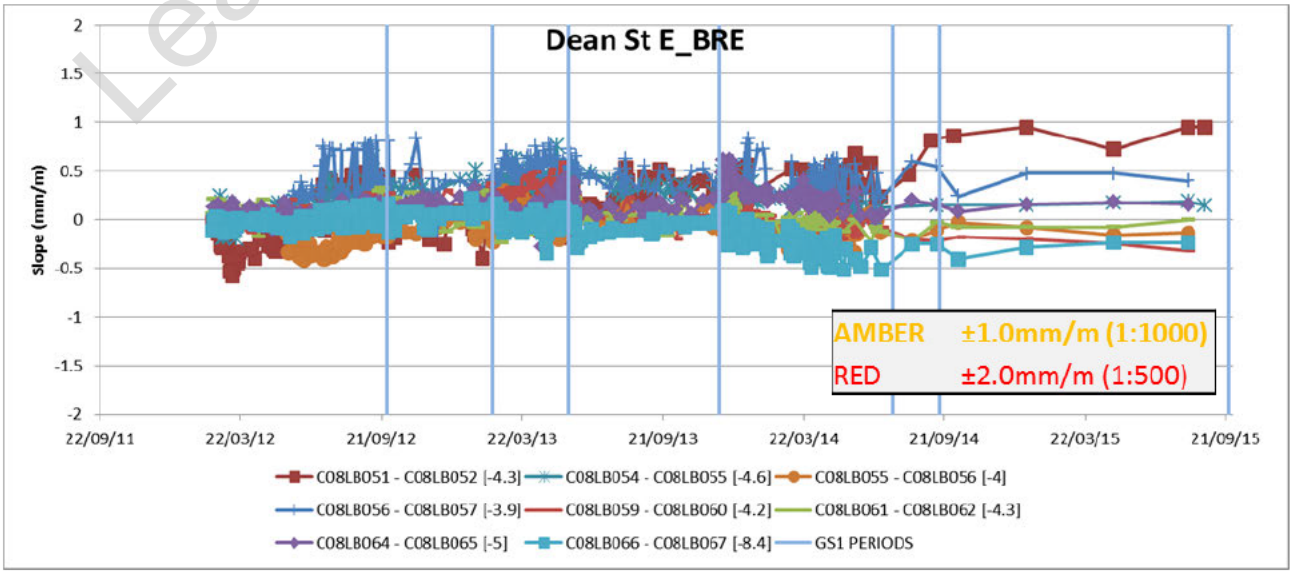
crown of the VWW was within the vertical exclusion zone. There was no significant effect from VWW works on the Dean Street façade.

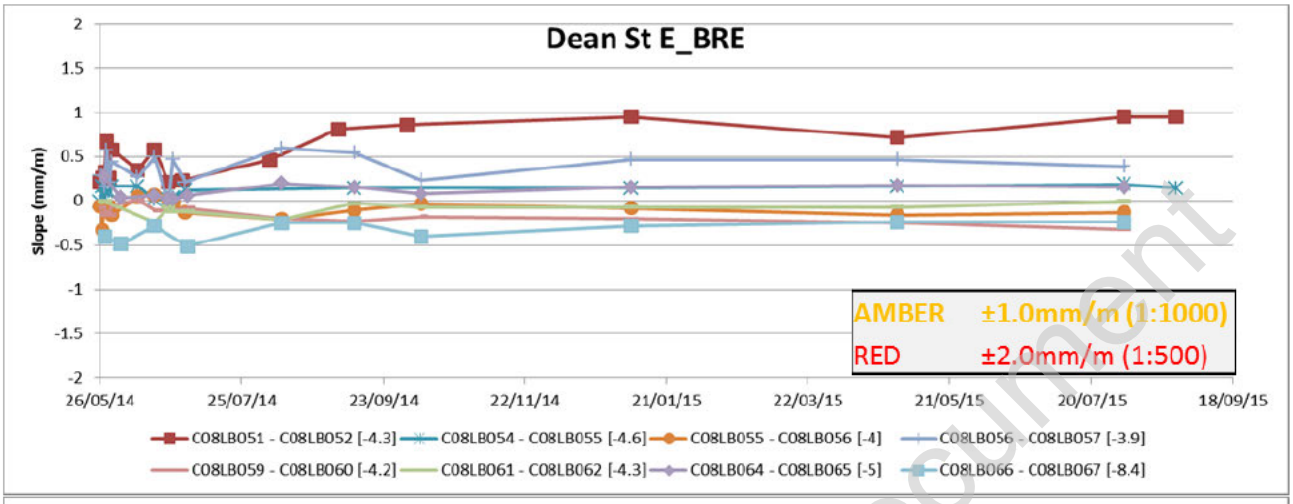
- No slope triggers occurred although an errant reading in Period E and two readings in Period G give values >0.95mm/m.
- The maximum increase in post construction settlement was approximately 5mm.

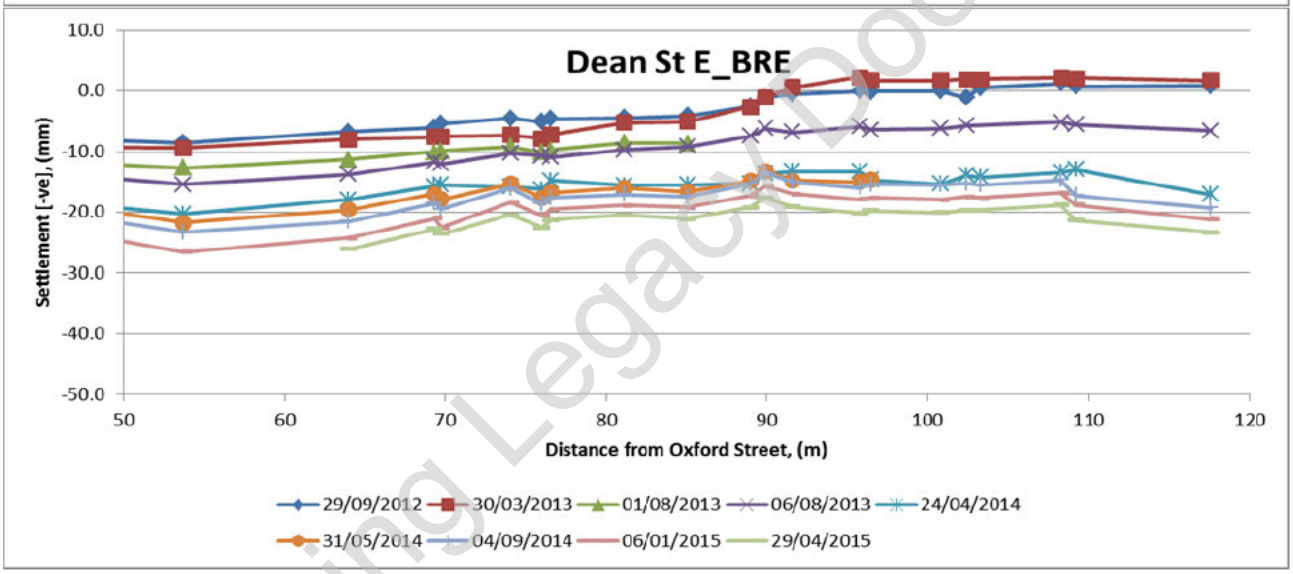
4.12. Dean Street – East











The following points are noted:

- The Dean Street east façade is located within the extent of the GS1 array from Carlisle Street to adjacent to the South Box south wall (between distances 75m and 118m on the profile plot).
- Heave is evident on points C08LB050 to C08LB055 during Period A pror to the commencement of TaM drilling from GS1. These points are at the northern end of the profile and were effected by the Tam drilling from the adjacent GS7 (see C300-BFK-C4-RGN-CRT00_ST005-51231).
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), the WBRT (Period D) and PTW (Period E), albeit the effects are small and the overall trend is characterised by gradual post tunnelling increases. Uplift is evident in Periods C and E, associated with concurrent grouting with CH1Ext and PTW respectively.
- Settlement reached ~8mm due to the WTH excavation (Period A). Settlement then increased gradually to ~20mm at the end of Period E.
- No slope triggers occurred although two readings in Period G gave values >0.95mm/m.
- The maximum increase in post construction settlement was approximately 5mm.

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 5.1.1. A larger version of Figure 5.1.1 is included in Appendix C. Details of slope trigger breaches are given in Table 5.1. By inspection, no Deflection Ratio triggers have been breached.

Slope triggers are as follows:

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

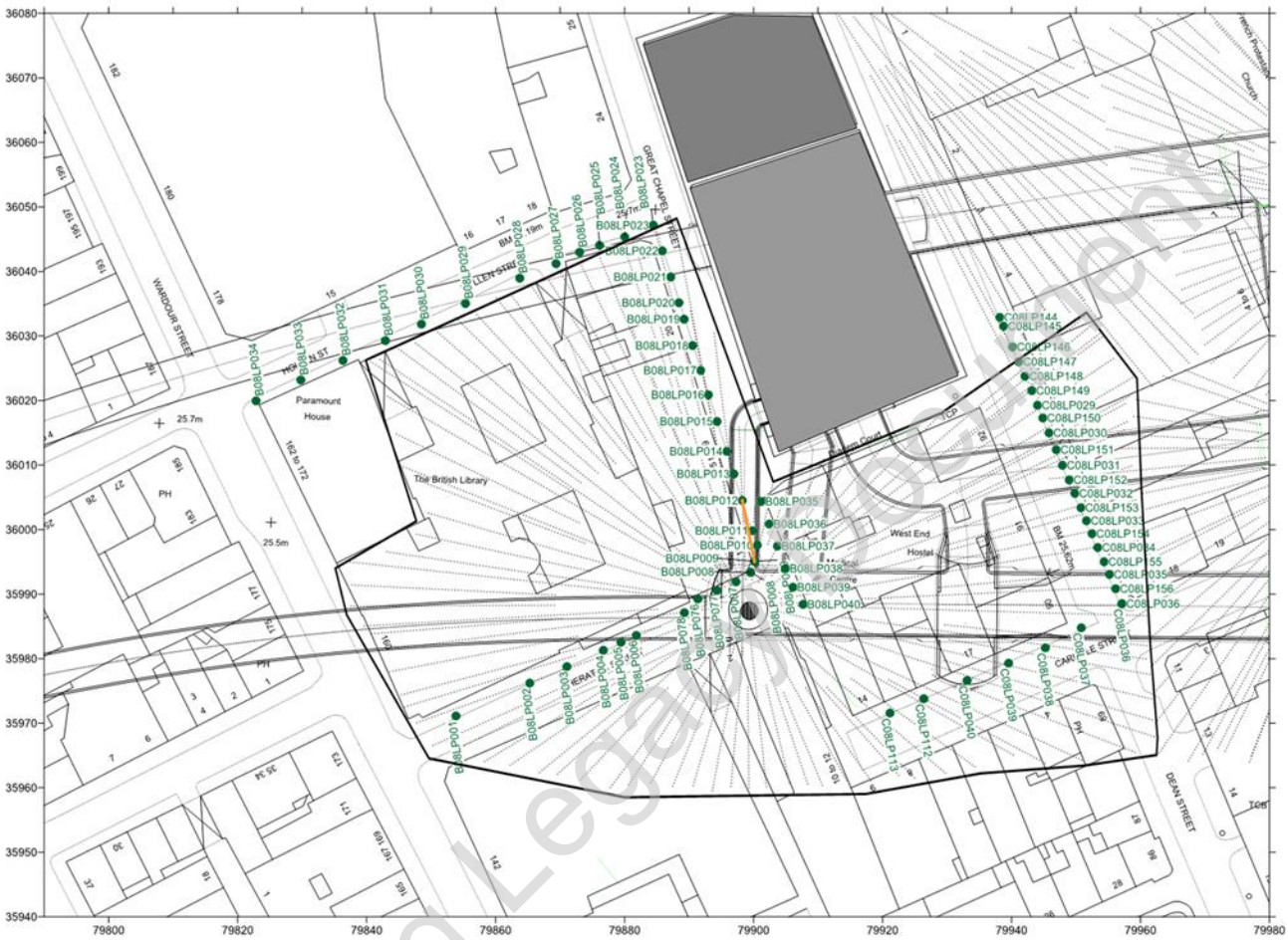
Table 5.1 Details of Amber trigger breaches on PLP

Kerb Lines		Comment	Date exceeded	Maximum (mm/m)	Final (mm/m)
Hollen Street South: NONE					
Sheraton Street North: NONE					
Great Chapel Street East: NONE					
Great Chapel Street West					
B08LP009 – B08LP012	Amber	Associated with VWW works after GS1 de-commissioned. PLP at corner of Sheraton St. 5mm settlement between 2 readings post construction	01/09/14	1.44	1.44
Carlisle Street West North: NONE					
Dean Street East: NONE					

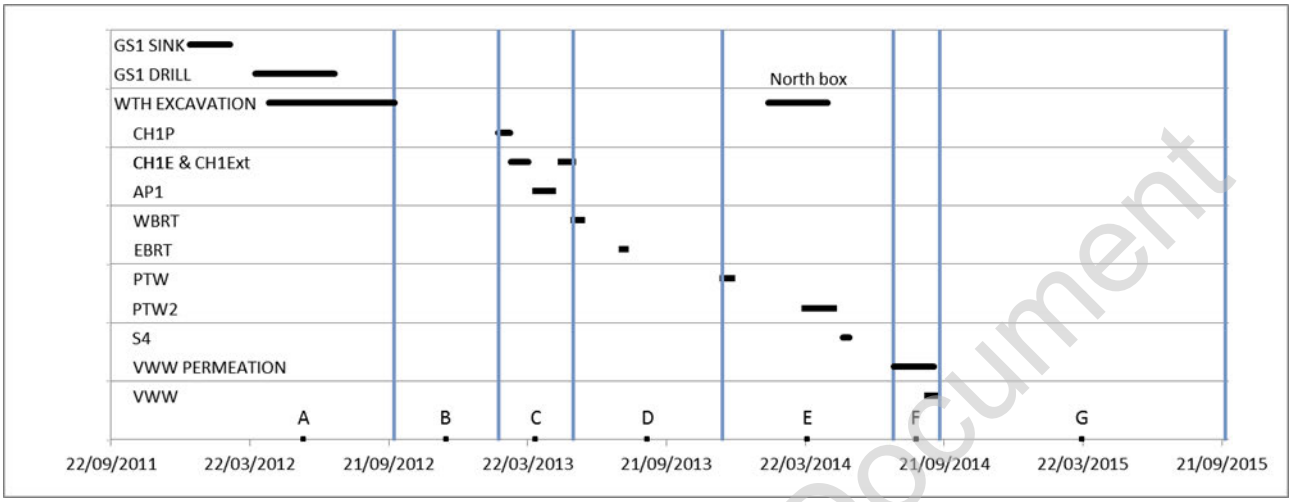
PLP monitoring data from the kerblines within the footprint of GS1 are presented in the following sections, namely Hollen Street south, Sheraton Street north, Great Chapel Street east and west, Carlisle Street north and Dean Street east. The plots presented for each comprise, as appropriate:

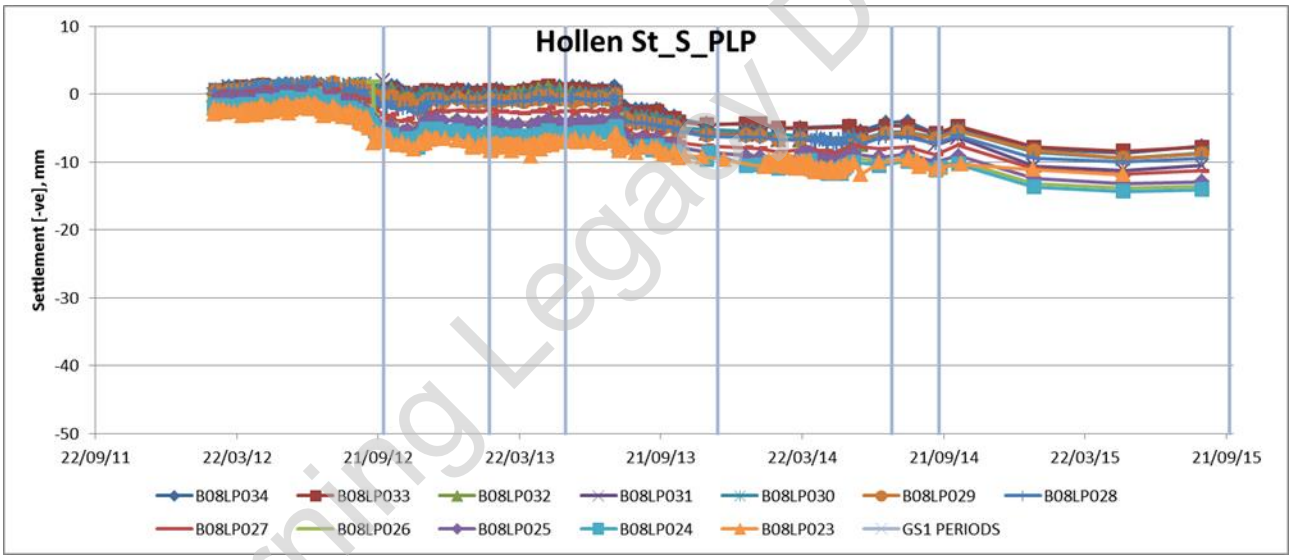
1. Summary of tunnel construction and associated construction periods
2. Time settlement history
3. Settlement profile plots with series as close to the end of each construction period as is available
4. Time slope history over the full construction period with the distances between the points in metres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

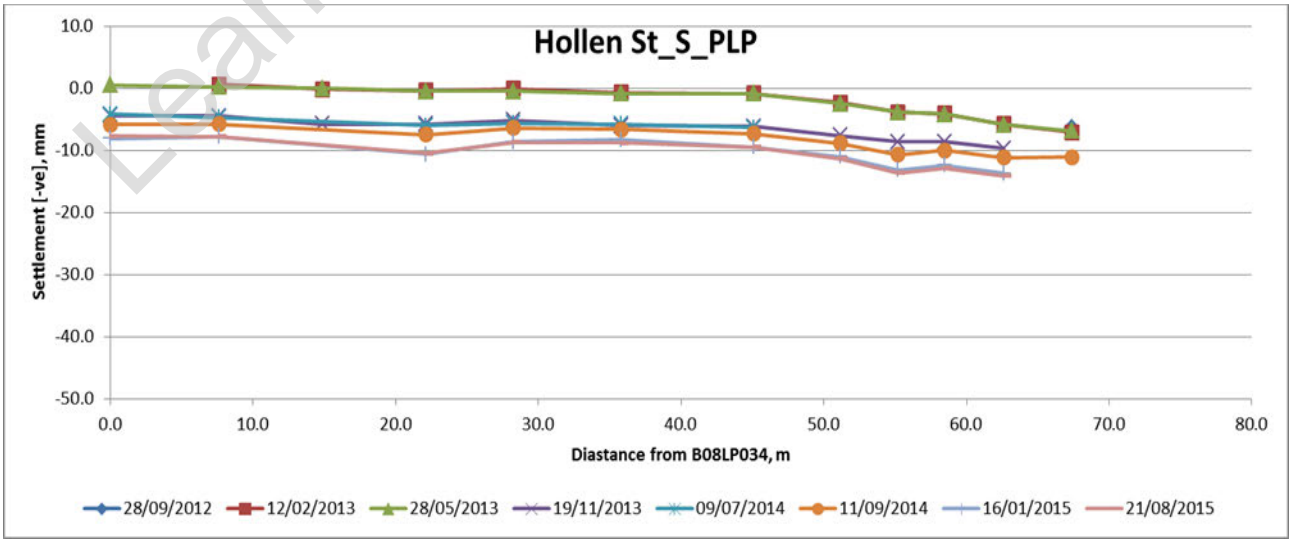
Figure 5.1.1 Location of PLP and ground slope trigger breaches



5.2. Hollen Street – south



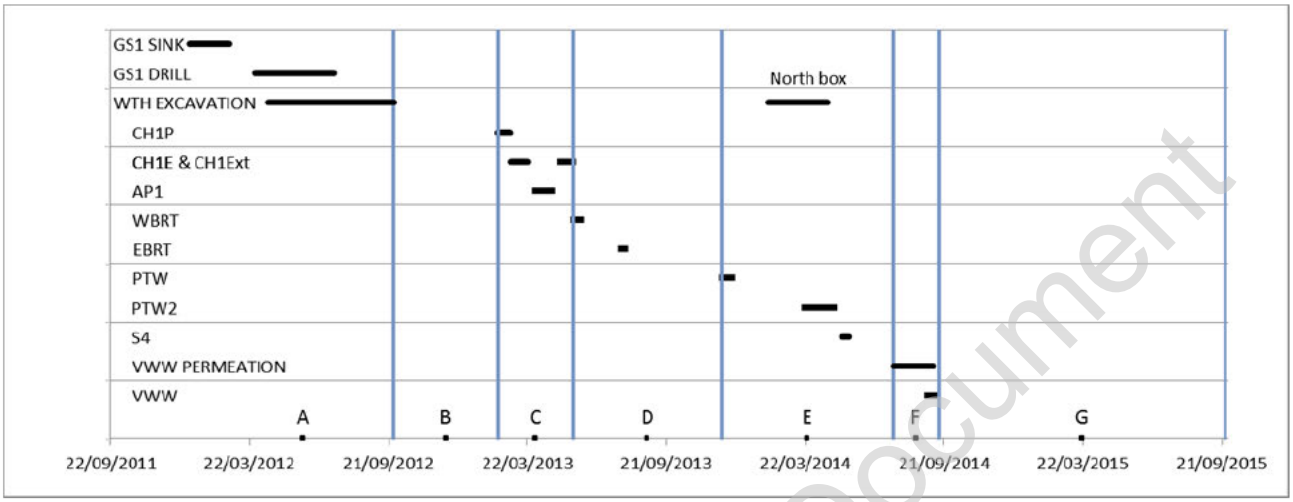


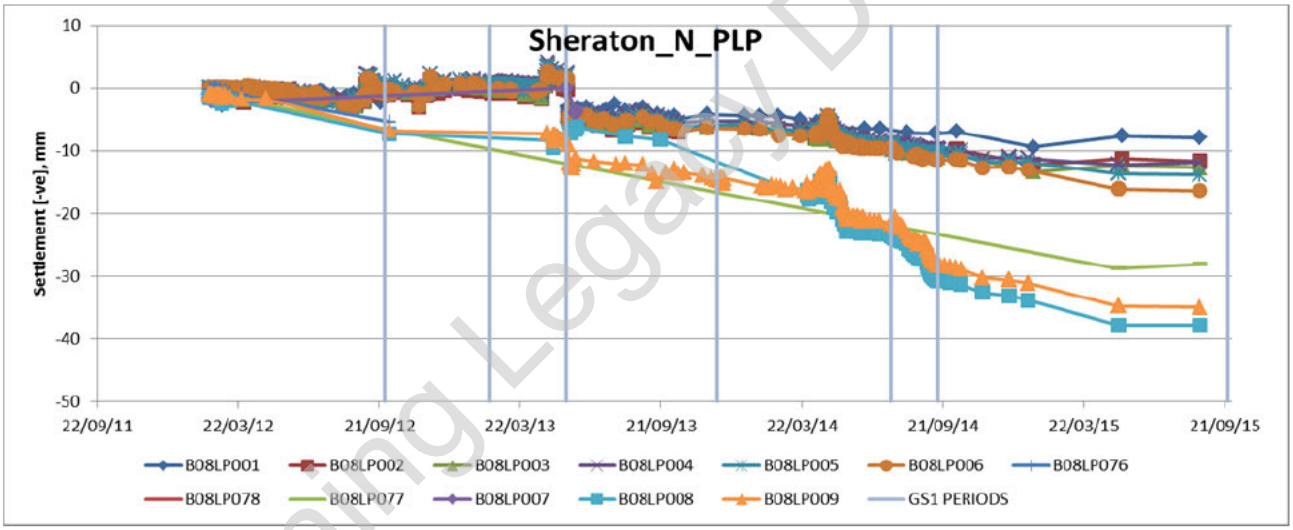


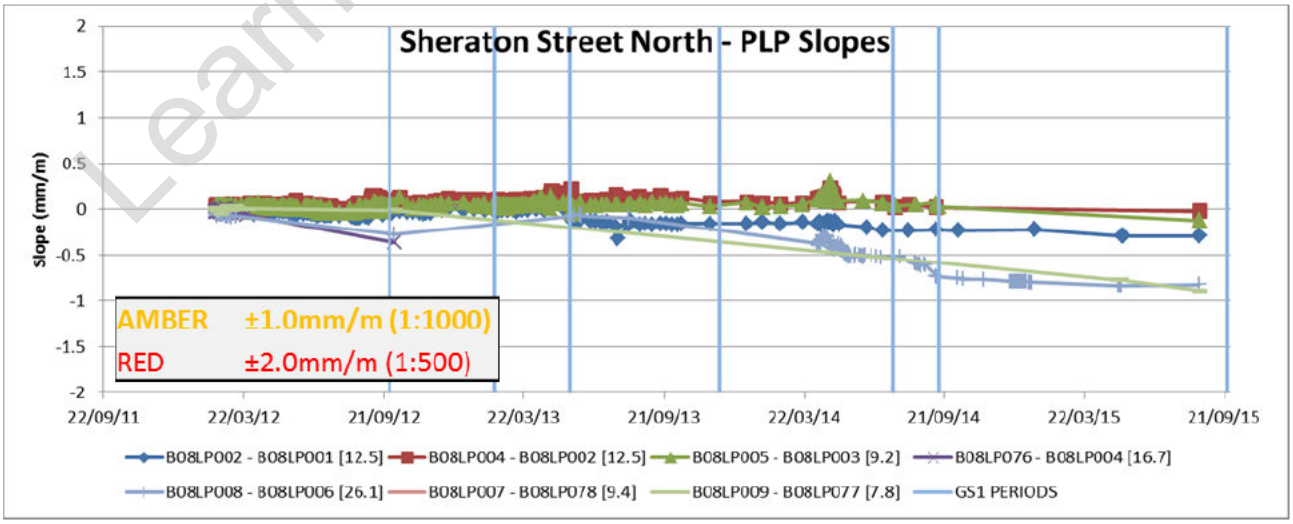
The following points are noted:

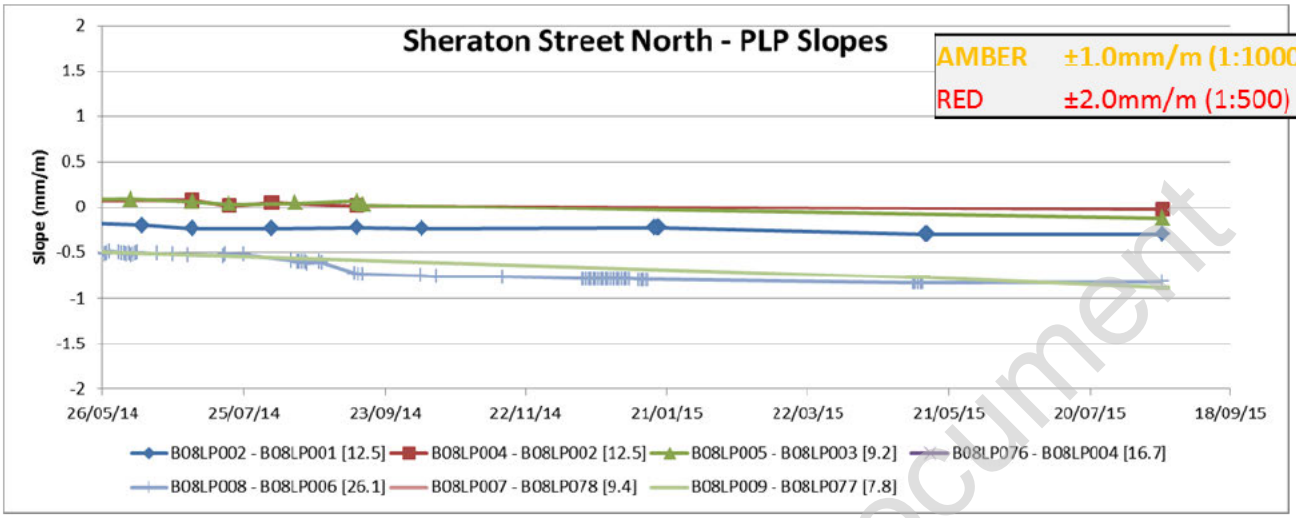
- The kerbline on the south side of Hollen Street is at the periphery of the GS1 arrays.
- The key events were the WTH excavation in Period A and the EBRT in Period D. It is noted that at the end of these activities the maximum settlement was about 10mm. At the end of Period A, the settlement had reached 8mm primarily due to the WTH excavation and in Period D the EBRT produced less than 5mm settlement.
- The profile plot confirms that the settlement was nearly uniform over the full profile and, by inspection, the resulting change in slopes were not significant.

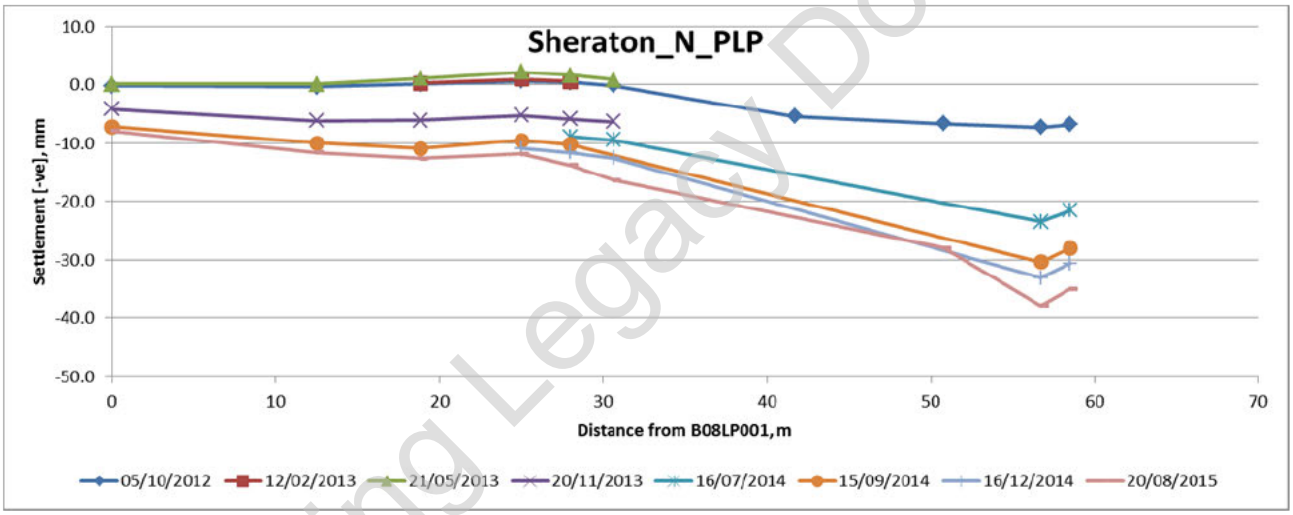
5.3. Sheraton Street - north









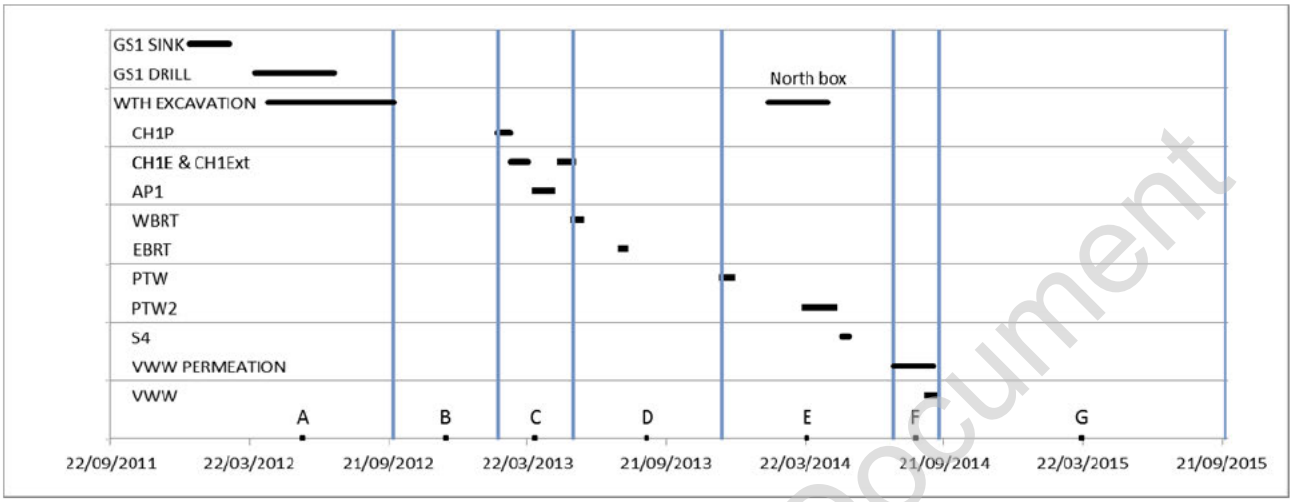


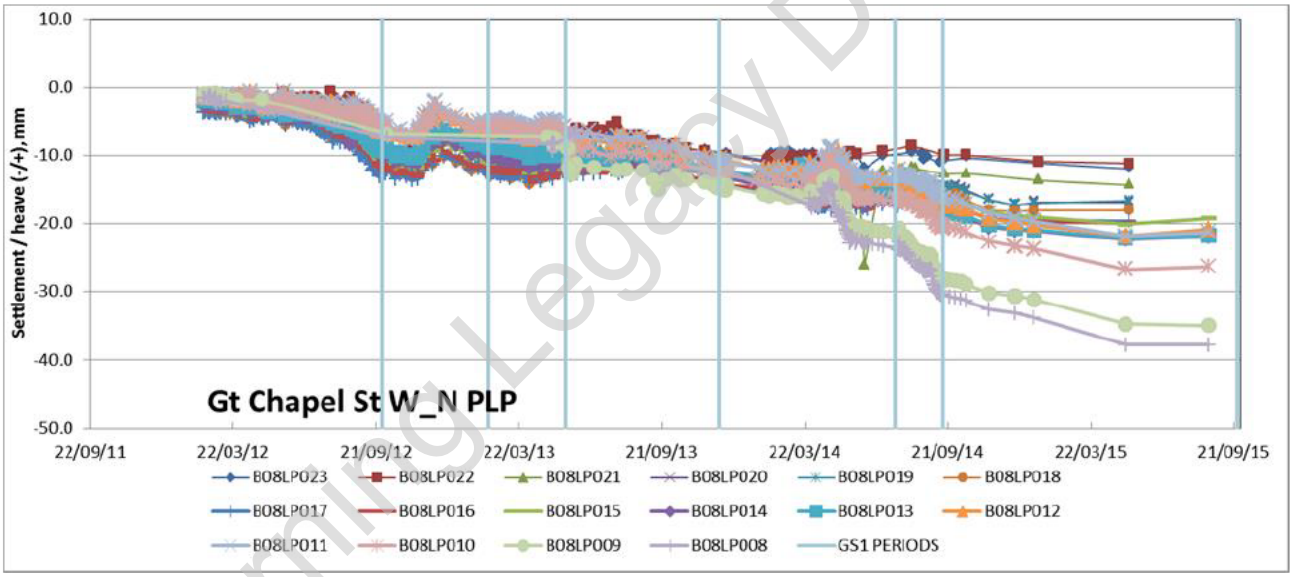
The following points are noted:

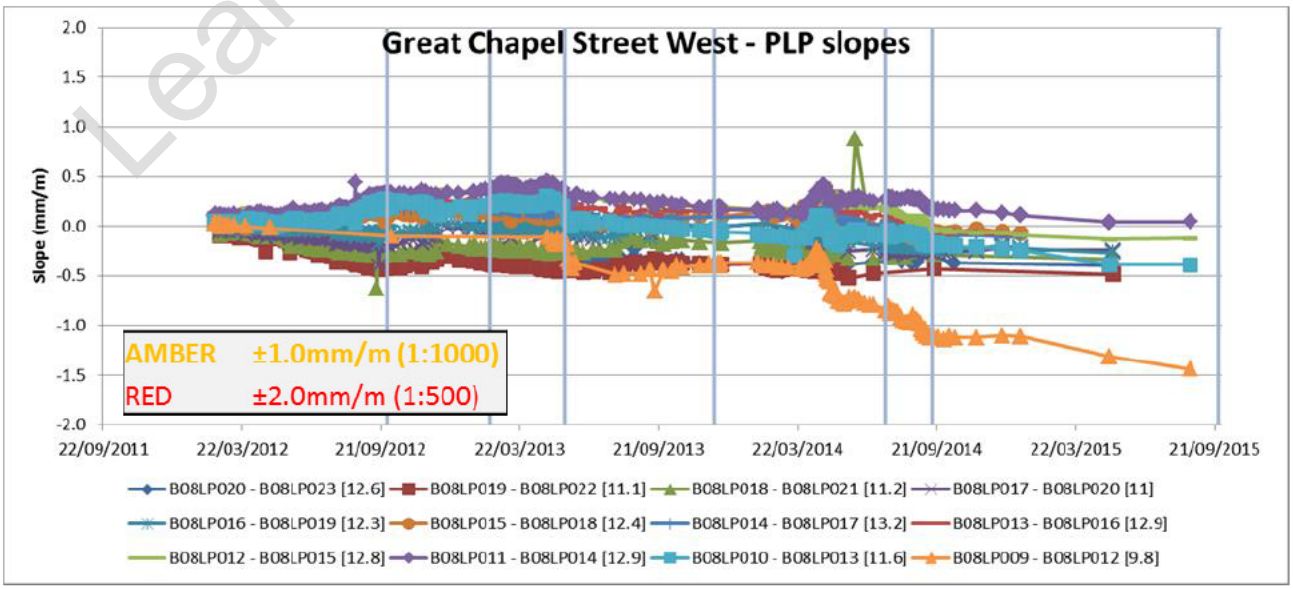
- GS1 is located at the east end of Sheraton Street and the north kerbline was close to the 3m exclusion zone around the shaft. The whole of the transect is within the extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), the WBRT (Period D), PTW2 and S4 (Period E) and the VWW permeation grouting and excavation in Period F. Heave associated with pre-treatment and grout jacking maintained settlement to ~15mm at the end of Period D.
- A key activity in Period E was the PTW2 which passed directly below GS1 and no grouting was possible within a 5m radius of the shaft centre. An increase in settlement of about 8mm (to 23mm) was recorded at the corner of Sheraton Street and Great Chapel Street.
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.

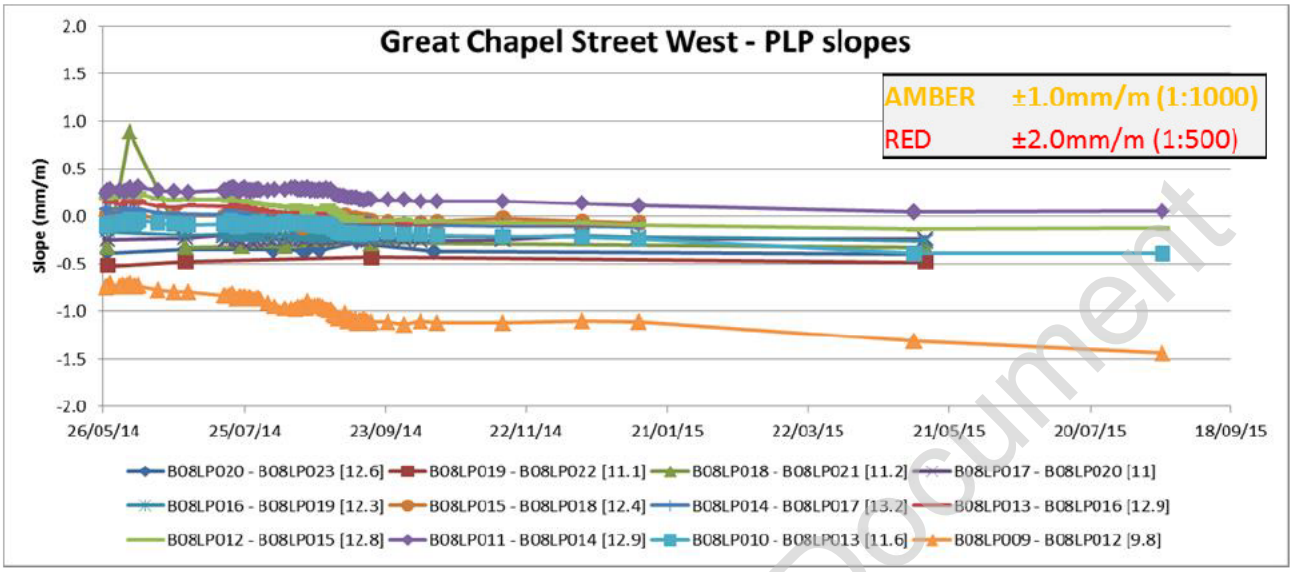
- The permeation grouting continued after the start of excavation of VWW. The combined effect of the grouting and tunnelling was a further increase in settlement of 8mm (to 30mm).
- The maximum increase in post construction settlement in Period G was approximately 8mm
- No slope trigger breaches were recorded during or following construction.

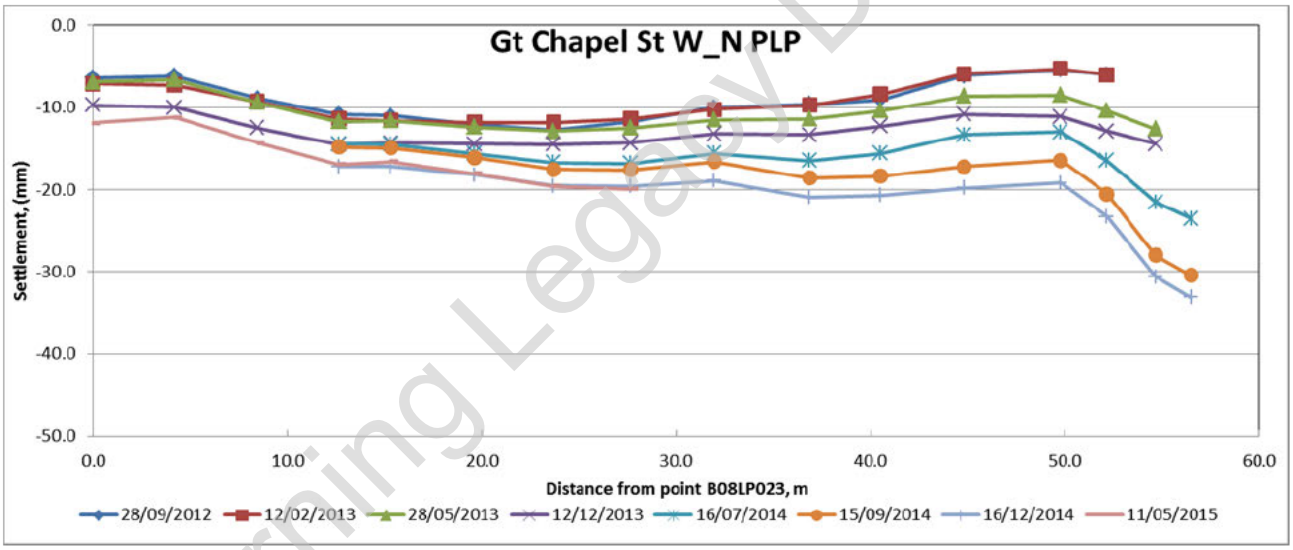
5.4. Great Chapel Street - west











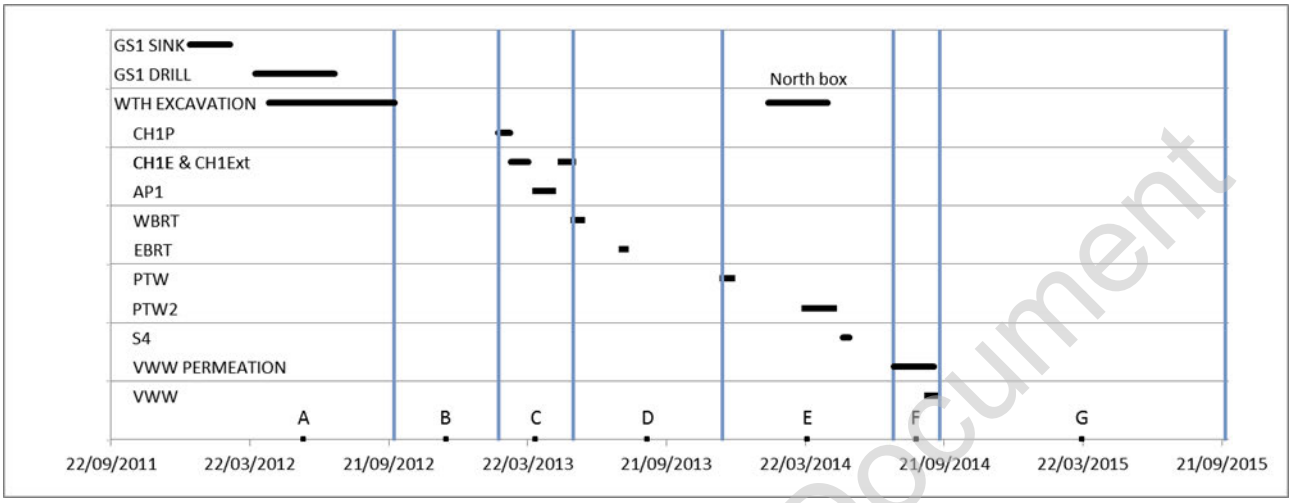
The following points are noted:

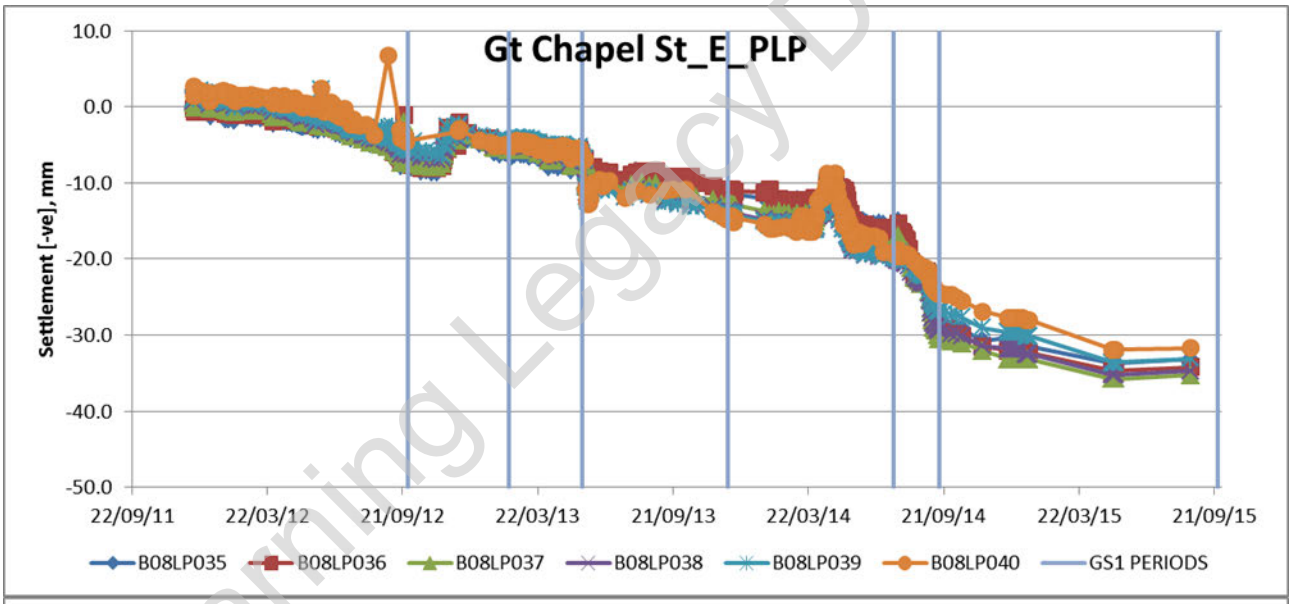
- The Great Chapel Street west kerbline between Sheraton Street and Hollen Street is located fully within the extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), PTW2 and S4 (Period E) and the VWW permeation grouting and excavation in Period F. Very minor effects were recorded from the WBRT and EBRT drives in Period D. Uplift due to grout jacking is evident in Period B, prior to the start of tunnelling, and in Period E prior to and during PTW2 excavation due to concurrent grouting.
- Settlement reached ~12mm due to the WTH excavation (Period A), was reduced by up to 5mm by grouting in Period B. Settlement then increased gradually to 17mm ahead of PTW2 which resulted in an increase in settlement of about 5mm (to 22mm).
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the

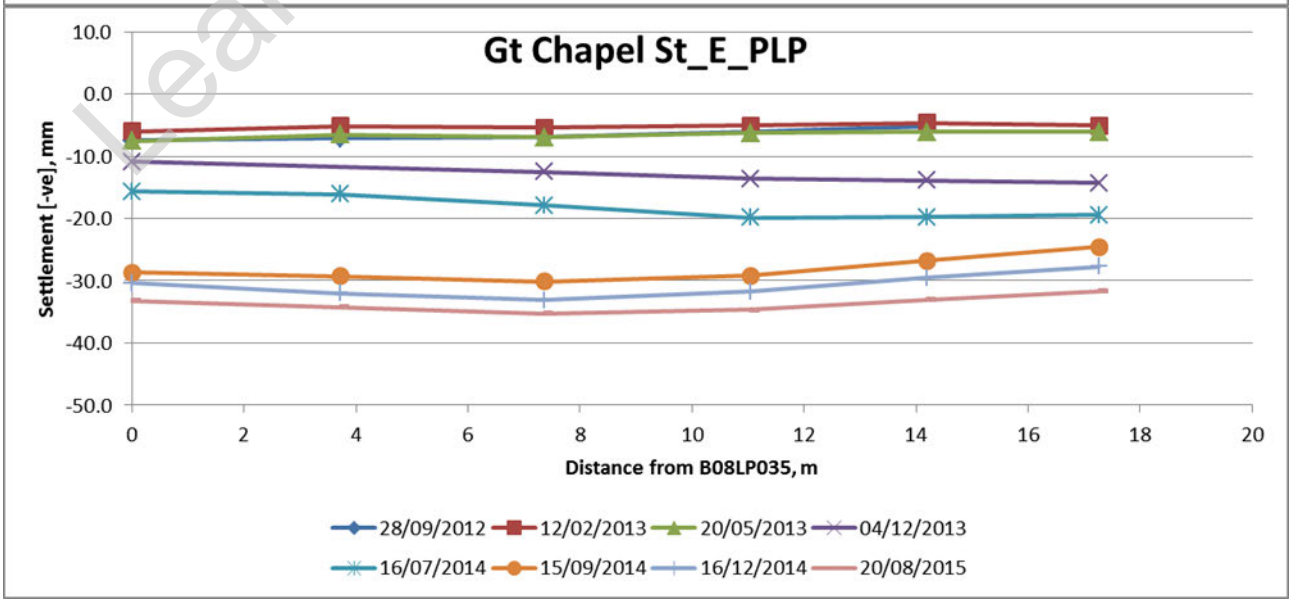
appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.

- The permeation grouting continued after the start of excavation of VWW. The combined effect of the grouting and tunnelling was a further increase in settlement of 9mm to (31mm) and an associated Amber trigger breach between B08LP009 and B08LP012.
- The maximum increase in post construction settlement in Period G was approximately 7mm. An increase in slope between B08LP009 and B08LP012 from ~1.2mm/m to almost 1.5mm/m was also recorded in Period G.

5.5. Great Chapel Street – east



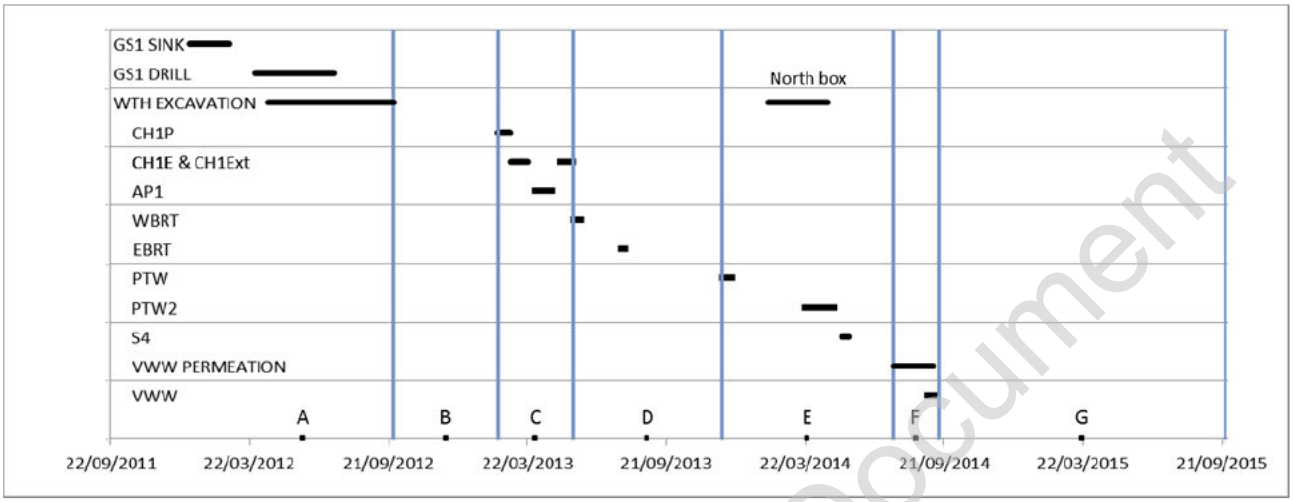


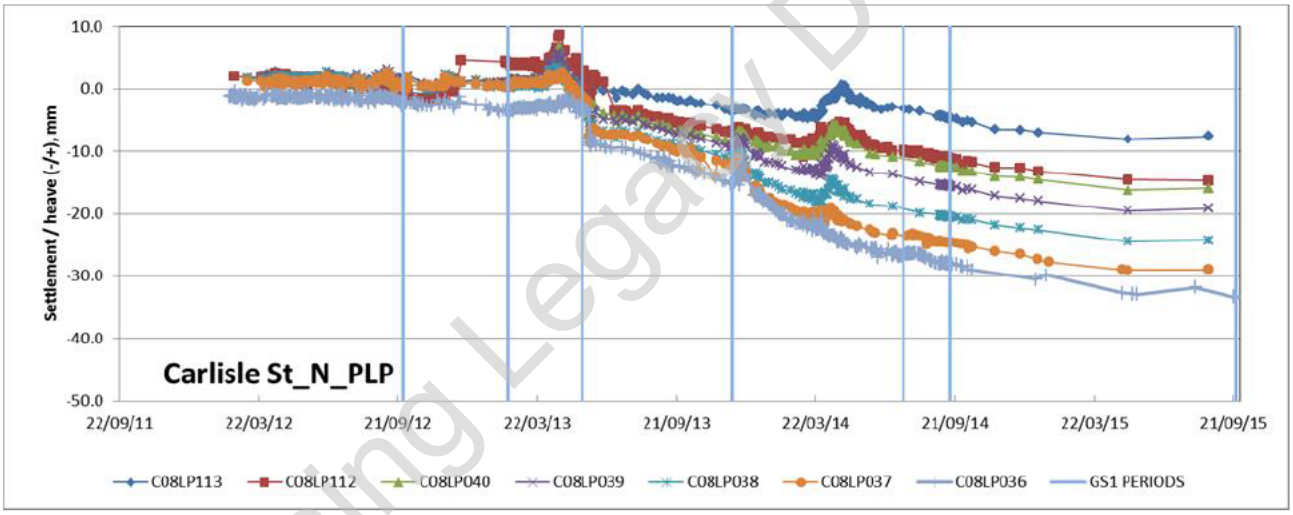


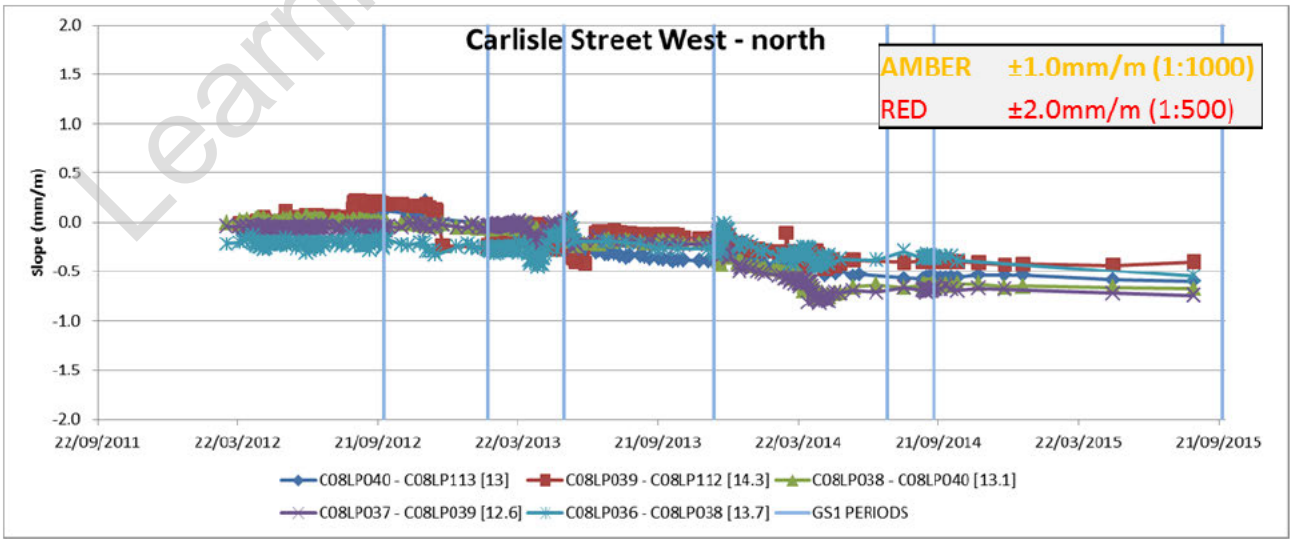
The following points are noted:

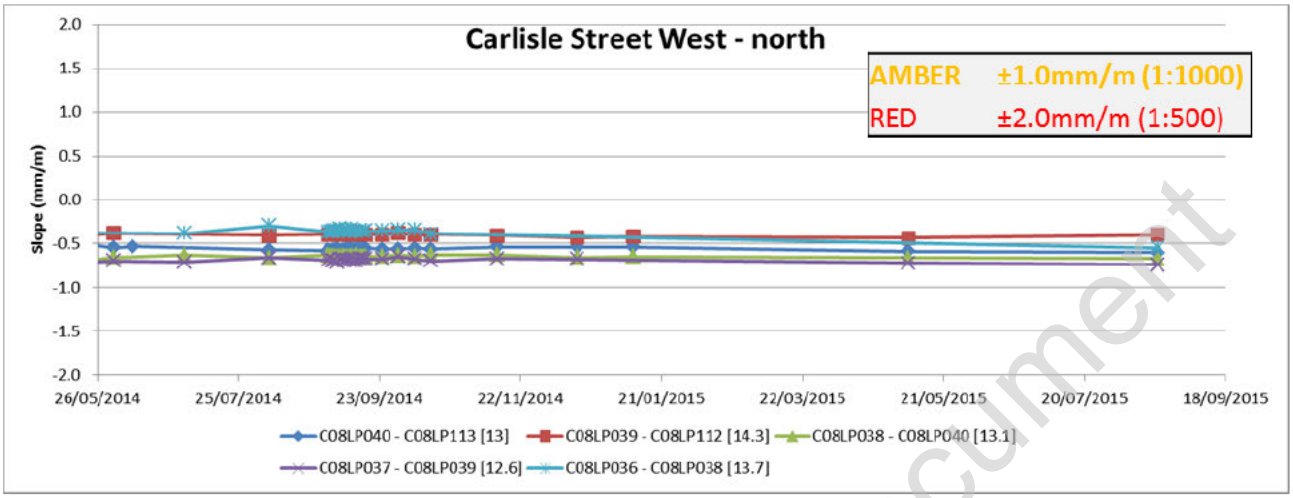
- The Great Chapel Street east kerbline is located fully within the extent of the GS1 array.
- Increases in settlement are evident associated in the time settlement history plot with the WTH (Period A), the WBRT (Period D), PTW2 and S4 (Period E) and the VWW permeation grouting and excavation in Period F. Uplift due to grout jacking is evident in Period B, prior to the start of tunnelling, and in Period E prior to and during PTW2 excavation.
- Settlement reached ~8mm due to the WTH excavation (Period A), was reduced by up to 5mm by grouting in Period B. Settlement then increased gradually to 16mm ahead of PTW2 and to 19mm following PTW2.
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone.
- The permeation grouting continued after the start of excavation of VWW. The combined effect of the grouting and tunnelling was a further increase in settlement of 12mm (to 31mm).
- The increase in settlement in Period G was ~5mm.
- By inspection of the profile plot, settlement was relatively uniform both during and following construction and no slope triggers occurred.

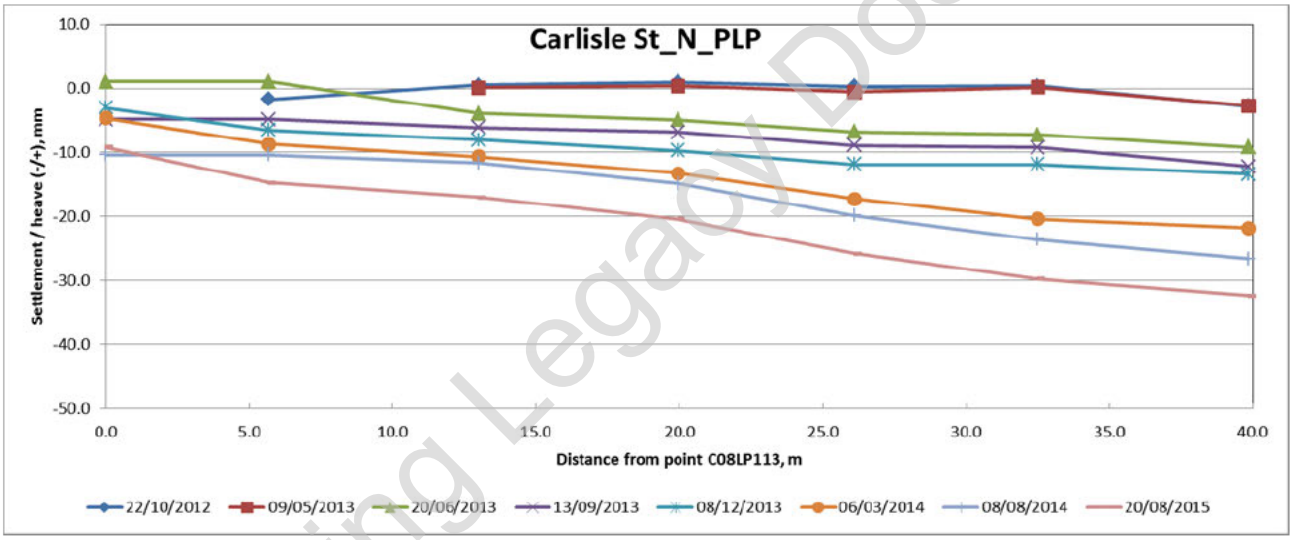
5.6. Carlisle Street - north











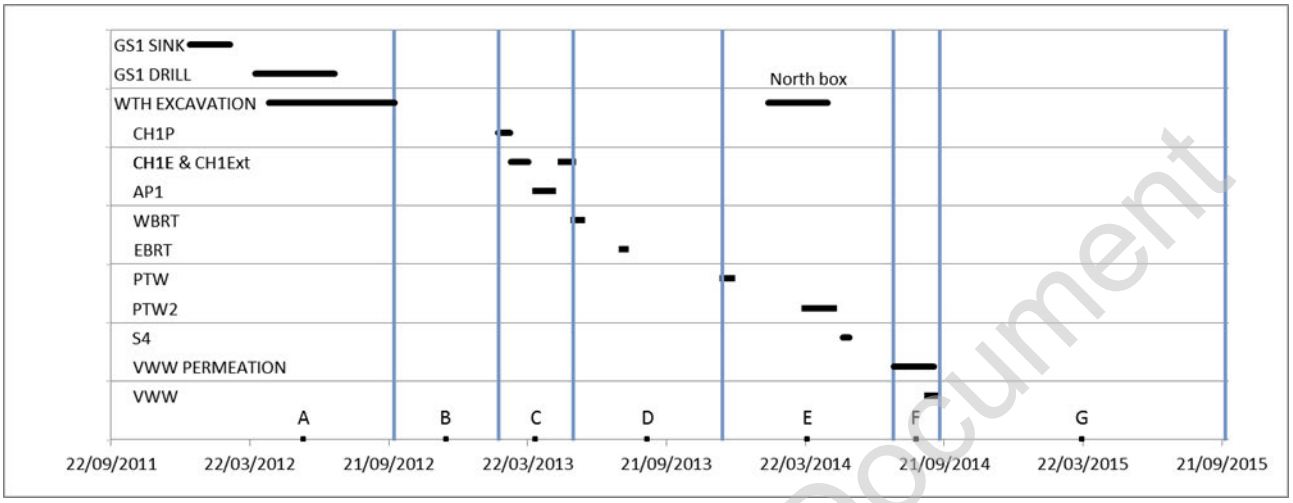
The following points are noted:

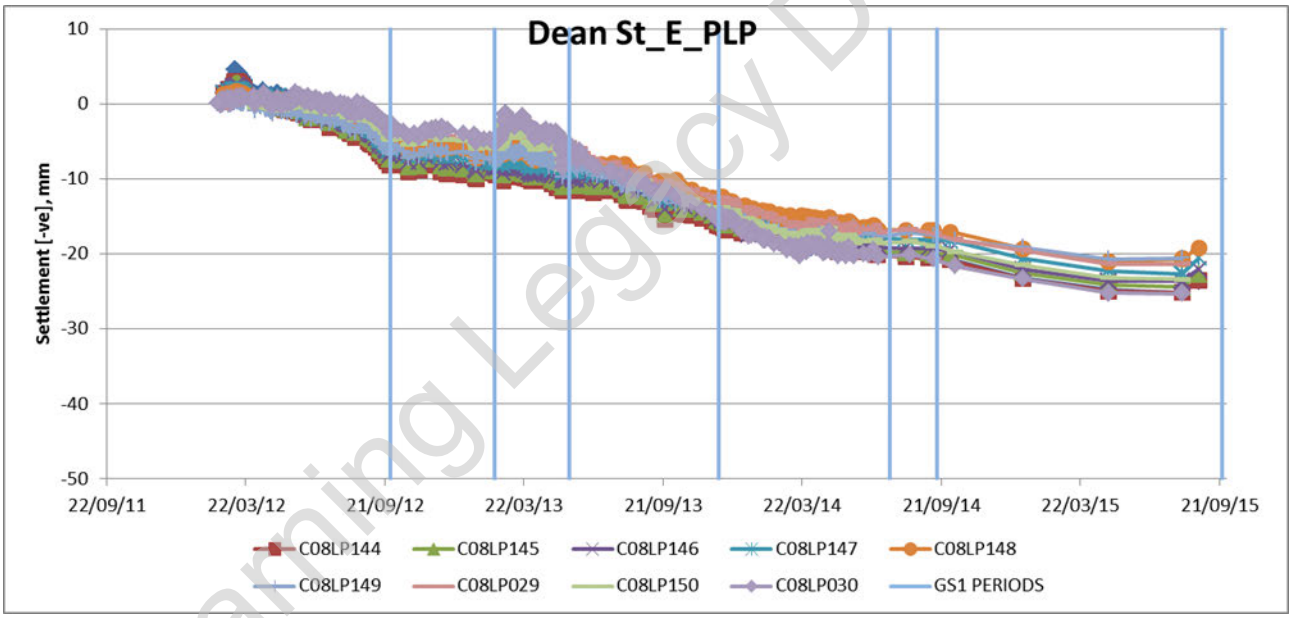
- The Carlisle Street north kerbline to the west of Dean Street is located fully within the extent of the GS1 array.
- Increases in settlement are evident in the time settlement history plot associated with the AP1 (Period C), WBRT (Period D) and PTW and PTW2 (Period E). Uplift due to grout jacking is evident in Periods C, D and E associated with concurrent grouting for AP1, PTW and PTW2 excavations respectively.
- There was negligible effect from the WTH excavation (Period A). Heave was generated with concurrent grouting with CH1P, CH1E and AP1 followed by settlement giving a small net settlement (~3mm) at the end of Period C. There was about 6mm settlement from the WBRT and a further 4-5mm during the remainder of Period D giving a total of about 15mm. Settlement during tunnelling for PTW and PTW2 was controlled to small values but post-construction movements in Period E occurred at an increased rate, giving 27mm total at the end of the Period.
- Permeation grouting of the River Terrace Deposits was necessary to allow safe construction of the VWW with limited clay cover. The TaMs to undertake this grouting were installed from GS1 and, to this end, the compensation grouting TaMs were backfilled and the shaft filled to the

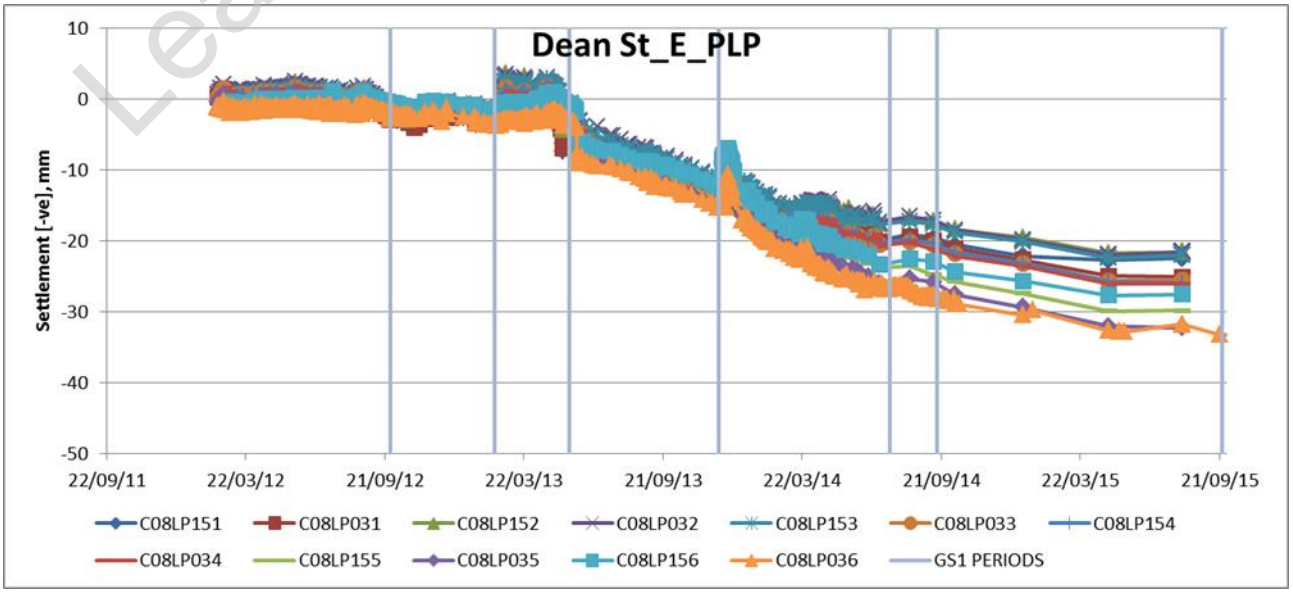
appropriate level for drilling. No compensation grouting was required (or possible) since the crown of the VWW was within the vertical exclusion zone. However, there was no significant effect from VWW works on the Carlisle Street façade.

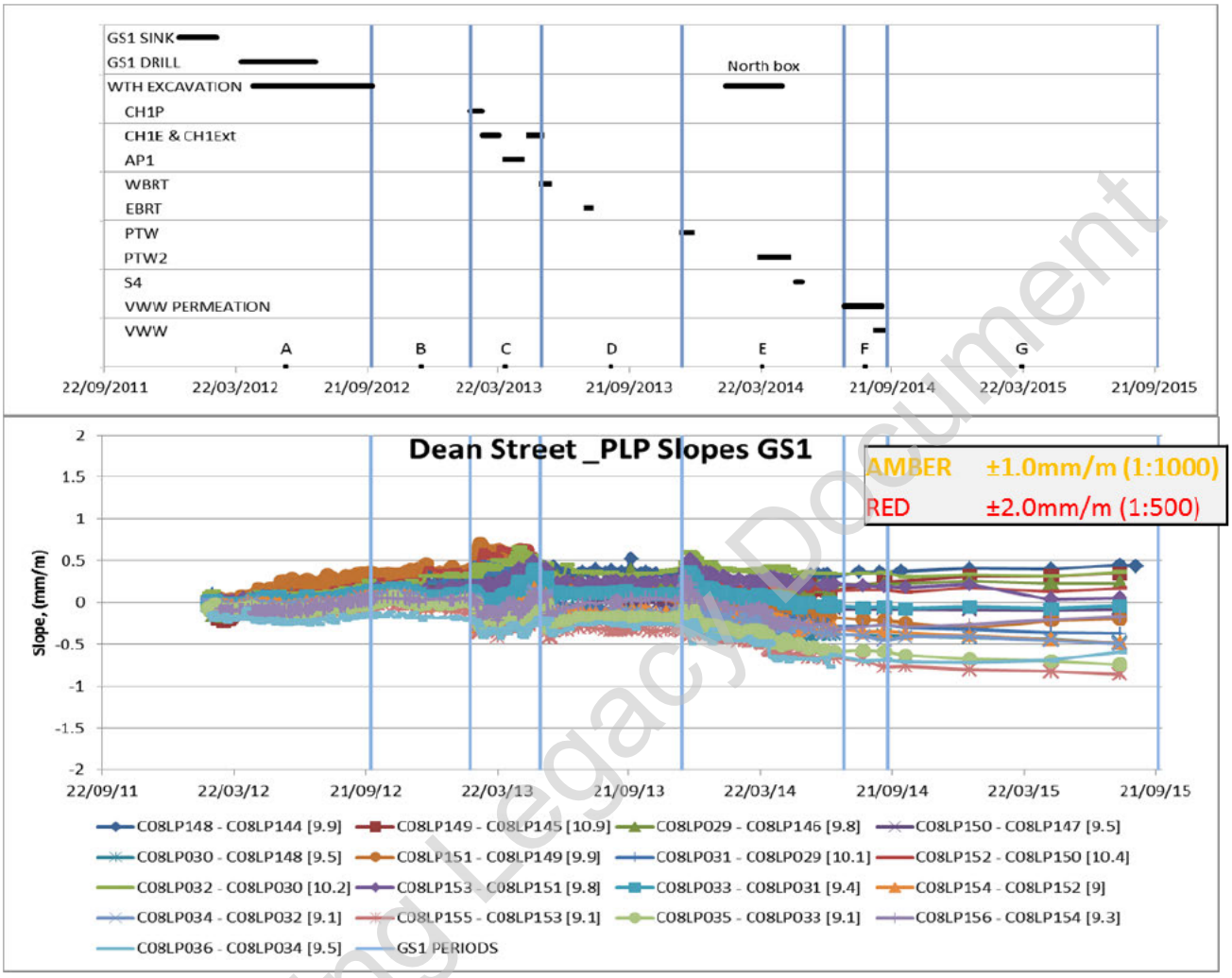
- Post construction settlement increased by ~5mm in Period G.
- There were no slope triggers during or following construction.

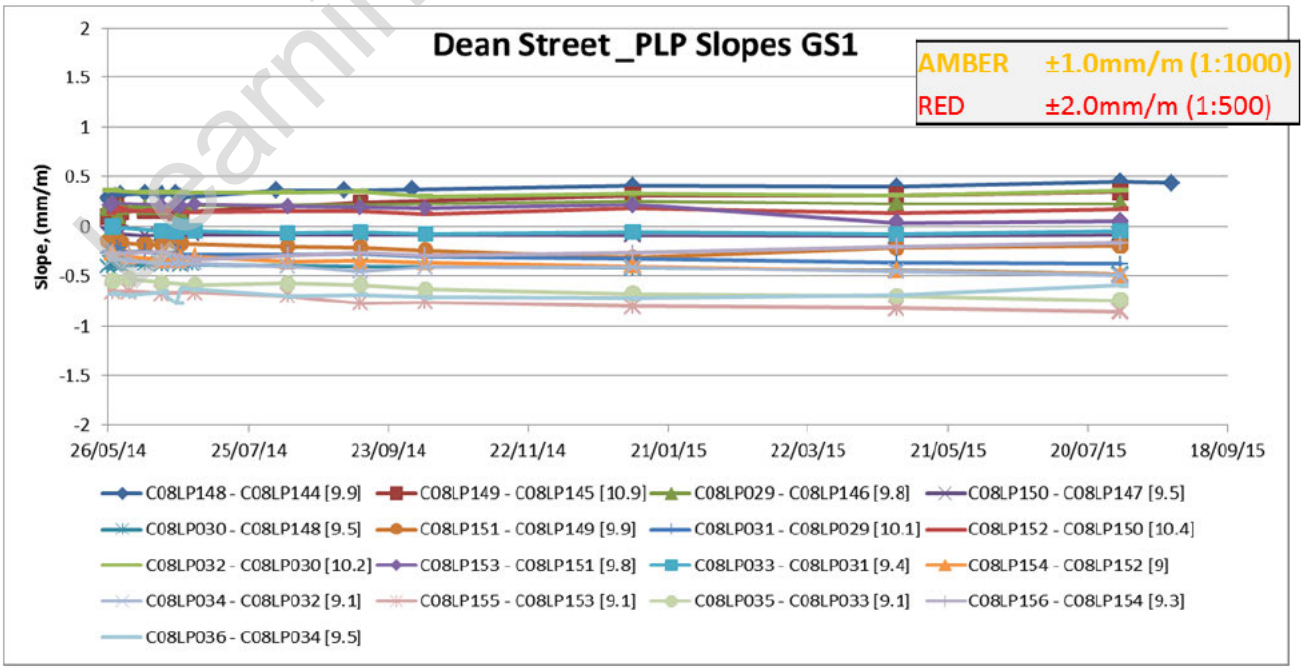
5.7. Dean Street – east

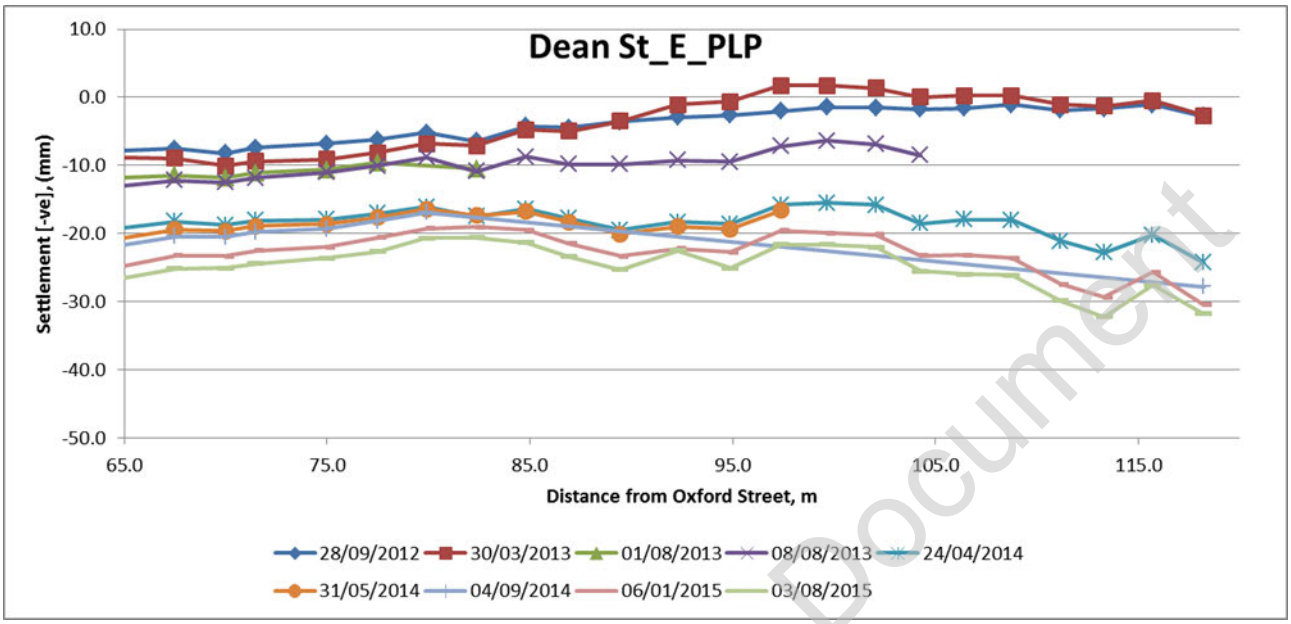












The following points are noted:

- The Dean Street east kerbline is located within the extent of the GS1 array from Carlisle Street to Adjacent to the South Box south wall (between distances 75m and 118m on the profile plot).
- Increases in settlement are evident in the time settlement history plot associated with the WTH (Period A), the WBRT (Period D) and PTW (Period E), albeit the effects are small and the overall trend is characterised by gradual post tunnelling increases. Uplift is evident in Period C and in Period E, associated with concurrent grouting with CH1 / AP1/ CH1Ext and PTW respectively.
- Settlement reached ~10mm due to the WTH excavation (Period A). Settlement then increased gradually to ~15mm at the end of Period D and ~28mm at the end of Period E.
- No slope triggers occurred during or following construction.
- The maximum increase in post construction settlement was approximately 5mm.

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 TCR Grout Shaft 1. There were 11 slope trigger breaches on BRE, but only 4 of these occurred prior to de-commissioning of the GS1 grouting facilities. All of these showed a transitory peak and were either below or close to (within 5%) the limiting value at the end of construction. Further trigger breaches were expected during construction of VWW, based on an assessment of the combined effect of the then existing settlements and the anticipated volume loss movements. It was agreed that no pre-heave grouting was necessary and consequently none was undertaken. There was only one slope trigger breach on PLP and this was also associated with VWW excavation. The data show that, in some locations the slopes continue to increase, albeit generally at a slow and decreasing rate.

It is BFK's view 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: this objective has been achieved.

7. CONCLUSION

Following the completion of low level tunnelling, monitoring data was reviewed together with the anticipated movement from VWW: no grout jacking was deemed necessary or desirable.

An abridged version of this report was submitted in August 2014, about 3 months after the end of tunnelling, to justify the de-commissioning of TCR Grout Shaft 1 (C300-CCM-08749). This report was accepted by CRL (C300-PMC-09405) and the grout shaft was subsequently de-commissioned.

Manual monitoring was terminated under C300-PMI-01858, and consequently, this report comprises a Final and Close Out report.

Appendix A

Assumptions used to produce contour plots of grout intensity

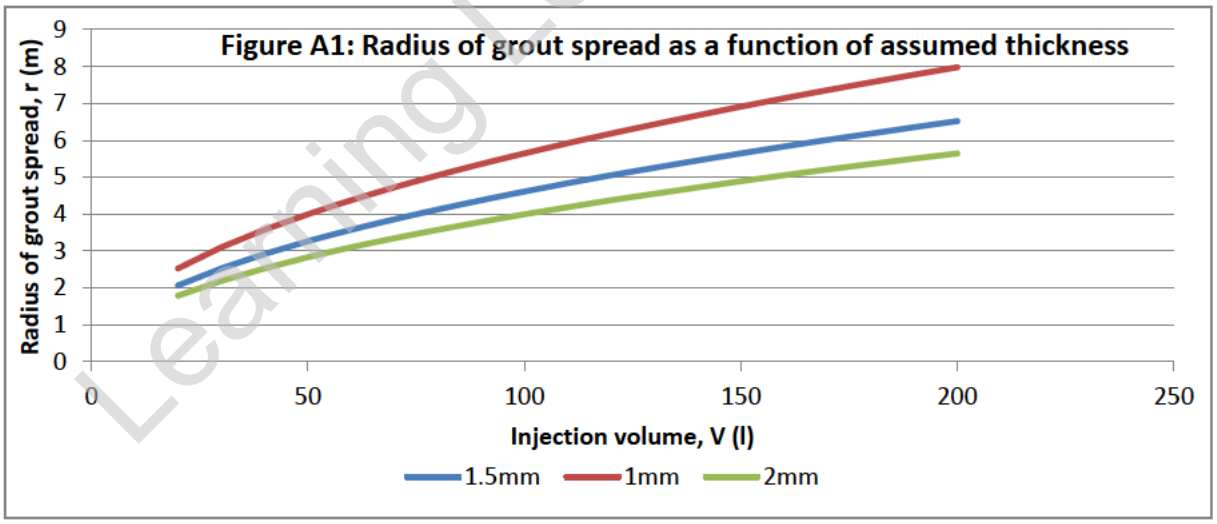
A method of producing a visualisation of the quantity and distribution of grout injected during compensation grouting is useful in interpreting performance. For each injection the volume and the location of the port used are known. The model used is intended to approximate the distribution of grout within 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:

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

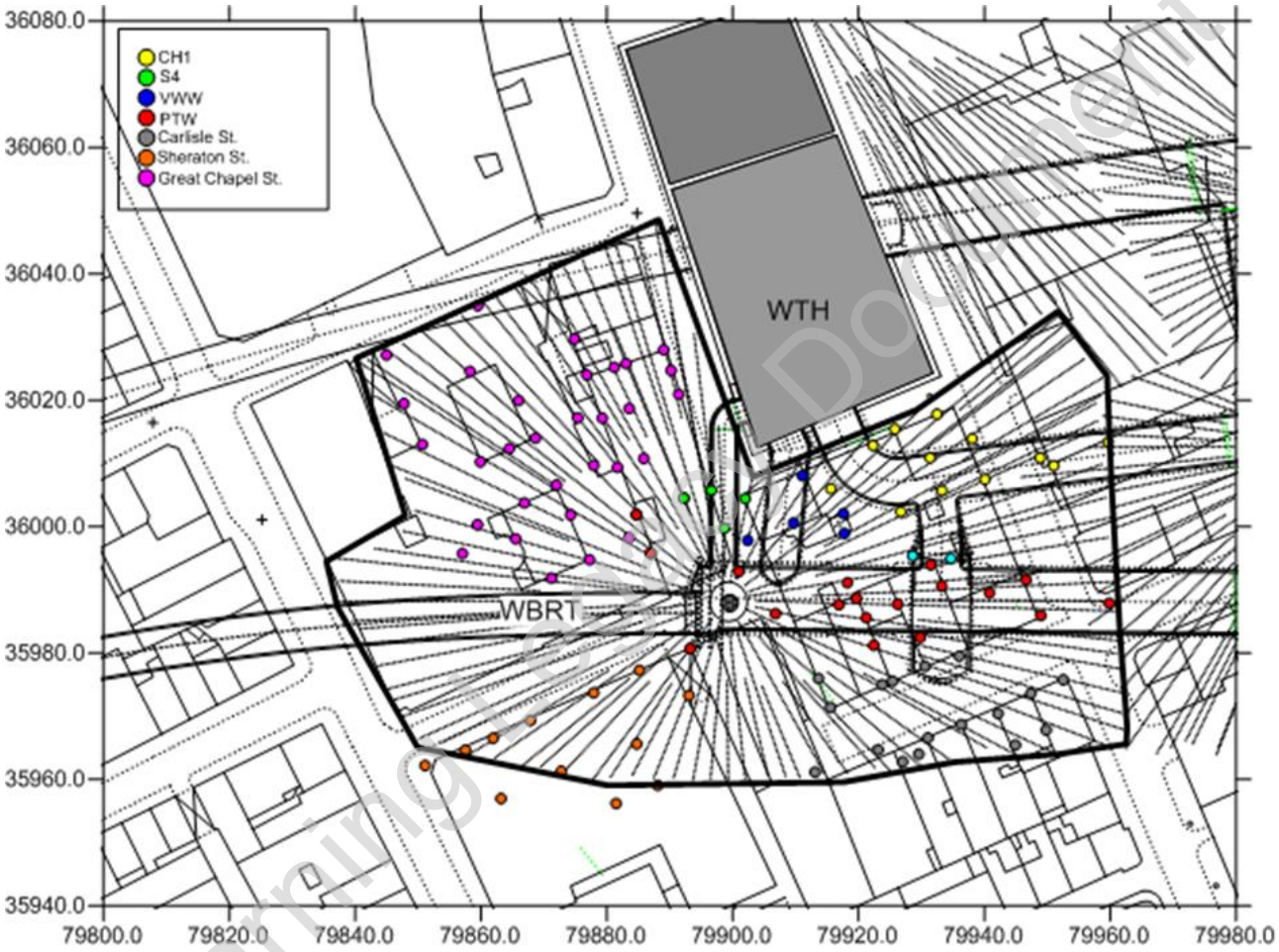


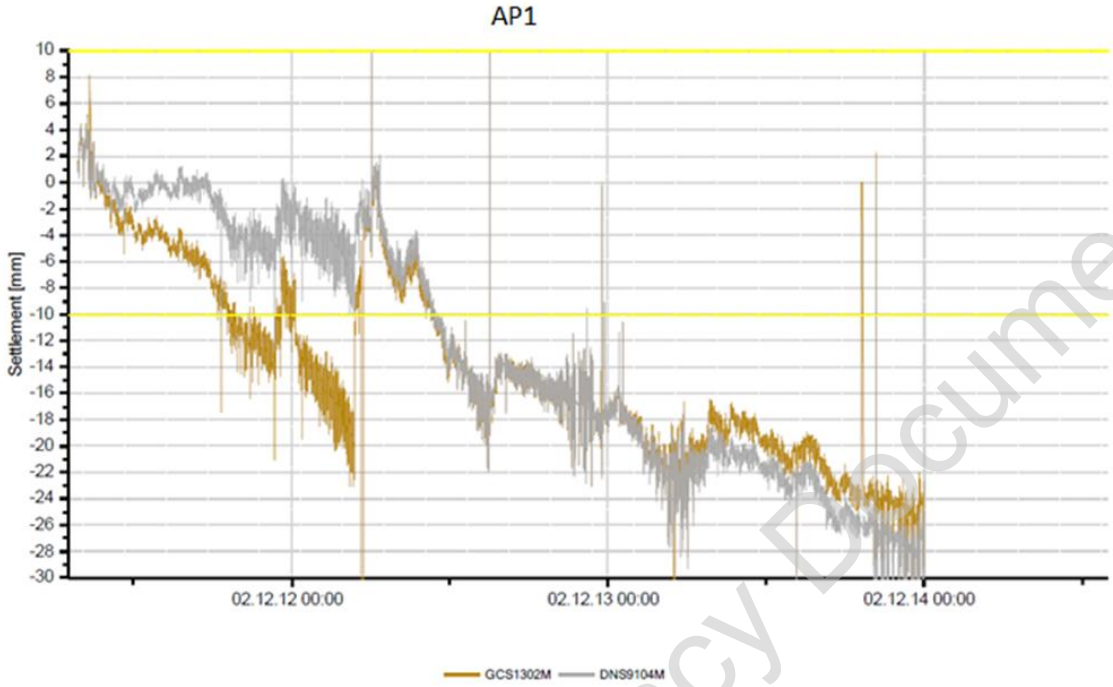
Observation of grout in the ground suggests that a thickness of 1 – 2mm is predominantly achieved. All of the plots included in this report are based on an assumed thickness of 1.5mm. Figure A1 shows the variation in radius for thicknesses of 1.0, 1.5 and 2.0mm.

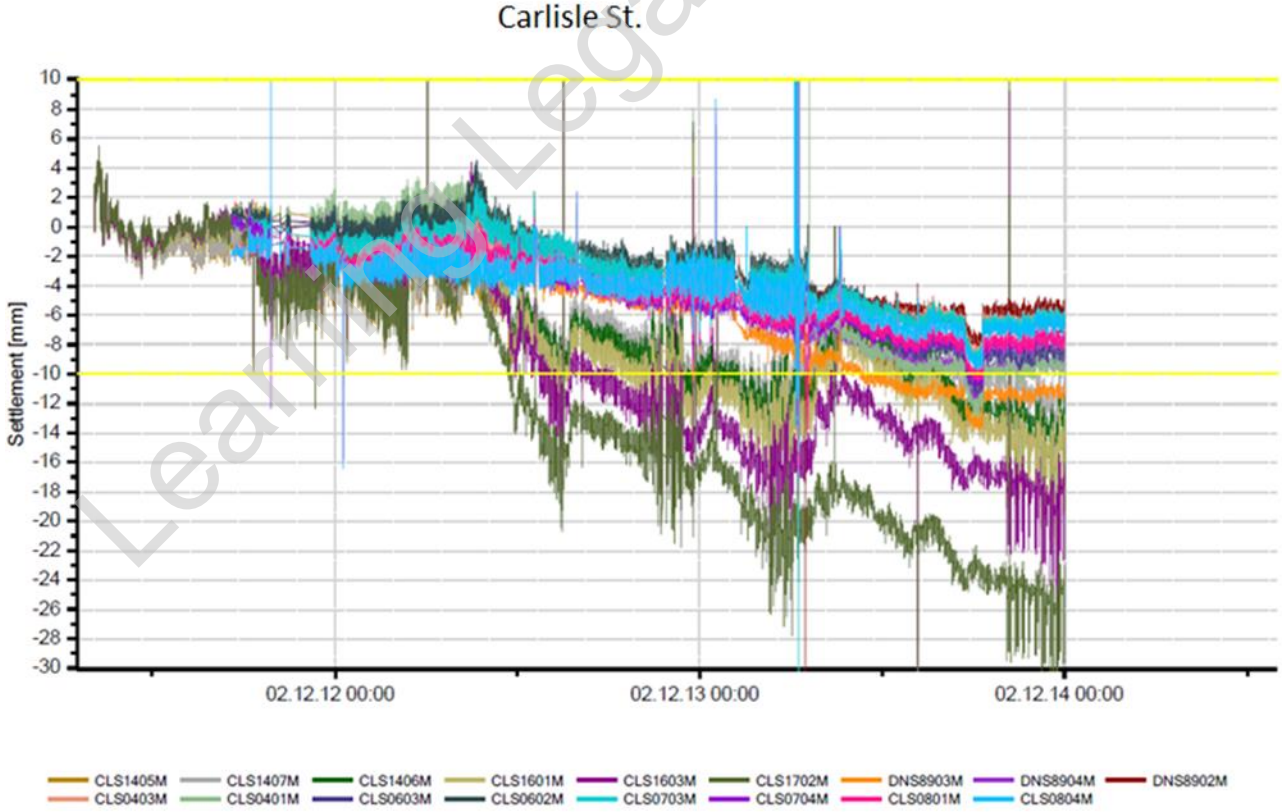
The contribution of each injection within a specified data set are summed at each node within a grid. This grid file is then contoured within Surfer.

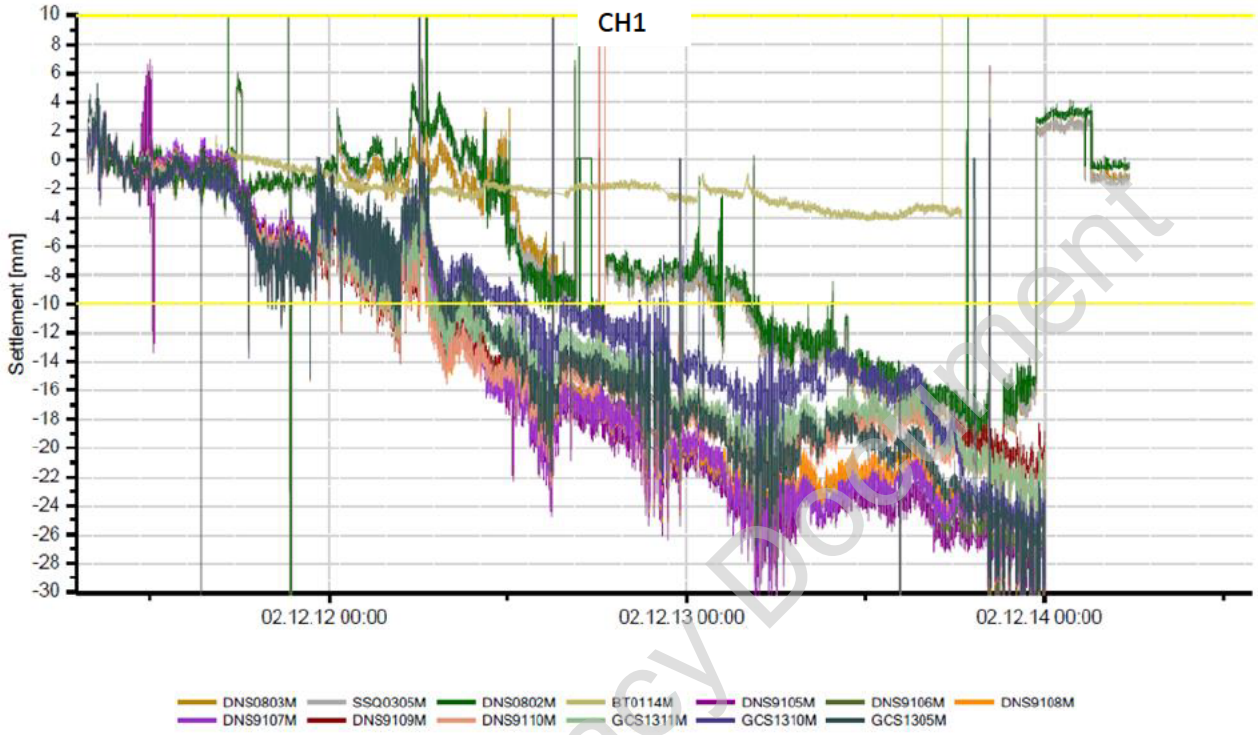
Appendix B

HLC plots, Tiltmeters 88-89 Dean Street and Crackmeters 22 & 24 Great Chapel Street

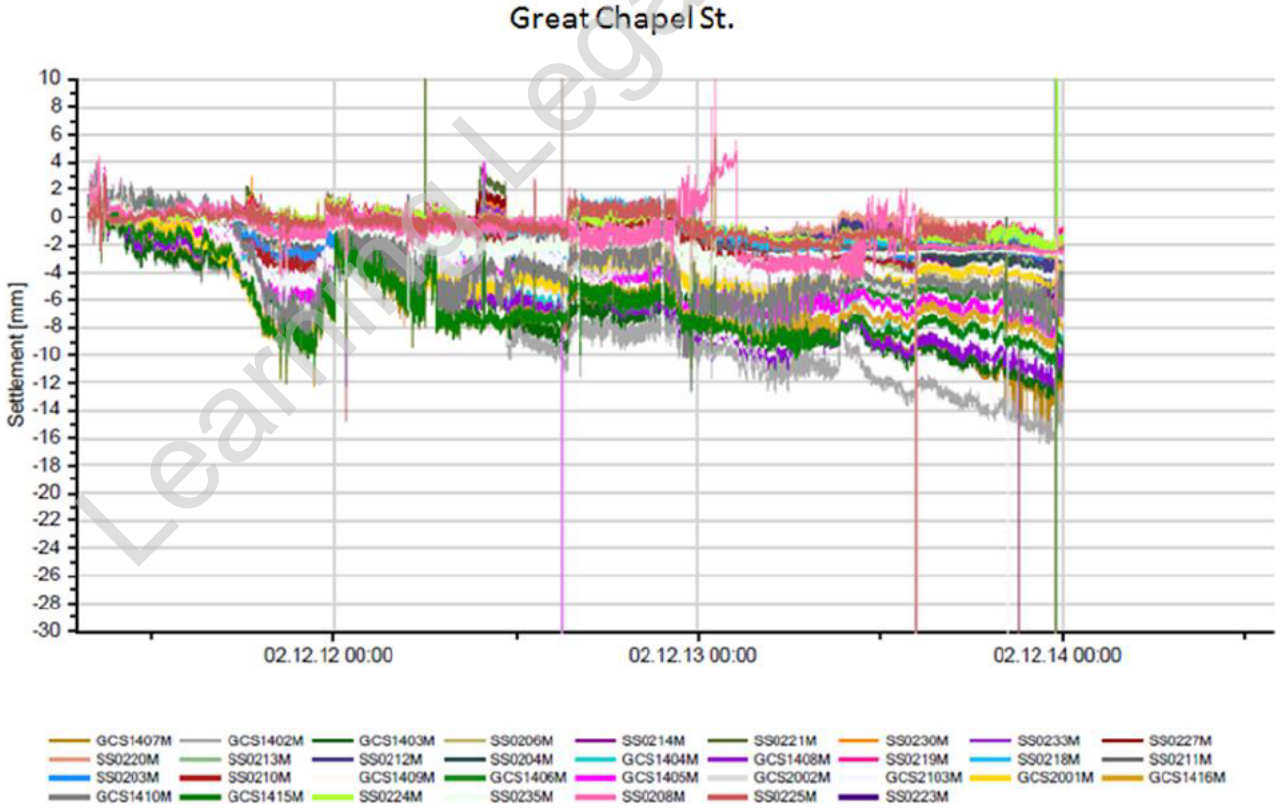


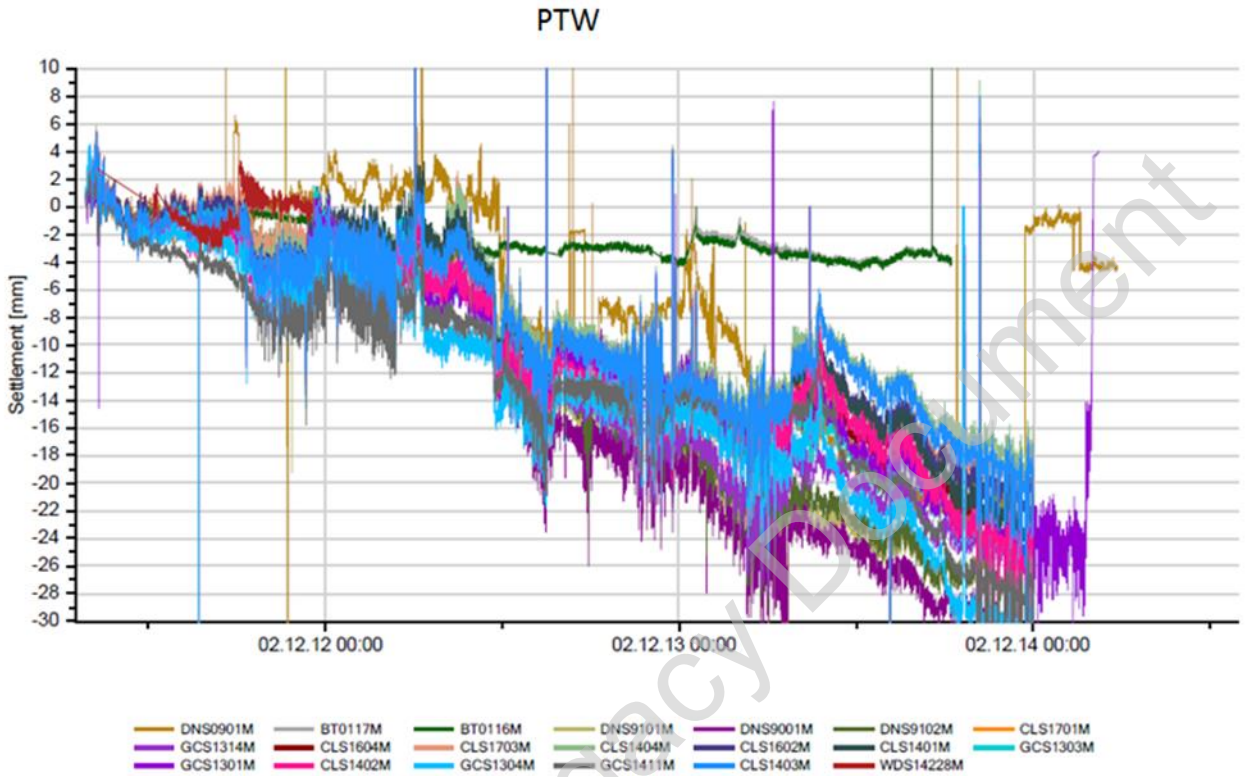


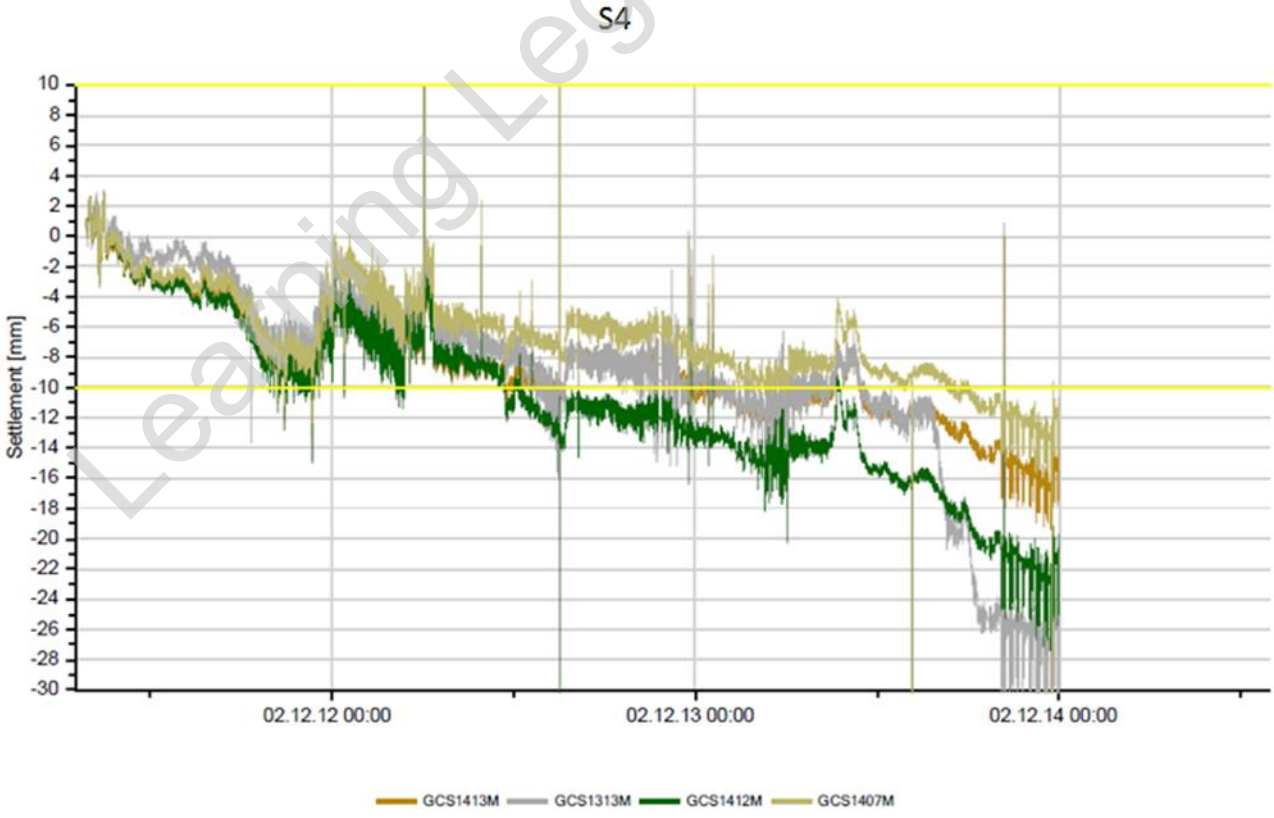




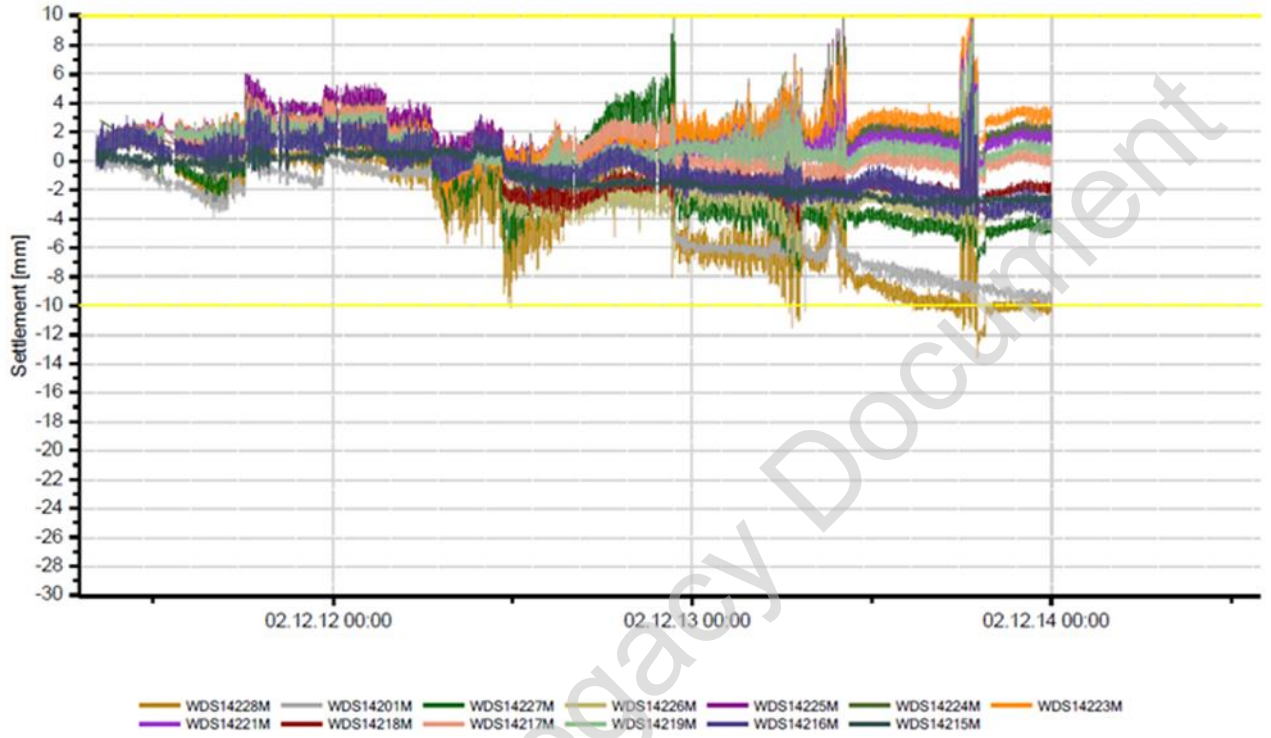
CH1



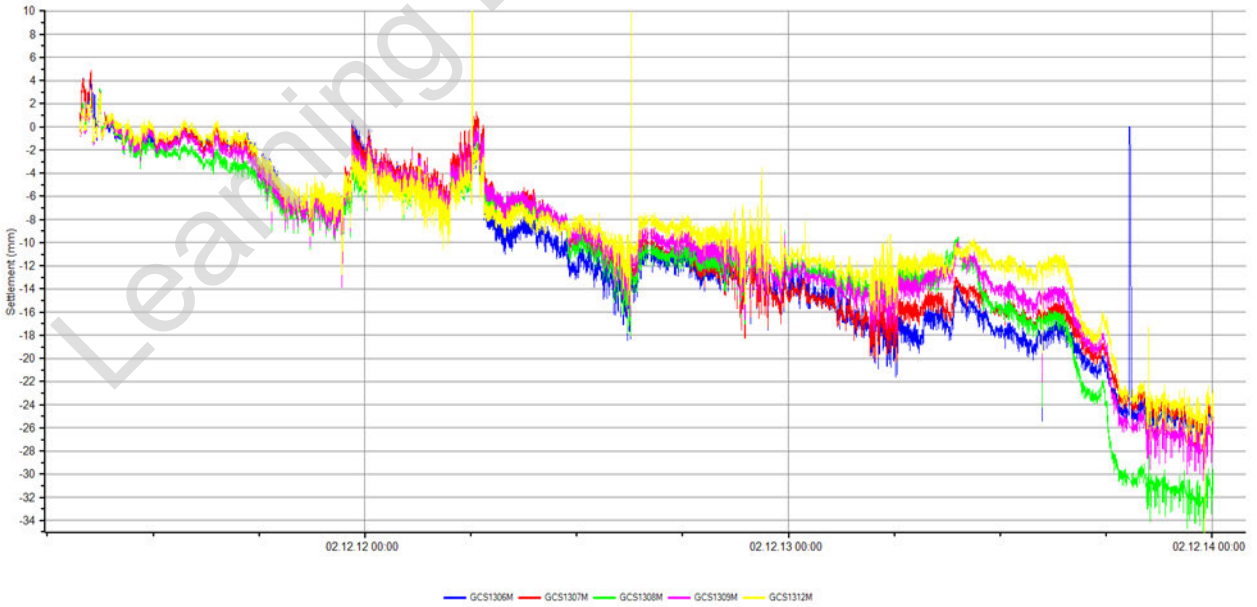




Sheraton St.



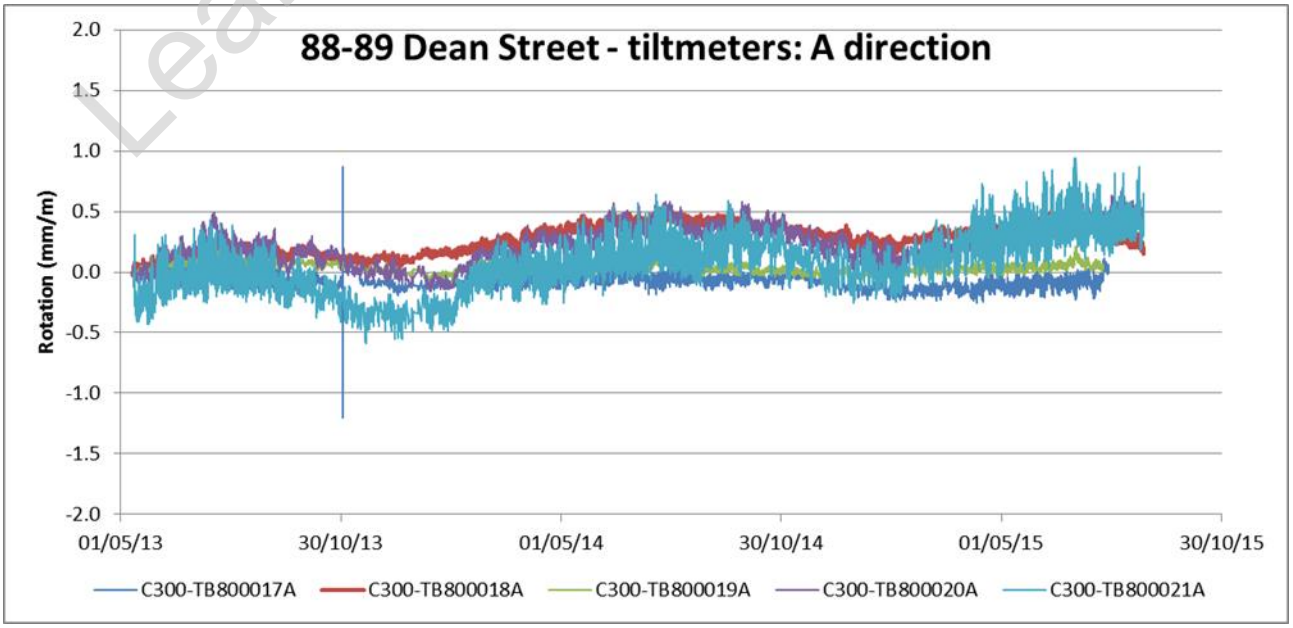
vww

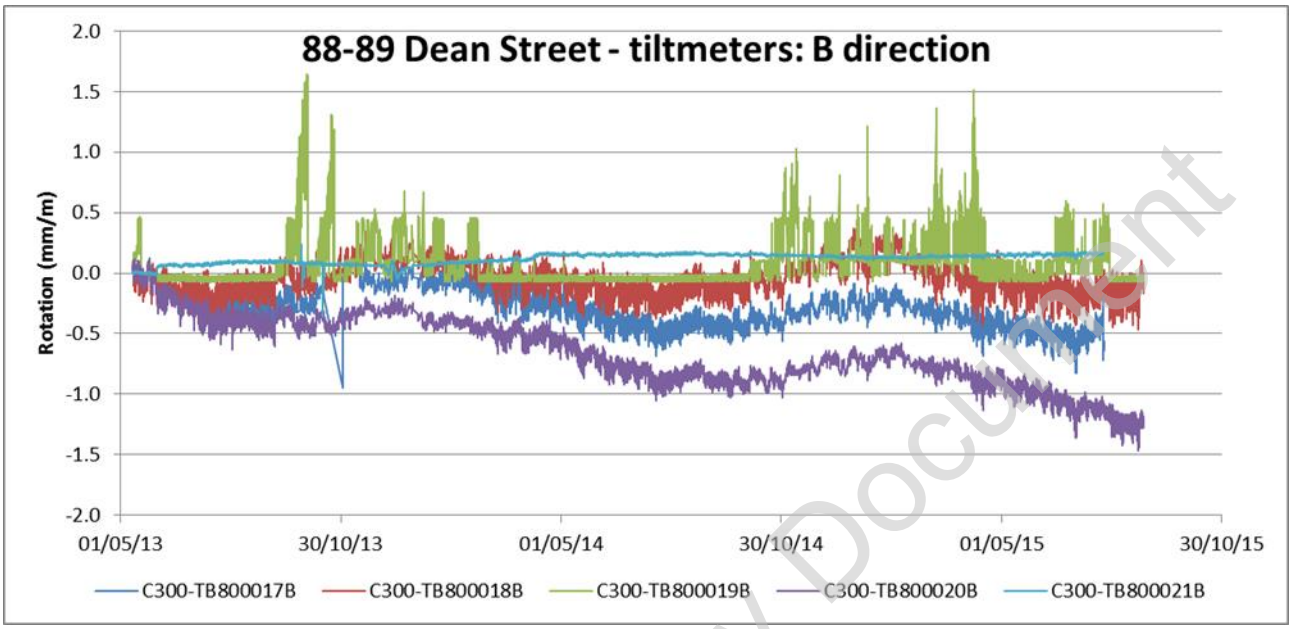


Tiltmeters and Crackmeters: location

Tiltmeter data 88-89 Dean Street:

Refer to Installation Report C300-BFK-C4-RGN-CRT00_ST005-50739



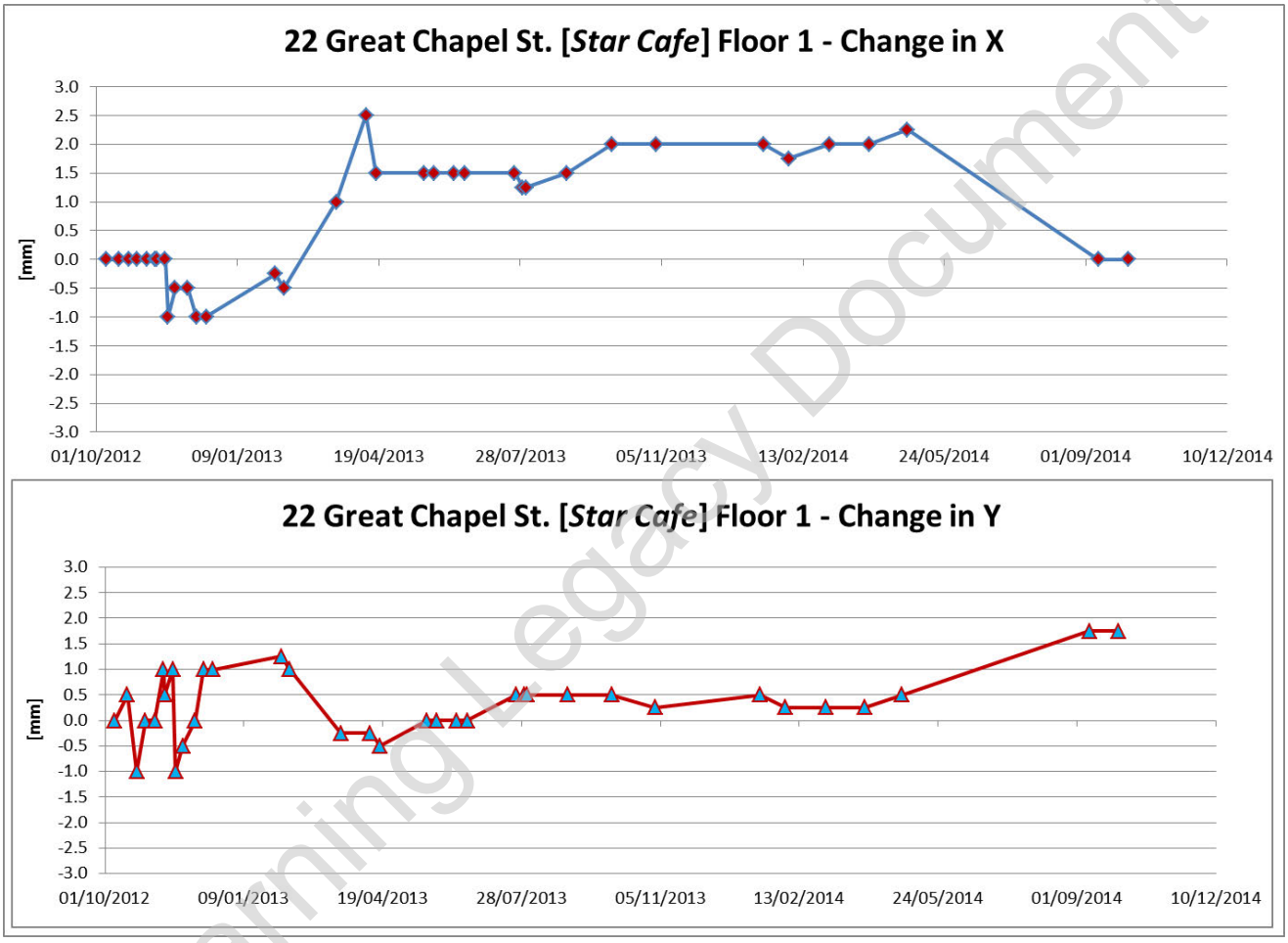


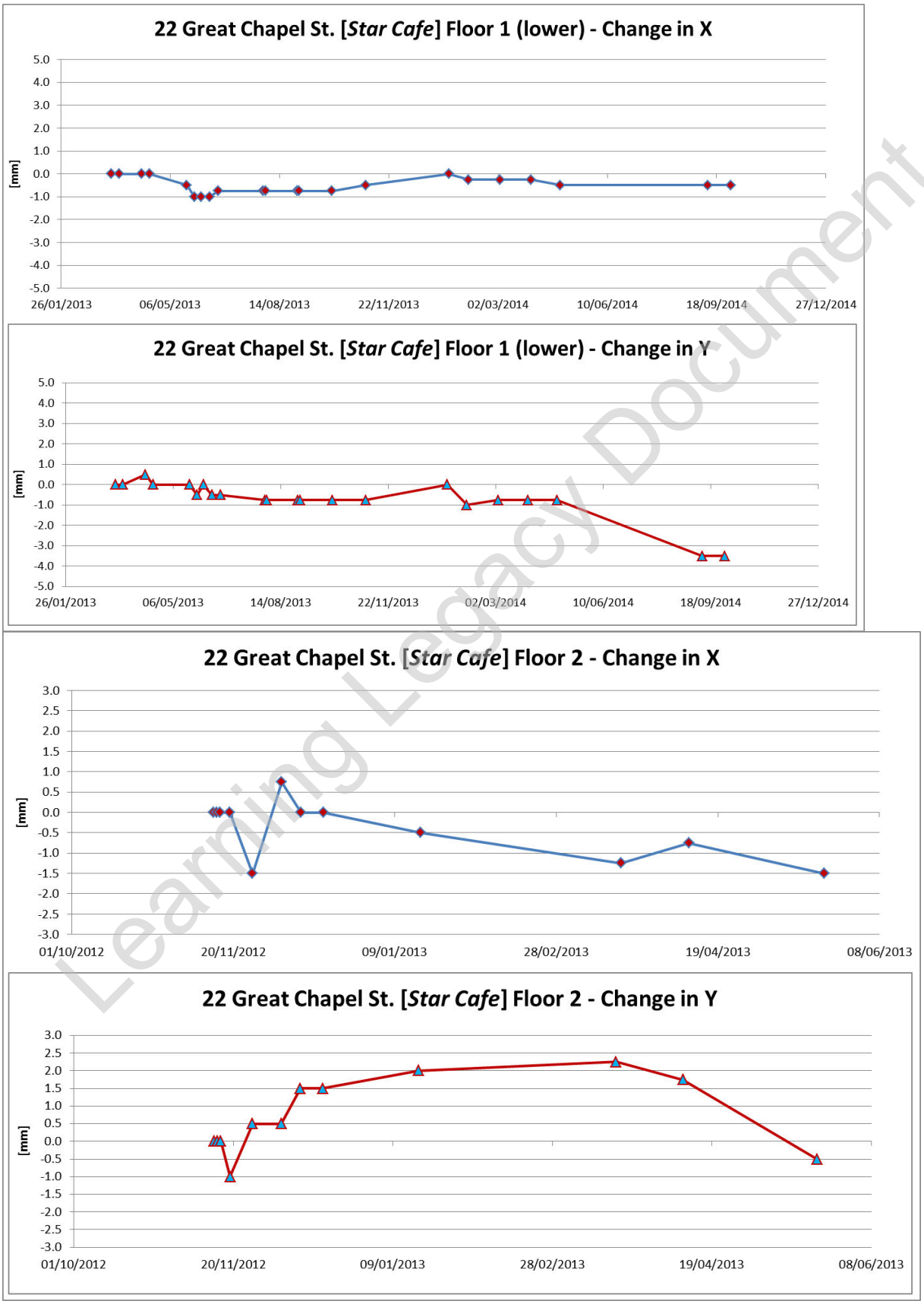
The tiltmeter data show an annual variation of about 0.5mm/m and show a consistent, if variable, correlation with the slopes calculated from the BRE data (see Section 4.11).

Crackmeter data: 22 & 24 Great Chapel Street

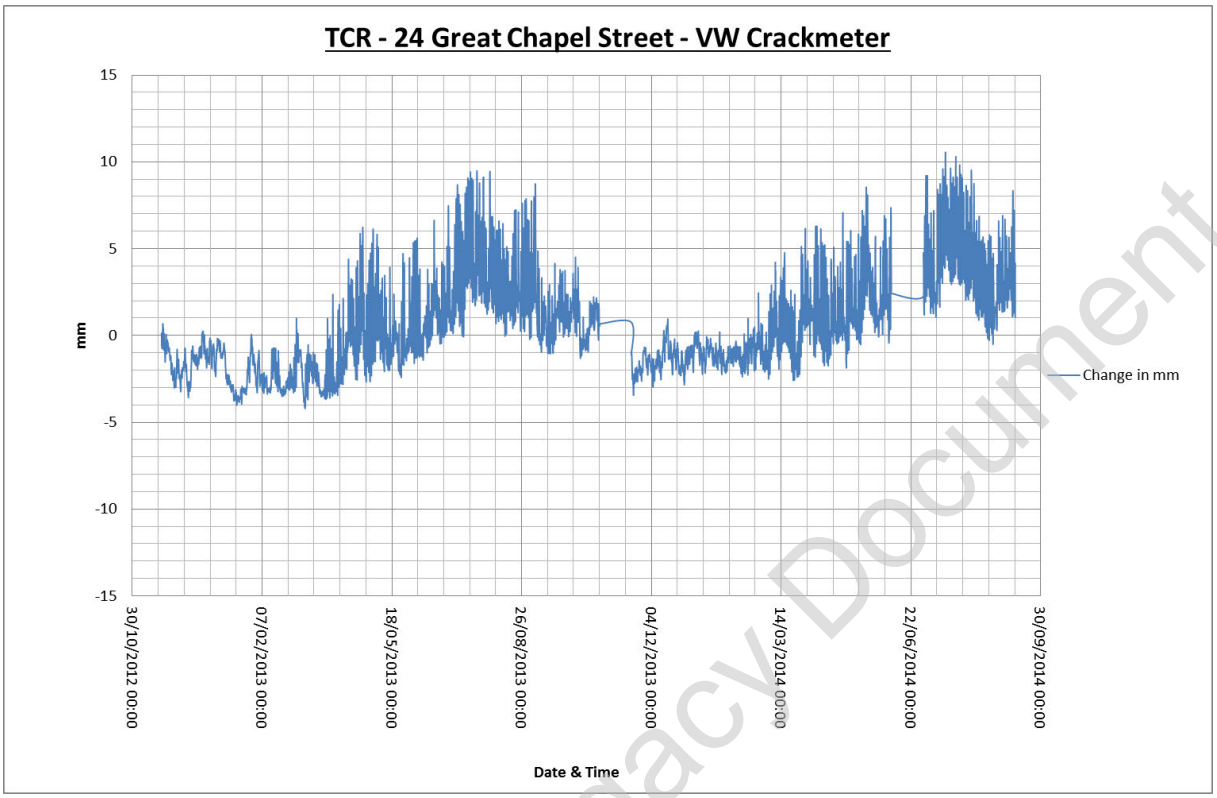
Refer to Installation Report C300-BFK-C4-RGN-CRT00_ST005-50561 & C300-BFK-C4-RGN-CRT00_ST005-50679

X = horizontal; Y = vertical



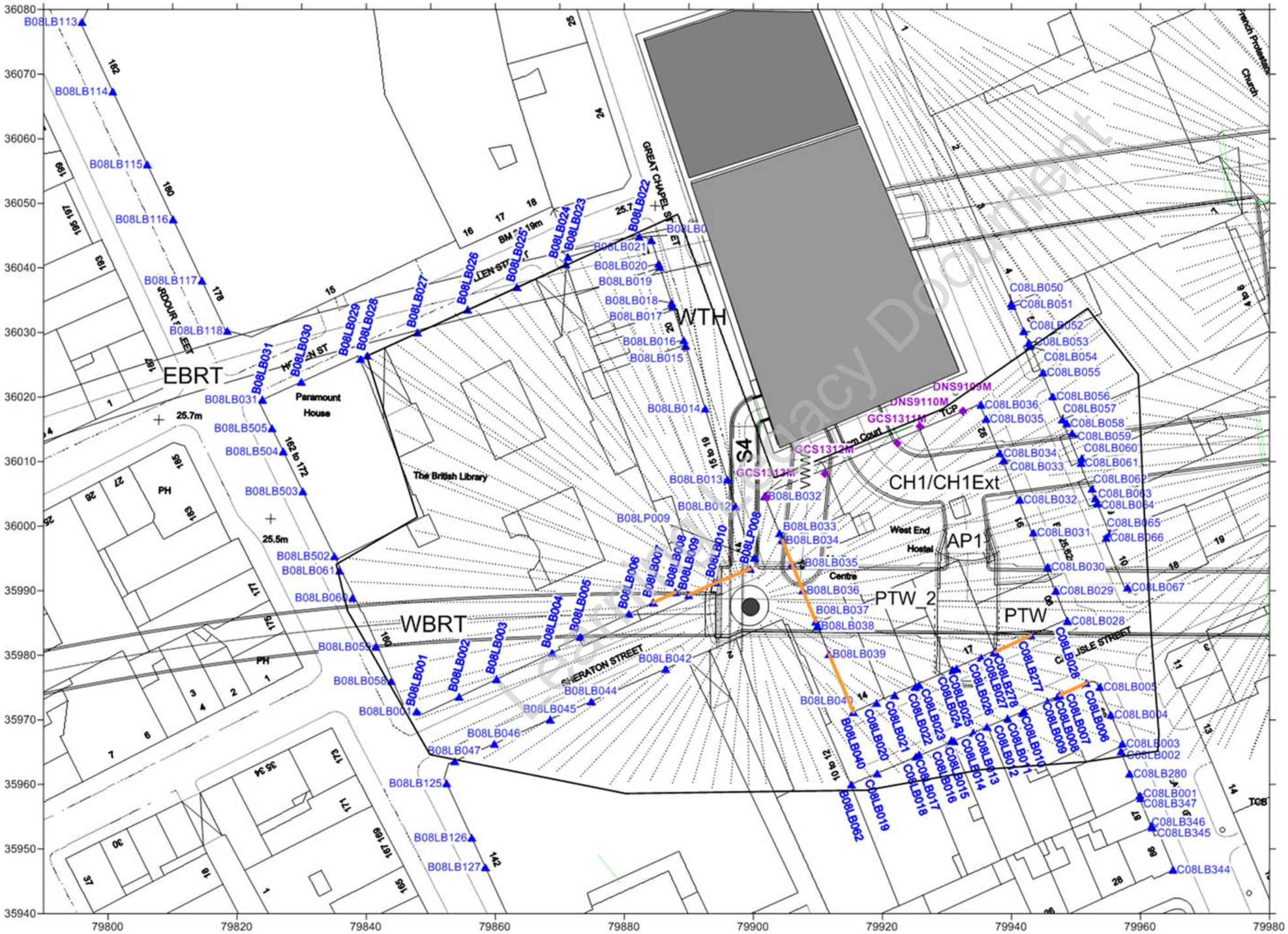


VW Crackmeter – change in horizontal crack width



Appendix C

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


B08LB113
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B08LB115
B08LB116
B08LB117
B08LB118
B08LB031
B08LB505
B08LB504
B08LB503
B08LB502
B08LB061
B08LB060
B08LB059
B08LB058
B08LB001
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B08LB127
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B08LB028
B08LB027
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DNS9110M
GCS1311M
GCS1312M
GCS1313M
TCP
EBRT
WBRT
WTH
PTW
PTW_2
AP1
CH1/CH1Ext
S4
Paramount House
The British Library
West End Hostel
Centre
GREAT CHAPEL STREET
SHERATON STREET
ISLE STREET
French Protestant Church
TCB
PH
25.7m
25.5m
36080
36070
36060
36050
36040
36030
36020
36010
36000
35990
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