C300/410

Western Tunnels & Caverns Project

Final Monitoring Report

TBM DRIVES ~ from Royal Oak Portal to Paddington Station

CRL Document No. **C300-BFK-C4-RGN-CRT00_ST005-51232**

Contract MDL reference: C14.022

1. Contractor Document Submittal History

Revision	Date	Prepared by	Checked by	Approved by	Reason for Issue
6.0	16.01.2016	[redacted]	[redacted]	[redacted]	For CRL Acceptance
		[redacted]	[redacted]		

2a. Stakeholder Review Required? YES ☐ NO ☒ – STAKEHOLDER REVIEW NOT REQUIRED AS REPORT BEING ISSUED TO LU FOR INFORMATION AS PART OF ISSUING LONO FOR IOLM DECOMMISSIONING ON LU ASSETS

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.

Sig[redacted] Name [redacted] Role: [redacted] Date: 19/01/17

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/Ac[redacted] Print Nam[redacted] Position: [redacted] Date: 19/01/17

by: (signatur[redacted]

Acceptance [redacted]eve the designer/supplier from its compliance with their con[redacted] does not constitute *Crossrail* approval of design, details, calculations, analyses, test methods or materials developed or selected by the designer/supplier.

Contents

1. Purpose and Scope

The purpose of the present document is to provide a summary of the observed movements relative to the TBMs works between Royal Oak Portal and Paddington Station in accordance with the requirements of the Instrumentation and Monitoring Specification KX10 C122-OVE-Z4-RSP-CR001-00007, Clauses KX10.2113 and KX10.2114.

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.

This report is one of a series of 5 which cover the TBM drives between Royal Oak Portal and Farringdon Station as listed in Table 1.

Report title: *Final and Close Out Monitoring*	**Report Number:** C300-BFK-C4-RGN-CRT00_ST005-	Eastbound Tunnel		Westbound Tunnel	
		Start Chainage	End Chainage	Start Chainage	End Chainage
Royal Oak Portal to Paddington Station (ROP to PAD)	51232	510	1312	510	1300
Paddington Station to Bond Street Station (PAD to BOS)	51015	1670	3561	1660	3568
Bond Street Station to Tottenham Court Road Station (BOS to TCR)	51016	4187	4672	4159	4679
Tottenham Court Road Station to Fisher Street Shaft & Crossover (TCR to FIS)	51129	5147	5792	5108	5856
Fisher Street Shaft & Crossover to Farringdon Station (FIS to FAR)	51130	6097	6860	6162	6945

Table 1: List of Final / Close Out Reports for TBM drives Royal Oak Portal to Farringdon.

1.1. Executive Summary

This document includes monitoring data from instruments installed for the TBM drives between Royal Oak Portal and Paddington Station.

A summary of the monitoring data is provided, with the influence of the two TBM drives identified. The rate of post-construction settlement is compared to the specified limit of 2mm/year (C122-OVE-Z4-RSP-CR001-00007 and C122-OVE-C2-RSP-CR001-00001) and the absolute magnitude of settlement is compared to the trigger values given in the C122 I&M plan (C122-OVE-C2-RGN-CRG01-50076). Points where trigger levels have been exceeded are listed. Monitoring data from Cross Passage 1 is also presented.

Information about Thames Water assets is provided, both within the report and in Appendix 4 (summary table). In general, no deflection amber trigger (average of 3 values) has been breached on Thames Water assets.

Transects from which data is presented are listed in Table 2. A summary of the final settlements recorded on all HLC, BRE and PLP is given in Appendix 5. The maximum recorded settlement due to C300 works between Royal Oak Portal and Paddington Station is approximately 20mm.

Data is presented from sub-surface instruments comprising inclinometers, extensometers and shape arrays.

TBM progress information and a plan showing the Eastbound and Westbound chainages are provided in Appendix 1, IDs, location coordinates and start/end monitoring dates for all instruments installed from ROP to PAD are included in Appendix 2 and a list of supporting documents references in Appendix 3.

Section	Transects	EB Chainage
2.1	Lord Hill's Bridge & Thames Water Ring Main	560 - 600
2.2	LU Royal Oak Station	580 - 720
2.3	Transects WB Ch. 680 & Ch 766	680 & 766
2.4	Ranelagh Bridge, Ranelagh Sewer & Harrow Road Wall	660 - 760
2.5	Westbourne Bridge north abutment, Transect Ch. 840 & Harrow Road Wall	760 - 900
2.6	Transect Ch 945, 1 Kingdom Street & Goods Yard Wall	920 - 1020
2.7	Bishop Bridge Area	1140 - 1190
2.8	London Underground Assets: H&C Line	920 - 1080
2.9	Network Rail Assets	980 - 1140
2.10	Cross passage 1	1020

Table 2 List of transects presented

It should be noted that some transects include a large number of measuring points. In these cases, for the sake of clarity, only the points within the ZoI of the TBMs have been included in the charts. The data from all instruments is available on the UCIMS platform.

2. Summary of the observed settlements

2.1. Lord Hill's Bridge & Thames Water Ring Main

2.1.1. Data

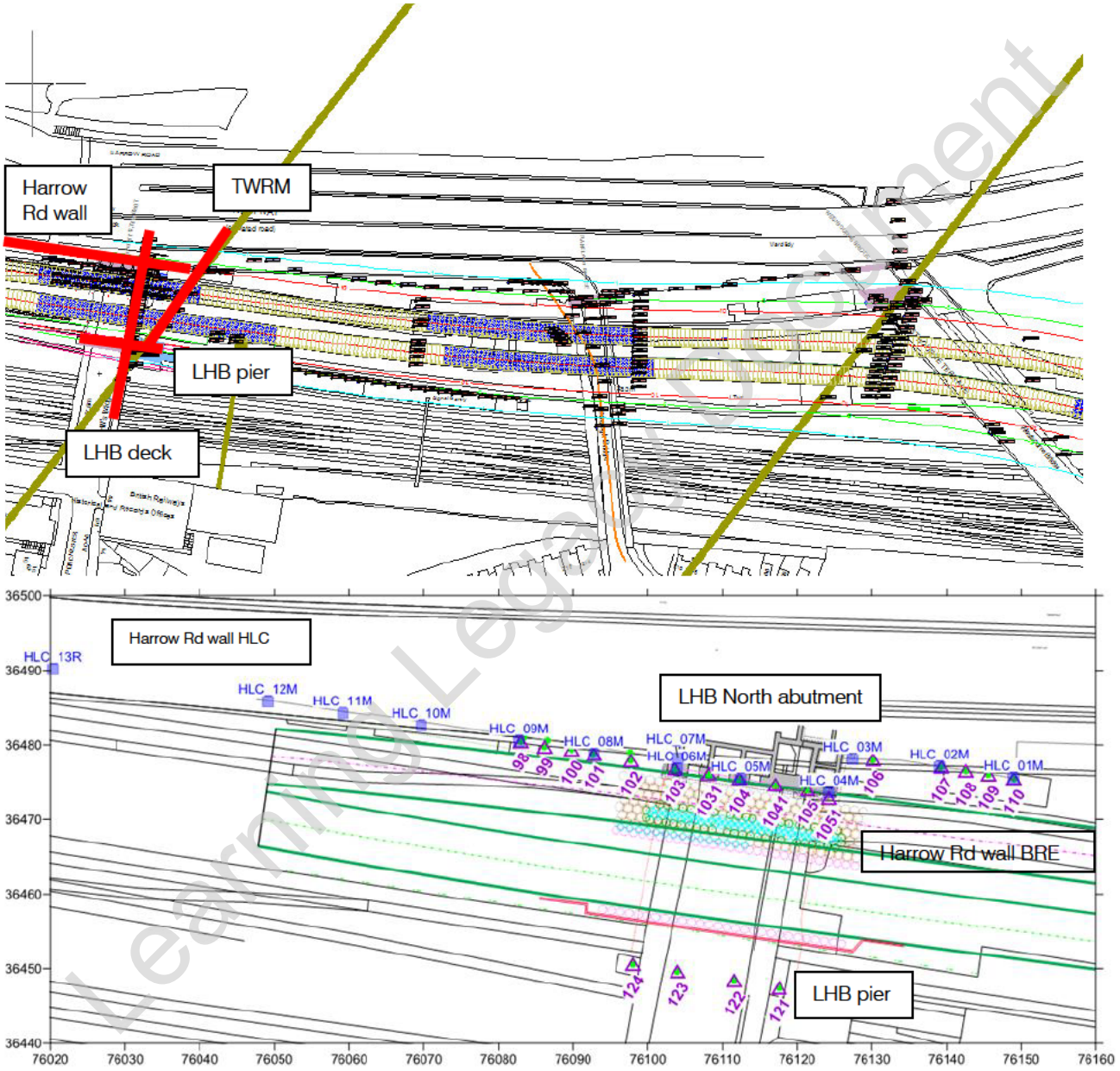


Figure 1: Transect Location Plan and HLC & BRE positions

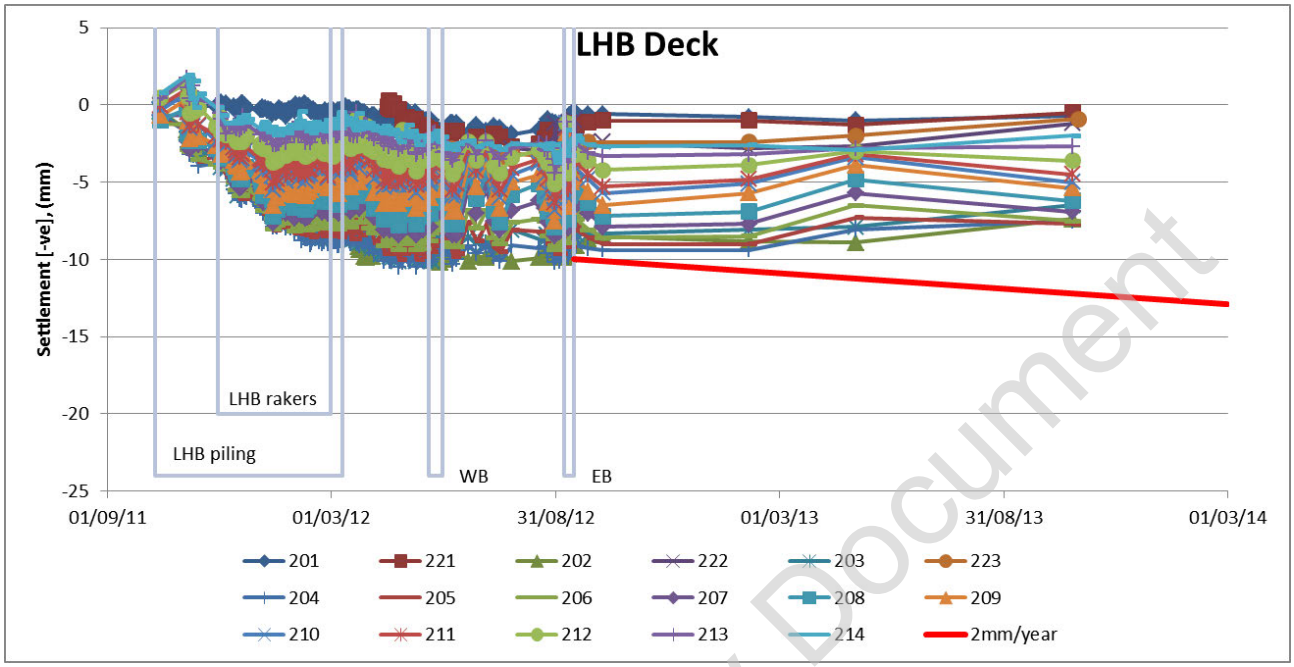


Figure 2: Bridge deck PLPs - data time-plot

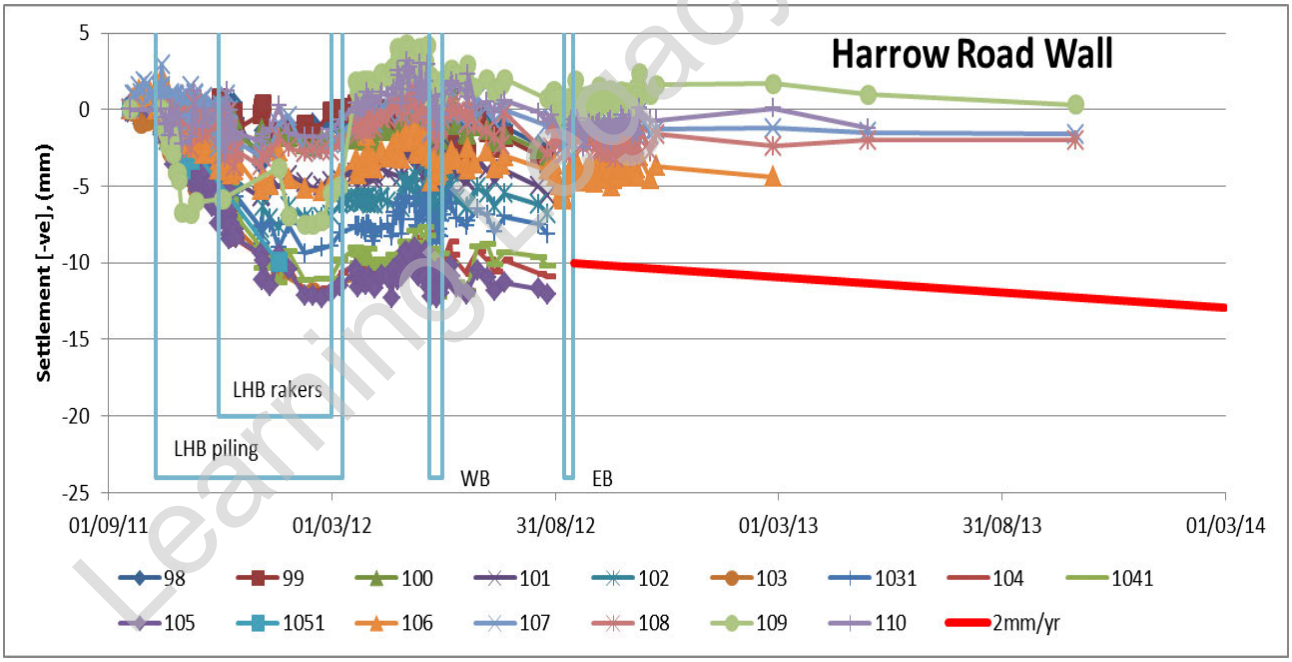


Figure 3: Harrow Road Wall and Lord Hill's Bridge north abutment – BRE data time plot

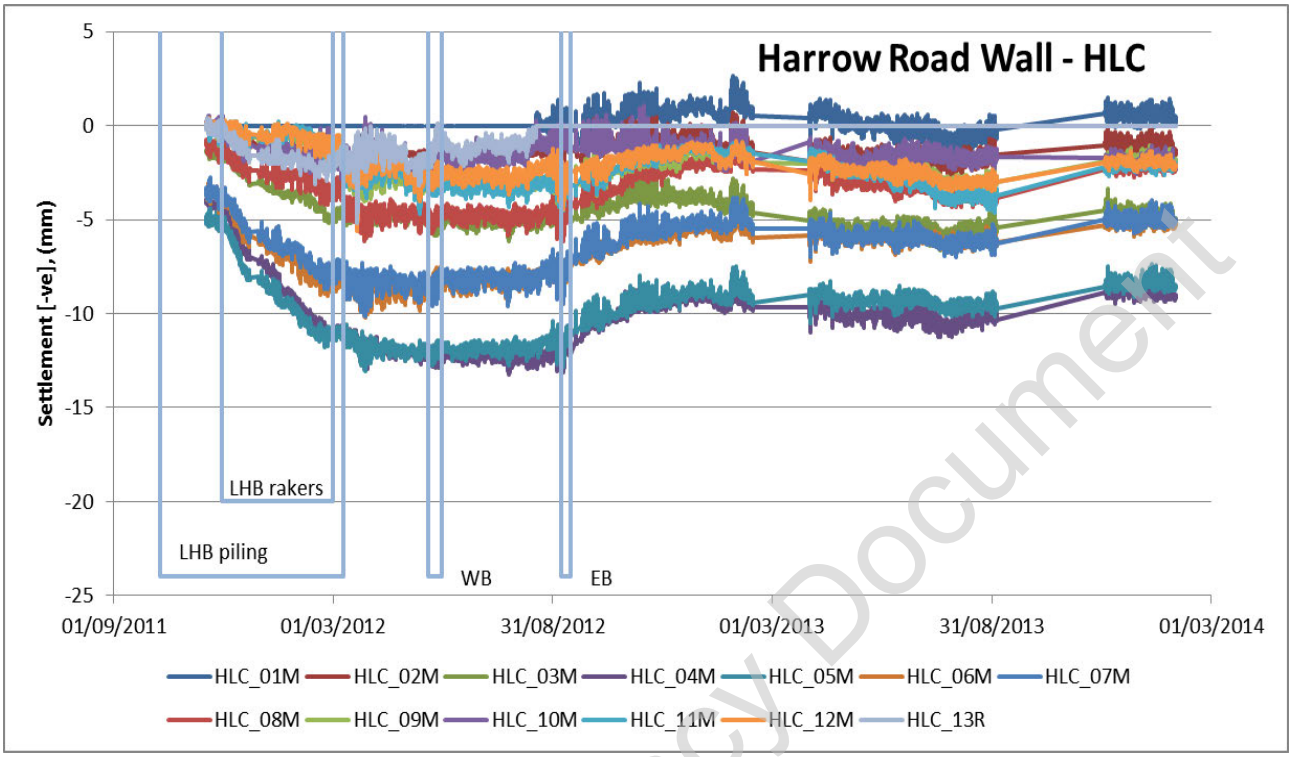


Figure 4: Harrow Road Wall and Lord Hill's Bridge north abutment – HLC data time plot

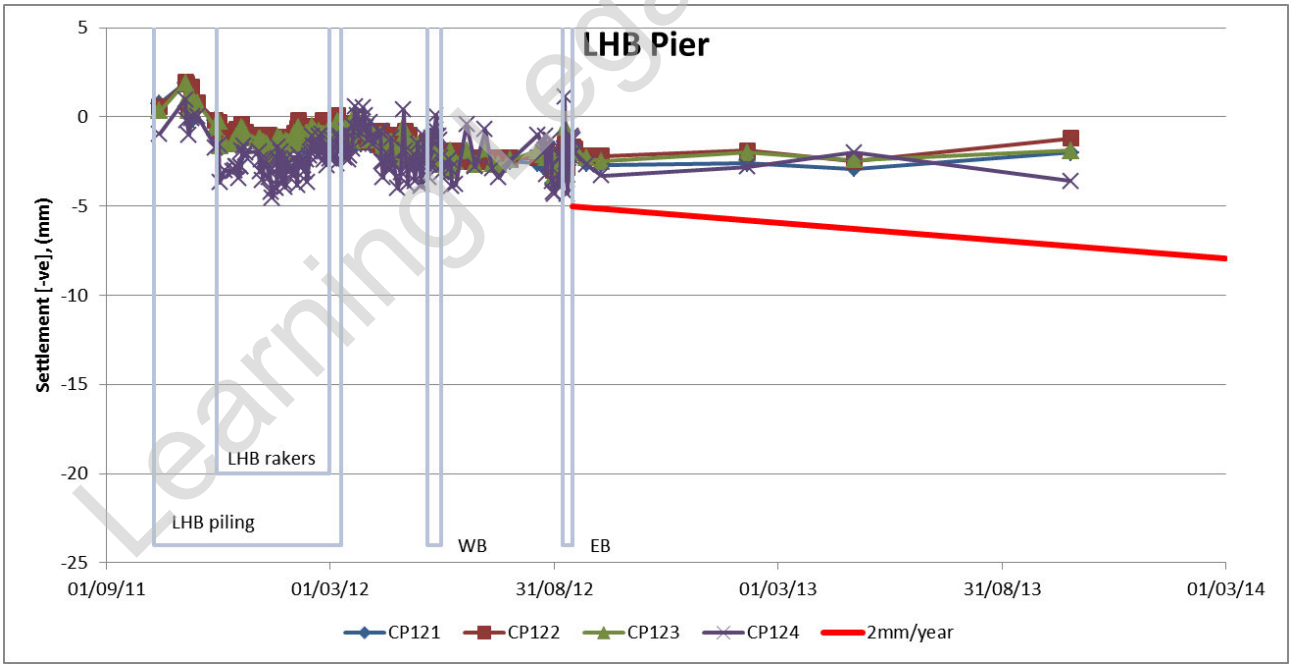


Figure 5: Lord Hill's Bridge Pier – BRE data time plot

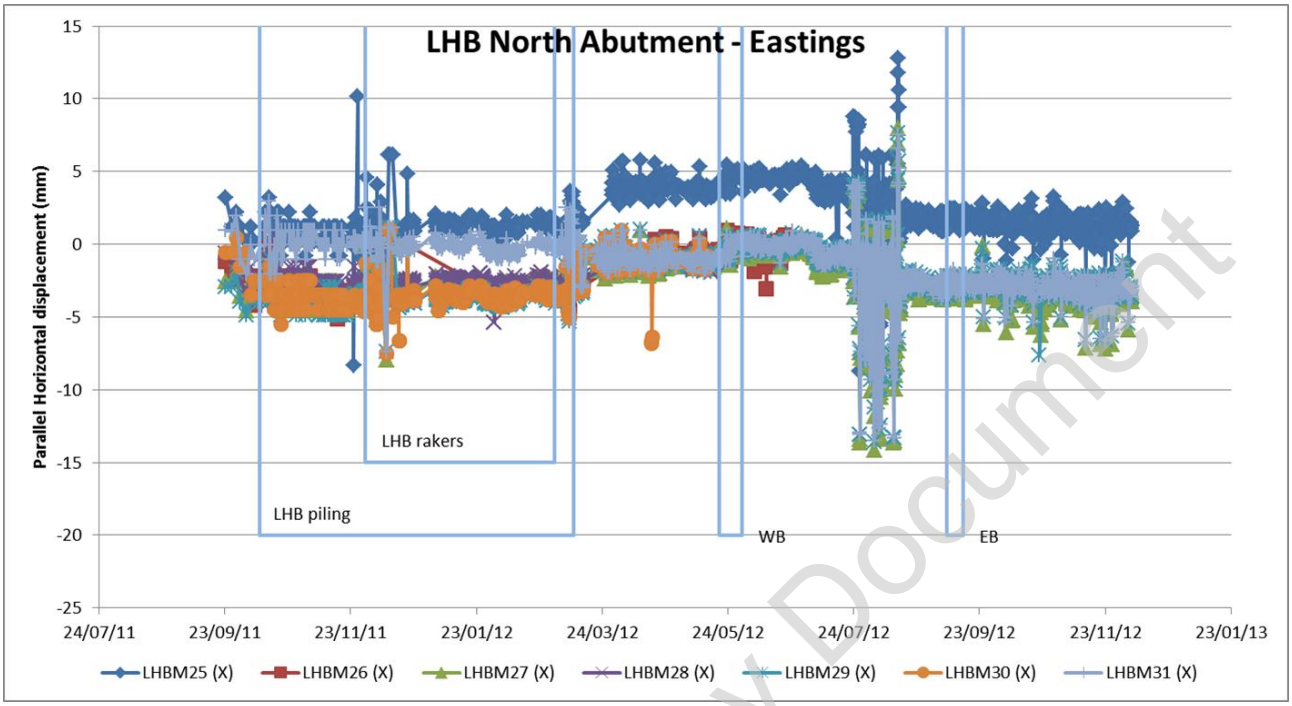


Figure 6: Lords Hill's Bridge north abutment – Eastings

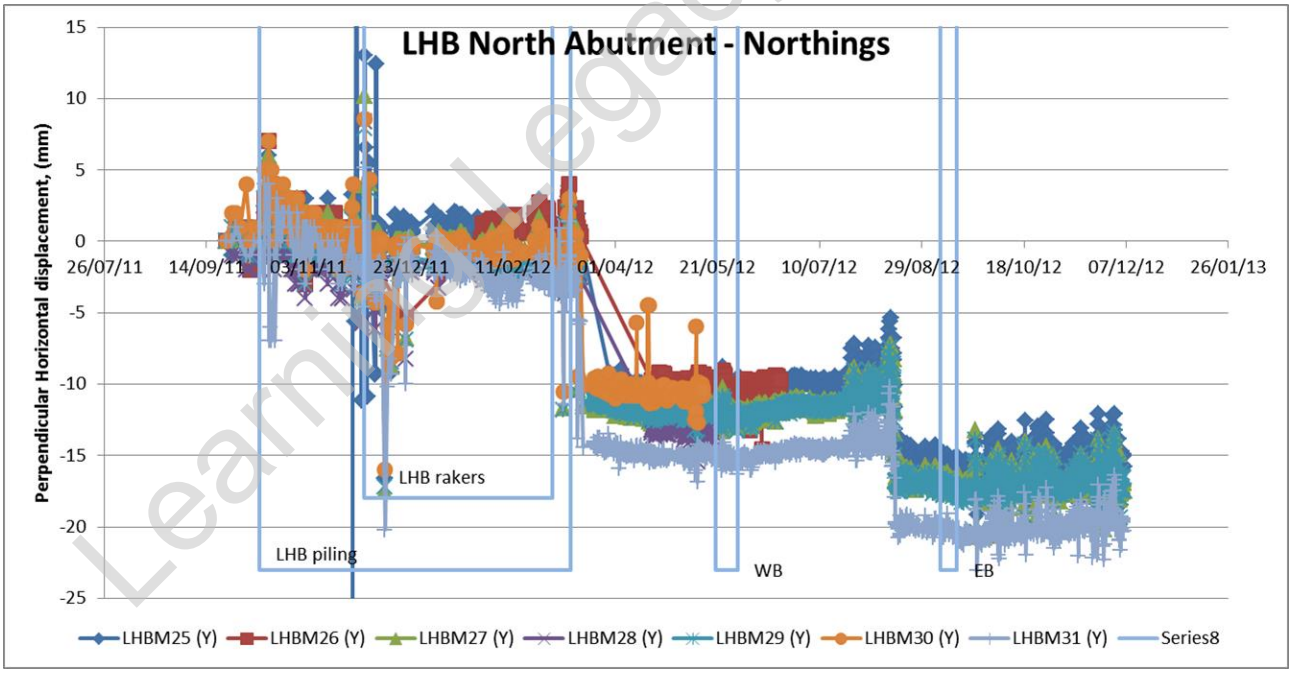


Figure 7: Lord Hill's Bridge north abutment – Northings

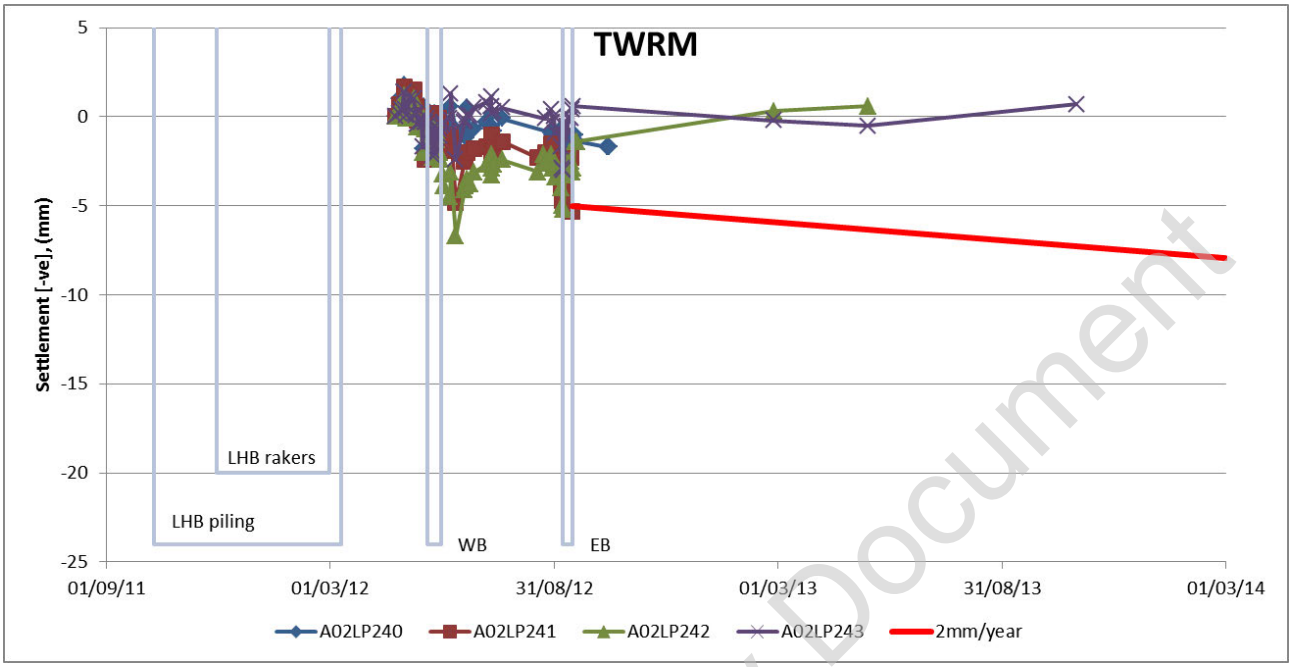


Figure 8: PLPs over Thames Water Ring Main: data time plot

2.1.2. Comments

Extensive protective measures were undertaken to mitigate the impact of the tunnel drives on Lord Hill's Bridge. These comprised replacement of the ground through which the Eastbound TBM would drive by piling. The piling consisted of vertical piles ranging from 600mm to 1200 mm diameter (as shown on Figure 1) and further 600mm raking piles below the bridge's north abutment, since the EB alignment passes partly below the north abutment.

The data show that up to 12mm settlement occurred on Lord Hill's Bridge north abutment during the installation of the piling, with the majority associated with the installation of the raking piles. Only minor movements were recorded during the TBM tunnel drives. Very small movements (~3mm) were recorded on the bridge pier to the south of the tunnel alignment.

The horizontal movements recorded by prisms on the north abutment are small. There are two steps in the data which are not associated with any construction activity and are not considered to represent real movement.

The measurement points above the alignment of the Thames Water Ring Main indicated a maximum of 5mm settlement. No trigger has been breached. The long-term behaviour is stable.

The residual risk associated with long-term settlements is considered to be negligible. The measurement points on Lord Hill's Bridge settled up to approx. 12mm. No trigger has been breached. The long-term behaviour is stable.

The measurement points on Thames Water Ring Main indicated a maximum of 5mm settlement. No trigger has been breached. The long-term behaviour is stable.

The residual risk associated with long-term settlements is considered to be negligible.

2.2. LU Royal Oak station

2.2.1. Data

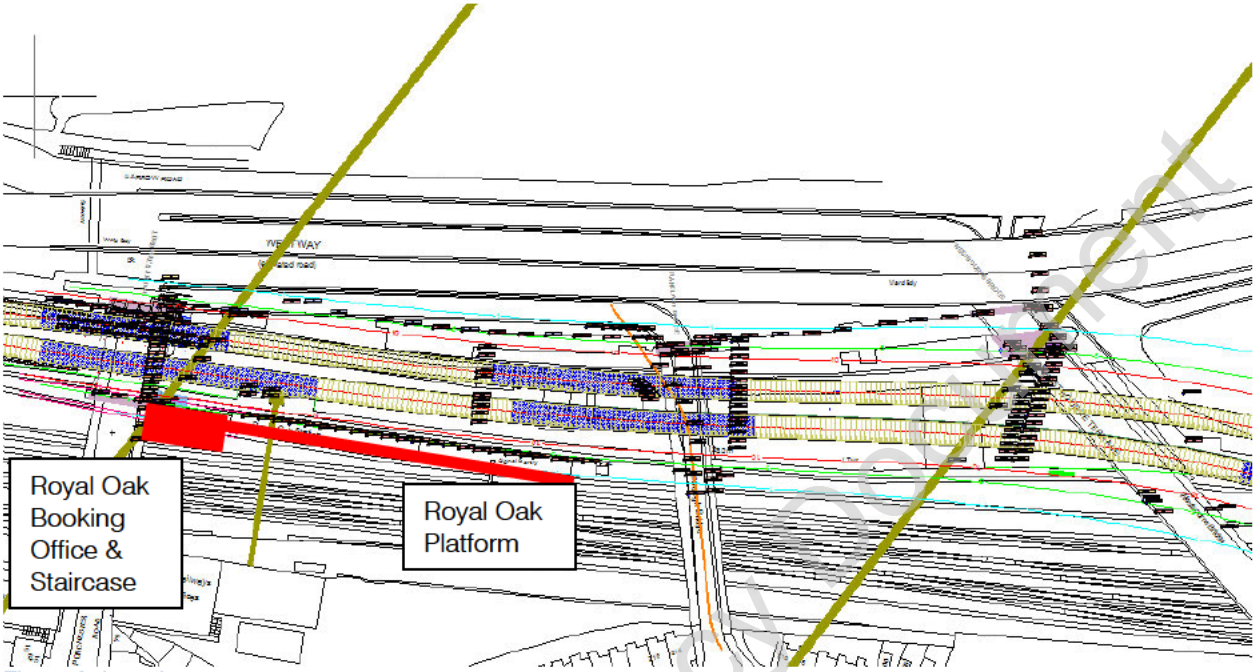


Figure 9: Location

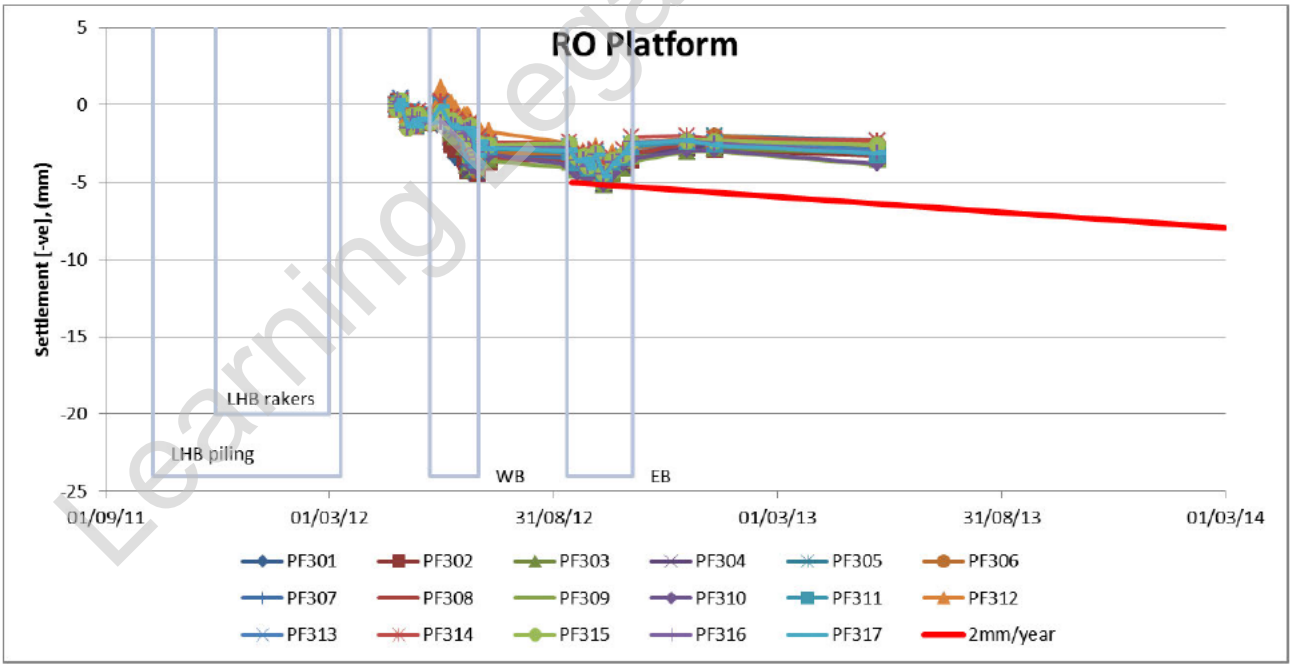


Figure 10: data time-plots: PLPs along Royal Oak Station platform

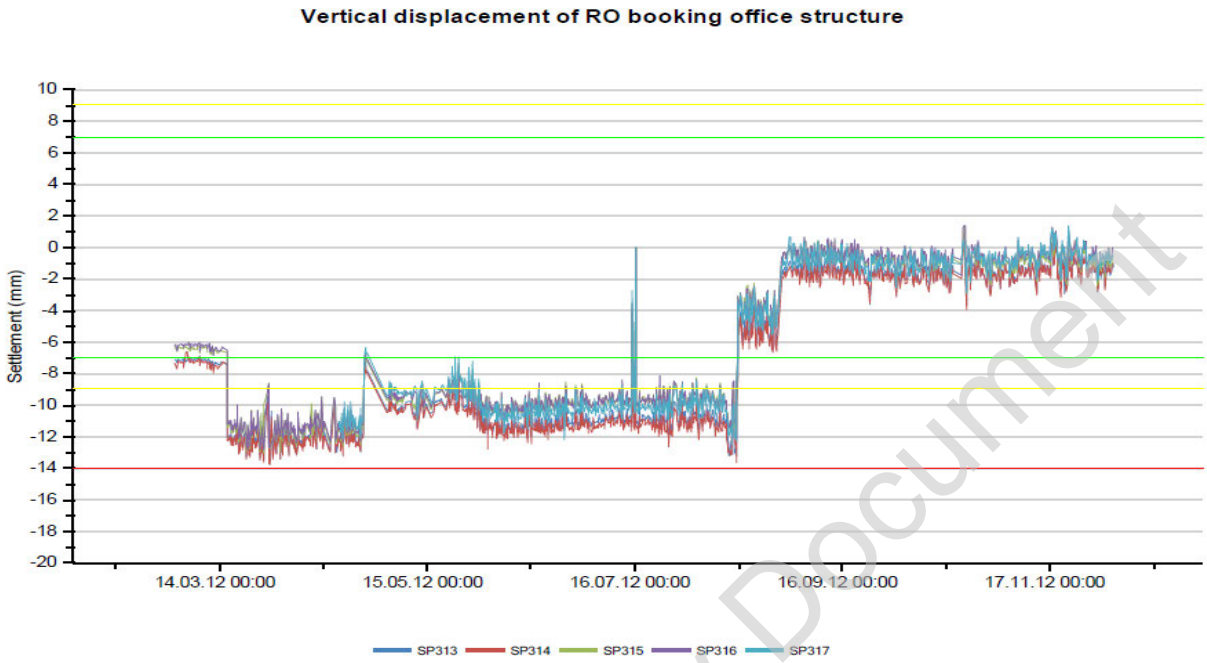


Figure 11: data time-plots: vertical displacement of Royal Oak booking office structure

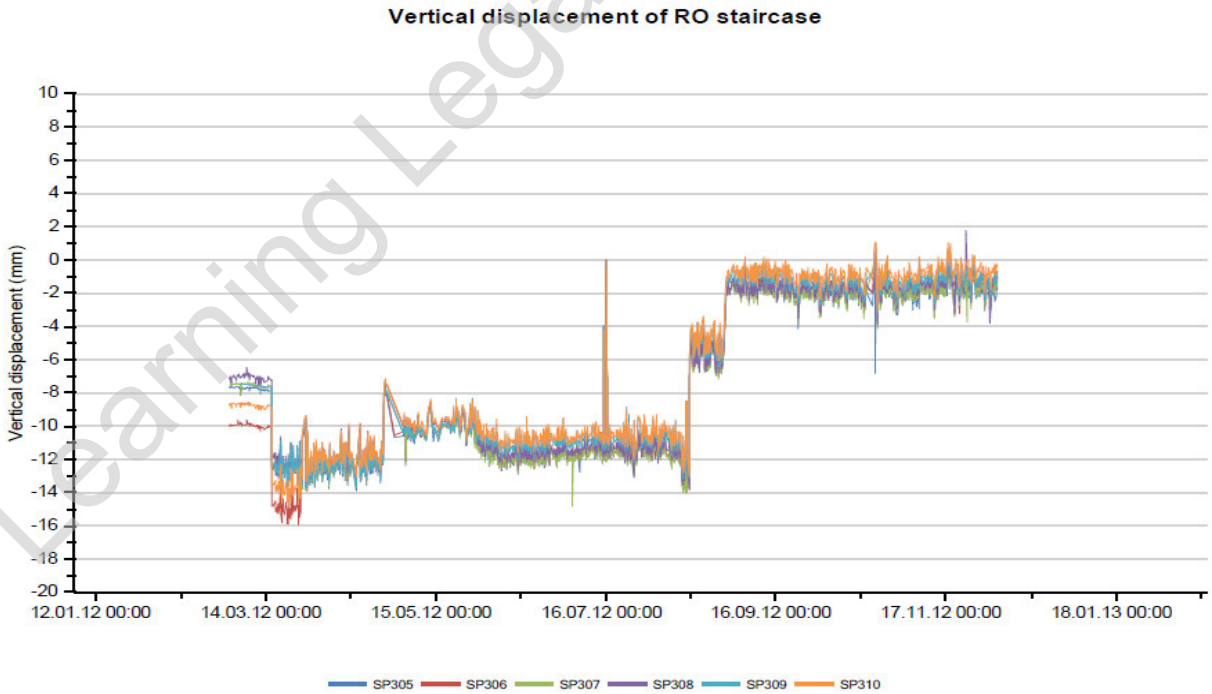


Figure 12: data time-plots – vertical displacement of Royal Oak staircase

2.2.2. Comments

The measurement points on Royal Oak station platform settled up to approx. 4mm. No trigger has been breached. The long-term behaviour is stable.

The steps in the data from prisms on the Booking Office and Staircase are not considered to represent actual movement, since there were no construction activities in progress at the relevant times. The residual risk associated with long-term settlements is considered to be negligible.

2.3. Transects EB Ch. 680 & 766

2.3.1. Data

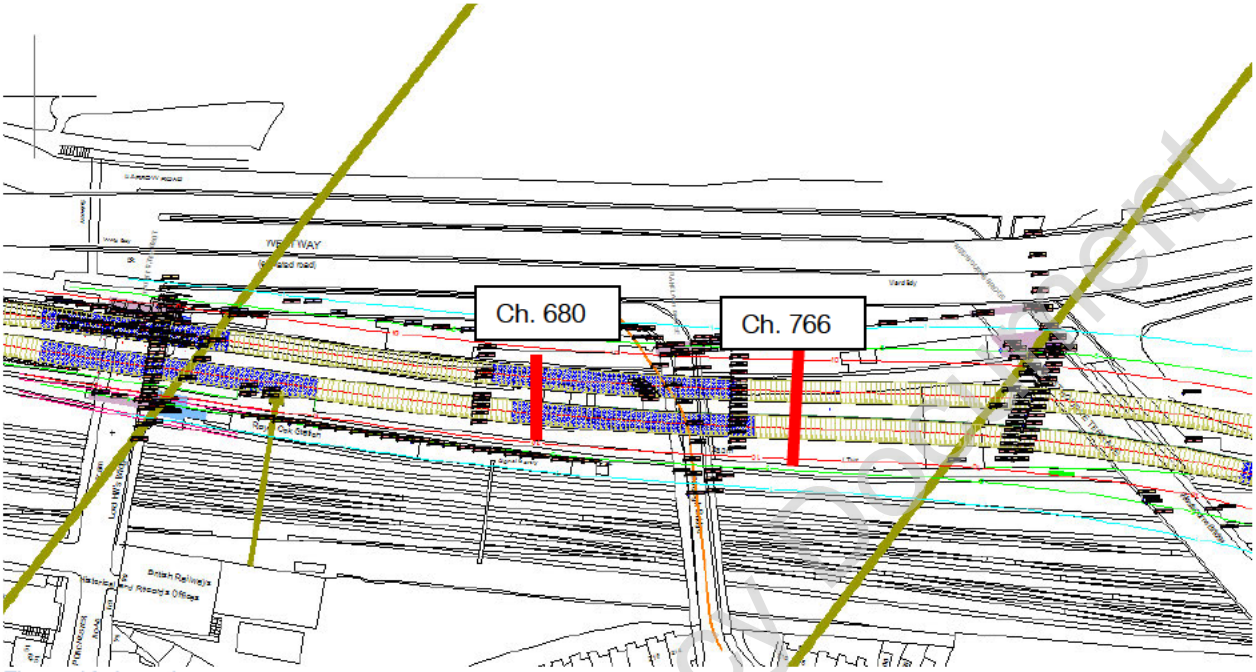


Figure 13: Location

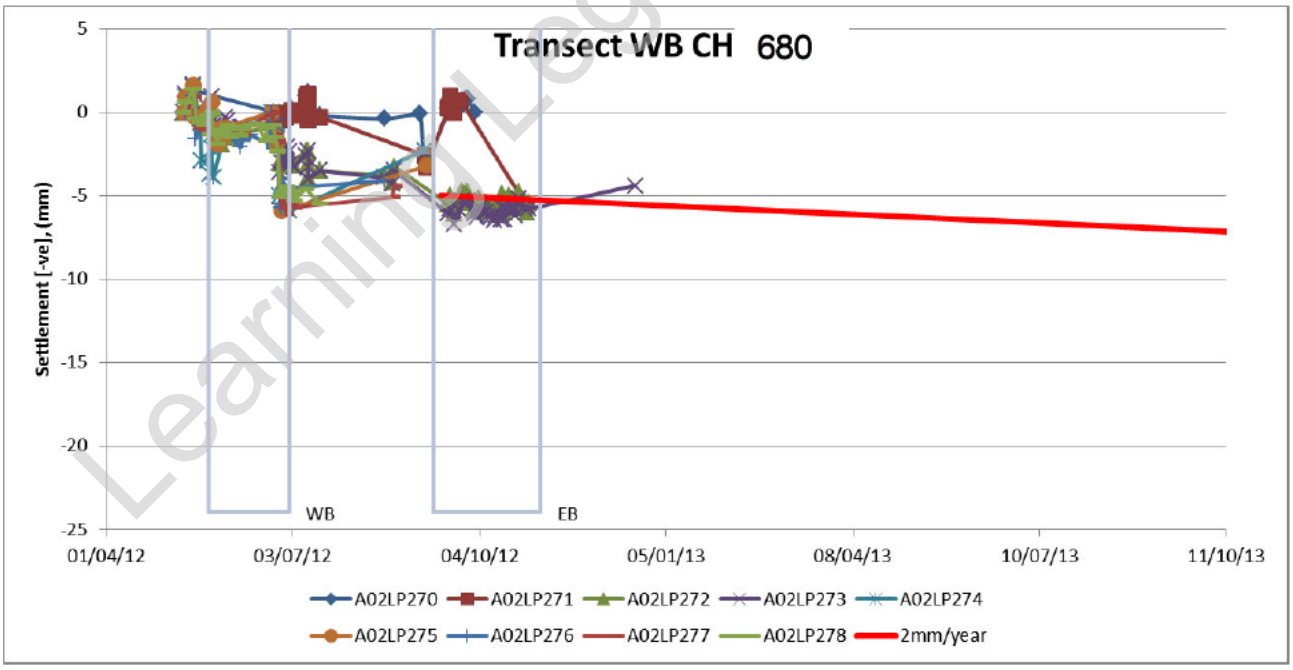


Figure 14: data time-plots for Transect WB Ch 680

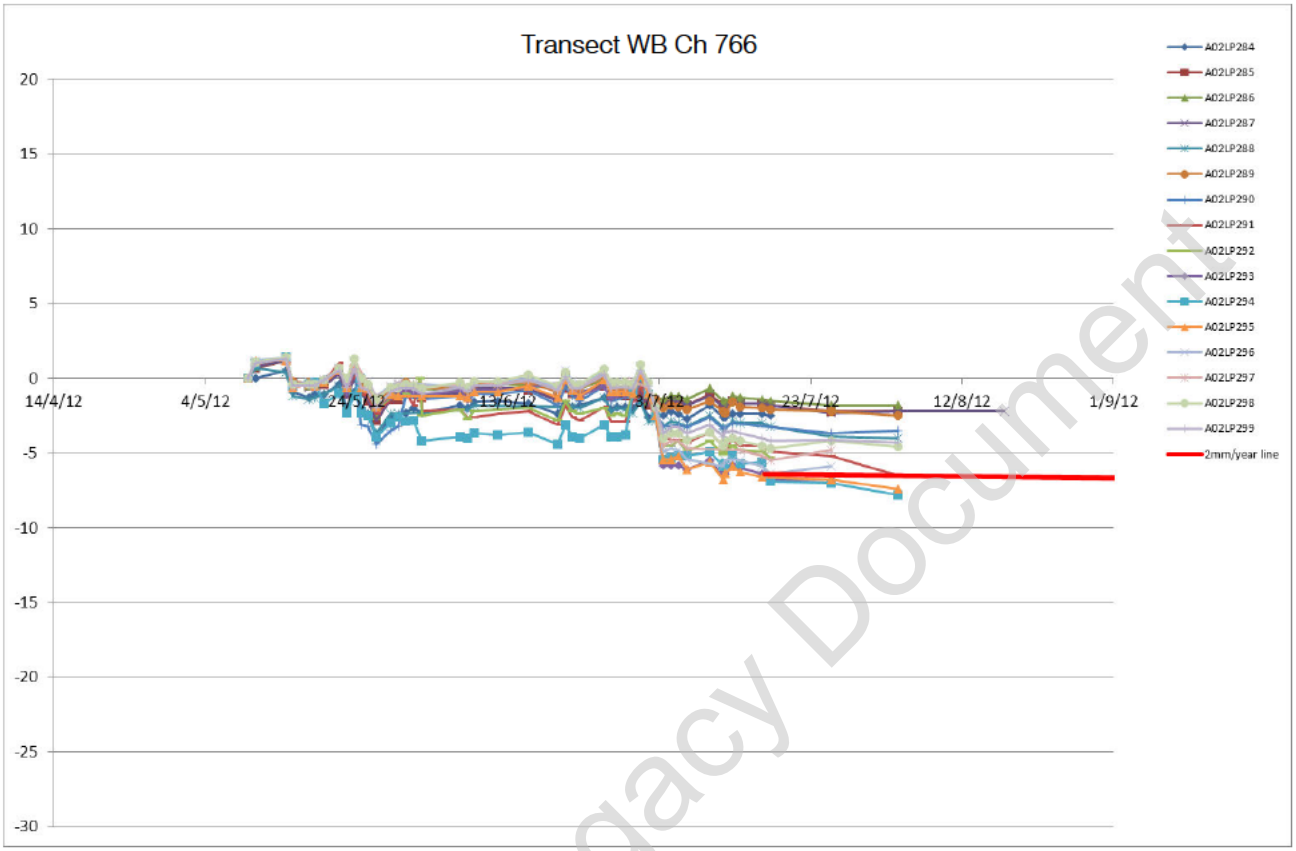


Figure 15: data time-plots for Transect EB Ch 766

2.3.2. Comments

The measurement points on PLP transects at EB Ch 680 and Ch 766 settled up to approx. 7mm. No trigger has been breached. No long-term monitoring was practicable since these points were located in the TBM muck stockpile area.

There are no assets associated with these transects and therefore the residual risk associated with long-term settlements is considered to be negligible.

2.4. Ranelagh Bridge, Ranelagh Sewer & Harrow Road Wall

2.4.1. Data

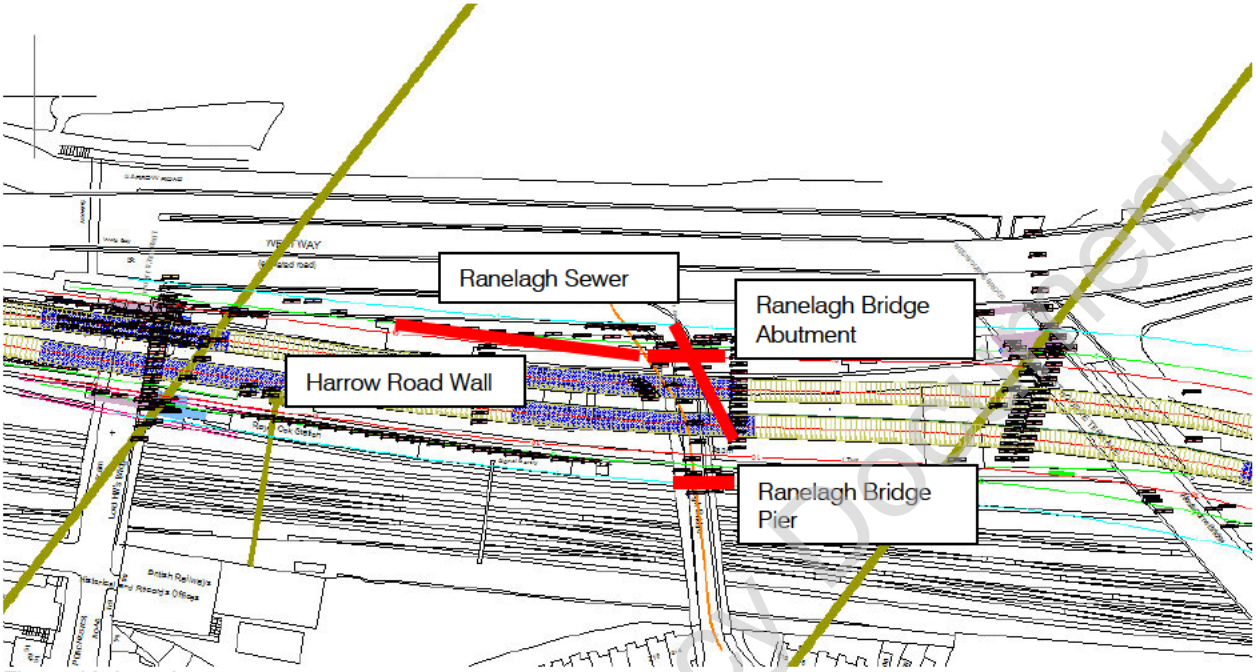


Figure 16: Location

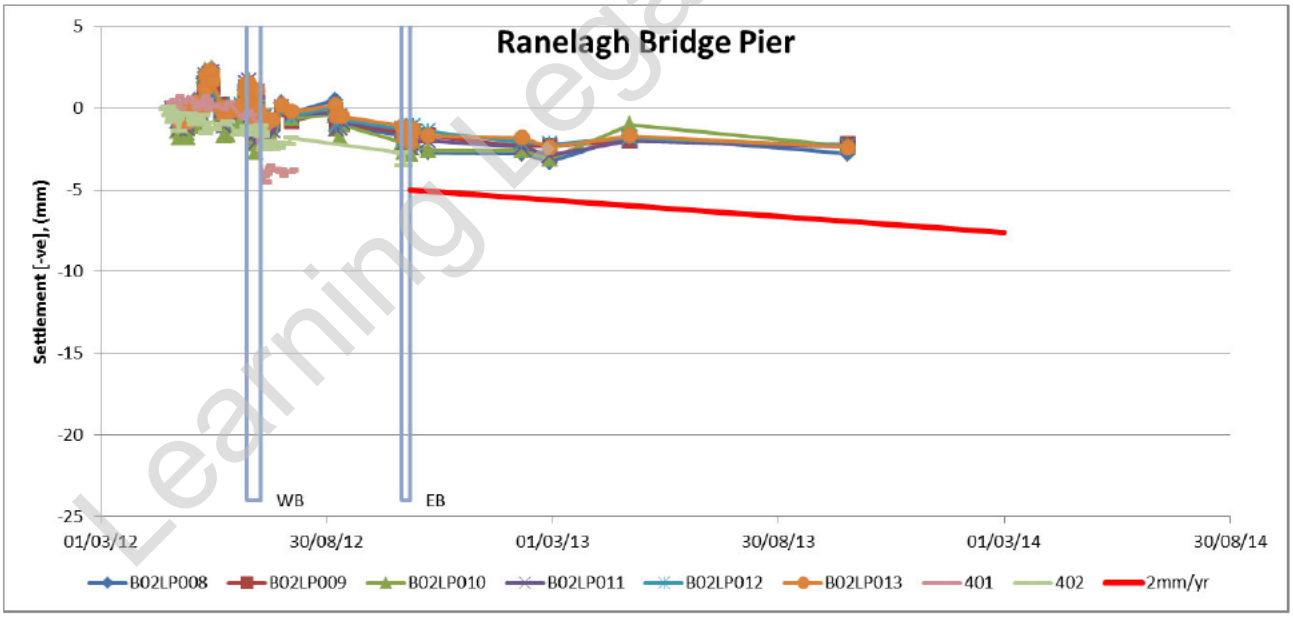


Figure 17: data time-plots – Ranelagh Bridge central pier settlement

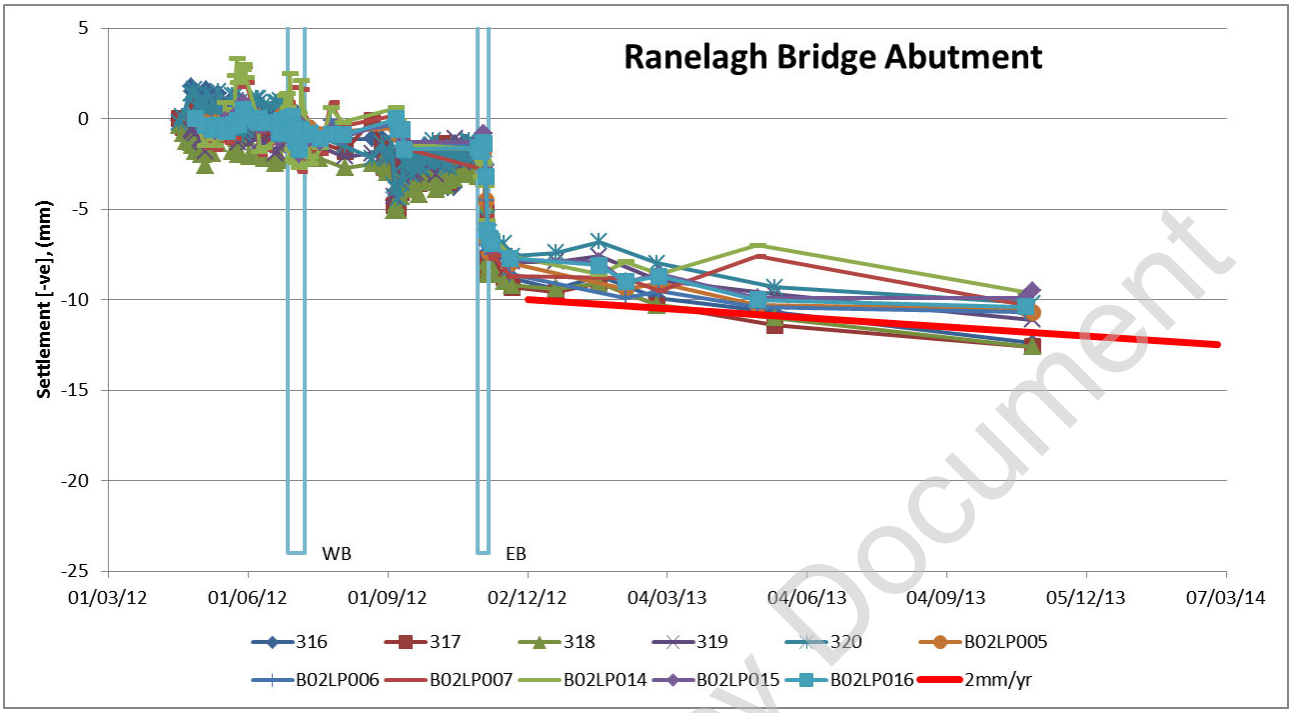


Figure 18: data time-plots - Ranelagh Bridge north abutment settlement

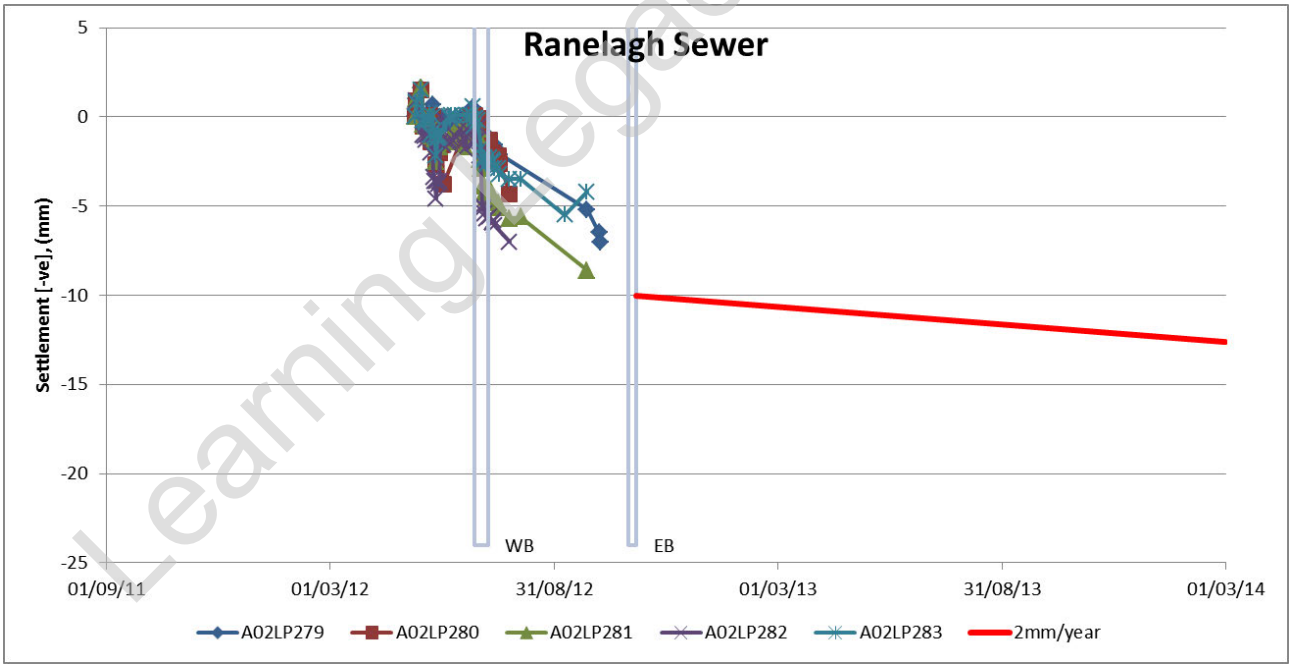


Figure 19: Ranelagh Sewer timeplots

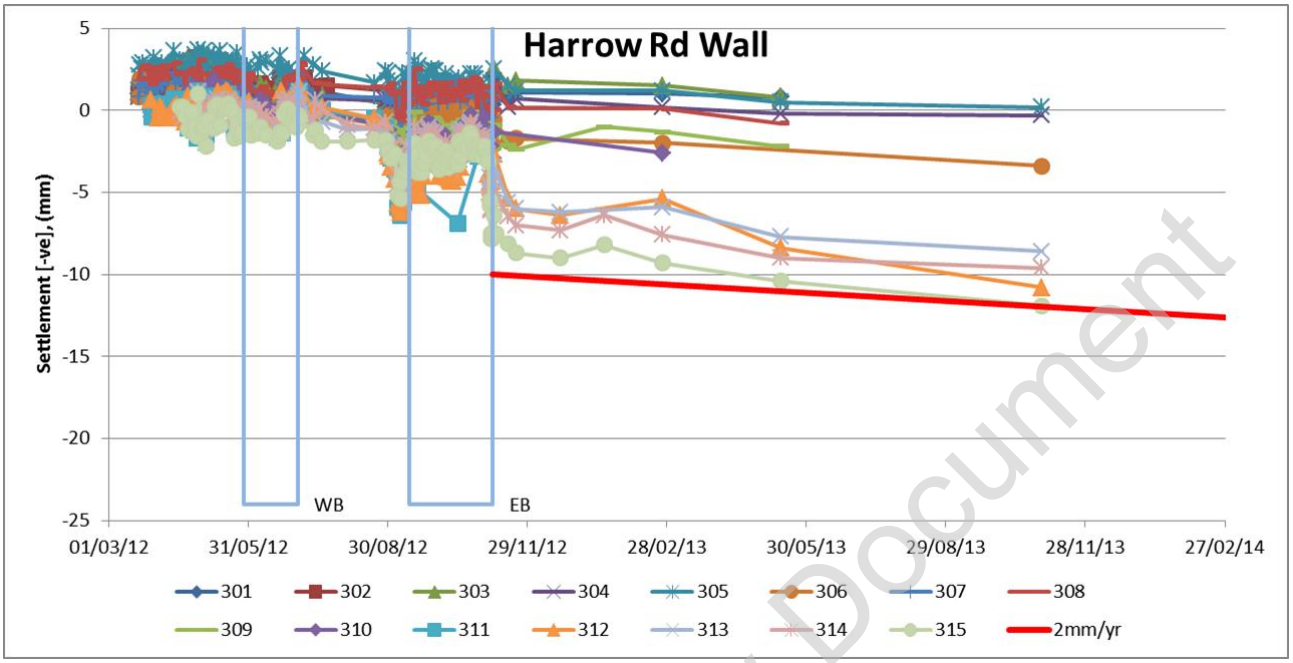


Figure 20: data timeplot – BREs at Harrow Road Wall between Lord Hill's Bridge and Ranelagh Bridge

Table 3: Achieved Triggers – settlements

Point Code	Point type	Achieved Trigger
312	BRE	Amber
313	BRE	Amber
314	BRE	Amber
315	BRE	Amber
316	BRE	Amber
317	BRE	Amber
318	BRE	Amber
319	BRE	Amber
320	BRE	Amber

2.4.2. Comments

The measurement points presented in Section 2.4 show maximum settlement of approx. 13mm. Nine points on the North Abutment breached the amber trigger. Monitoring of the Ranelagh Sewer points had to be terminated since this area was used as a stockpile for the TBM muck. Based on the data from Ranelagh Bridge and Harrow Road Wall, the residual risk associated with long-term settlements for all assets in this area is considered to be negligible.

2.5. Westbourne Bridge north abutment, Transect Ch. 840 & Harrow Road Wall

2.5.1. Data

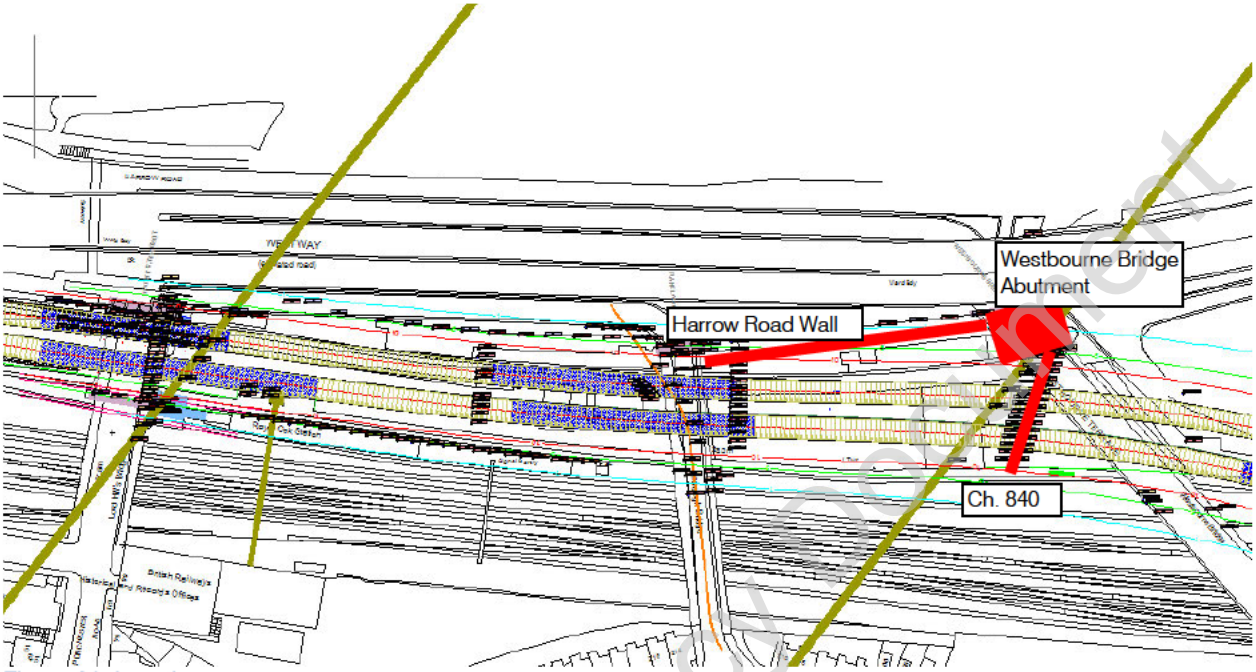


Figure 21: Location

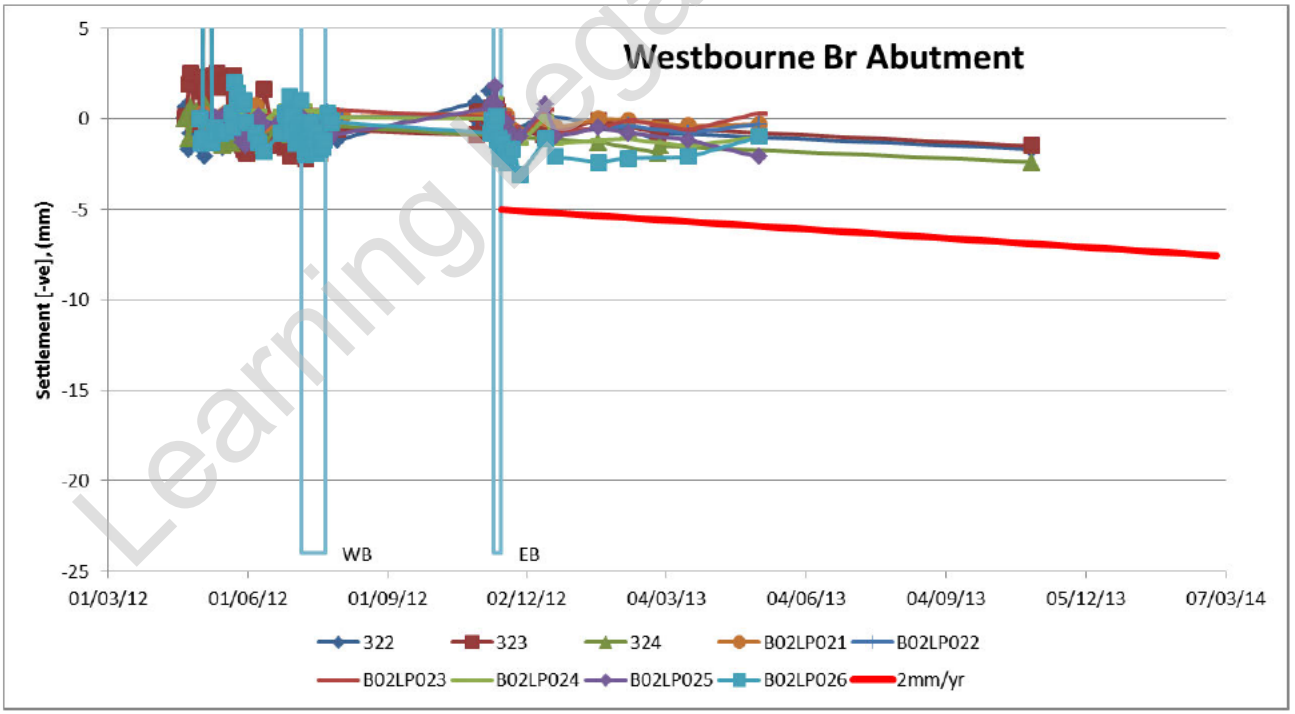


Figure 22: data time-plots - Westbourne Bridge north abutment

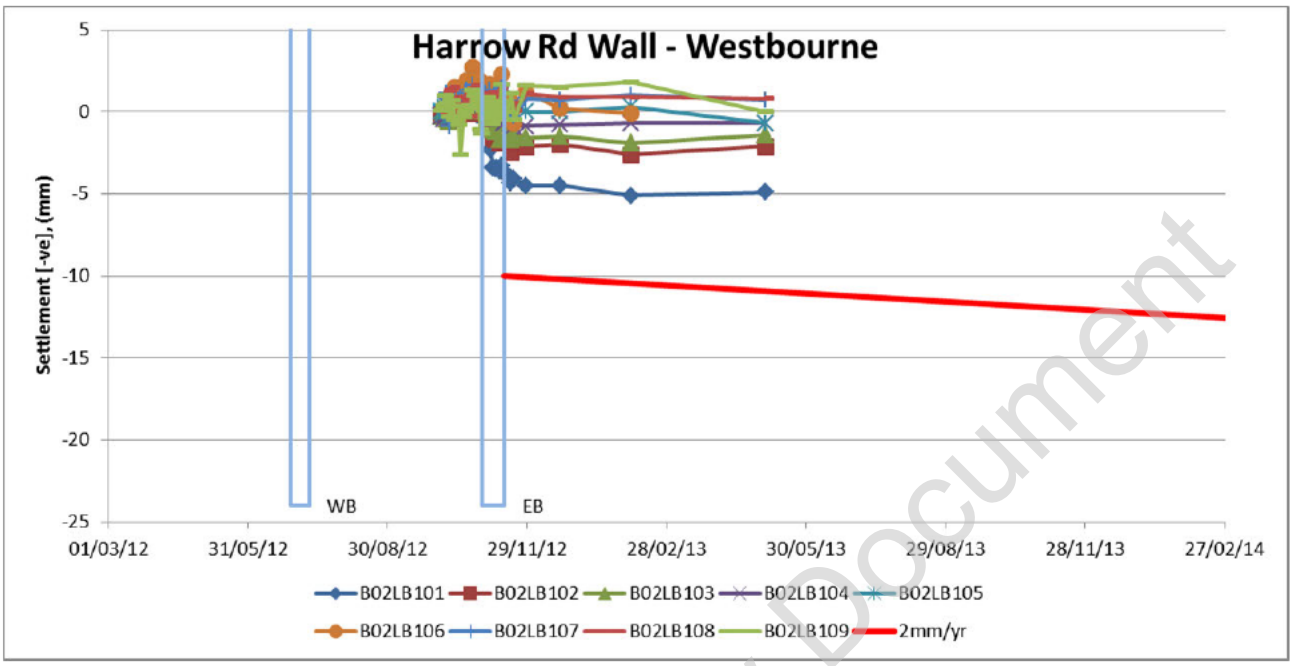


Figure 23: data time-plots - Harrow Road Wall between Ranelagh and Westbourne Bridge

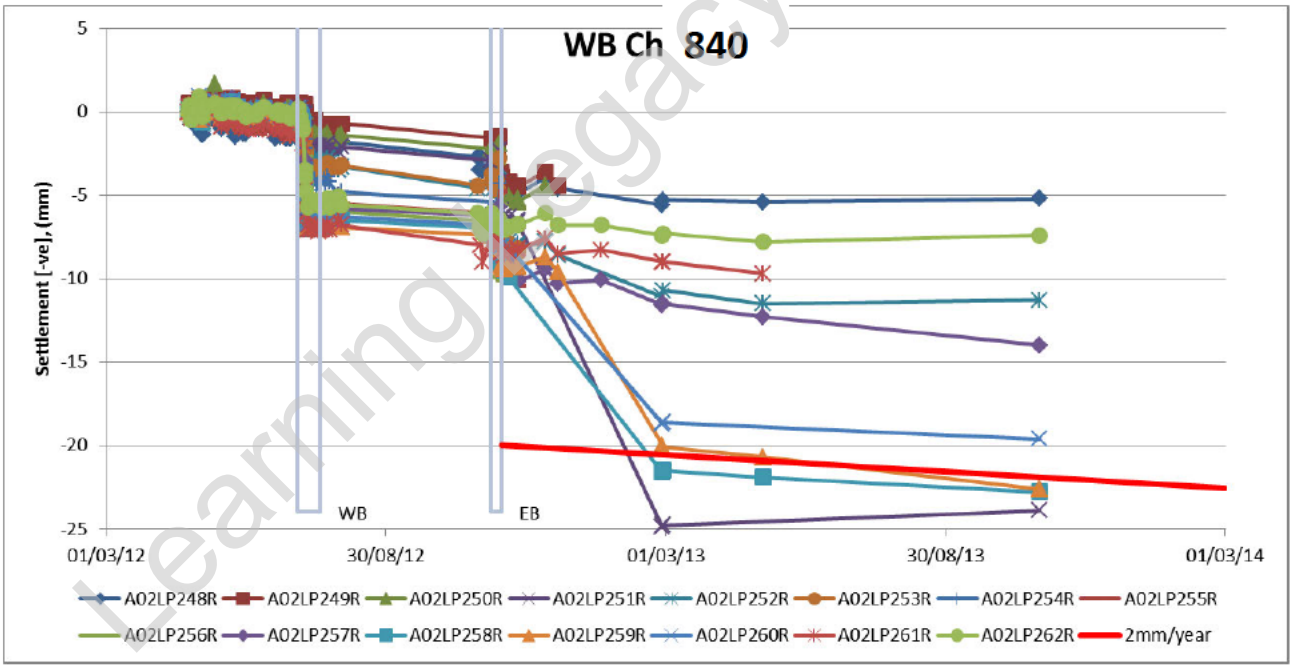


Figure 24: data timeplots - transect EB Ch 840

2.5.2. Comments

The measurement points presented in Section 2.5 show maximum settlement of approx. 25mm, however it is considered that the four points showing a sudden increase of 15mm, which is not associated with any construction activity, are not reliable and the actual maximum settlement is about 14mm. No triggers have been breached. The residual risk associated with long-term settlements is considered to be negligible.

2.6. Transect Ch 945, 1 Kingdom Street & Goods Yard Wall

2.6.1. Data

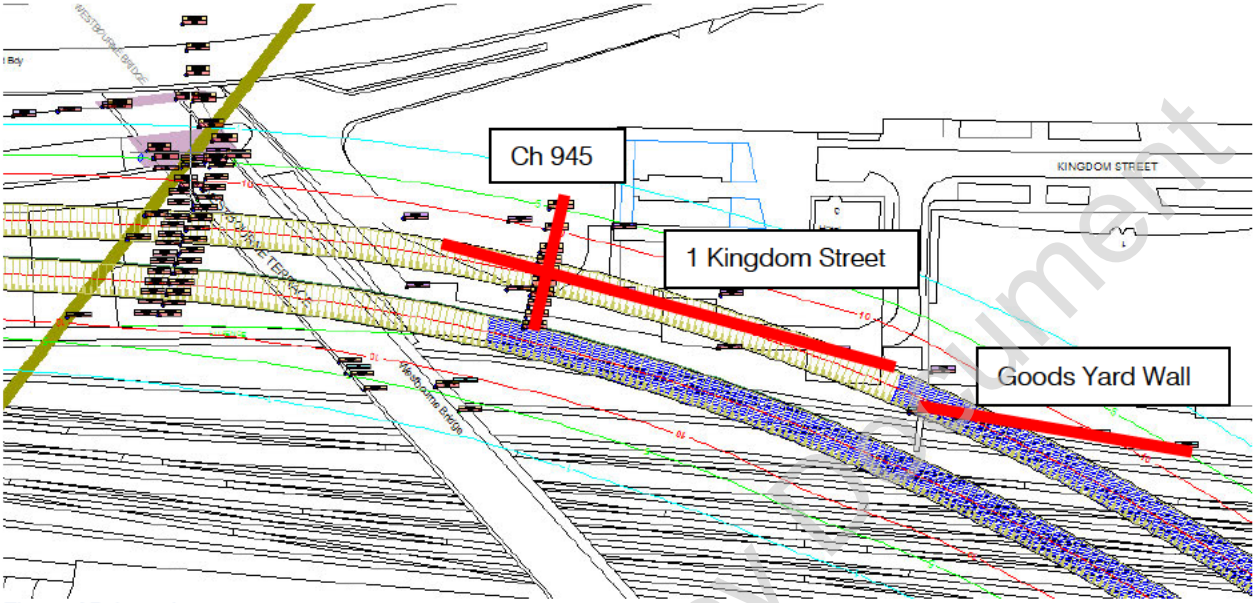


Figure 25: Location

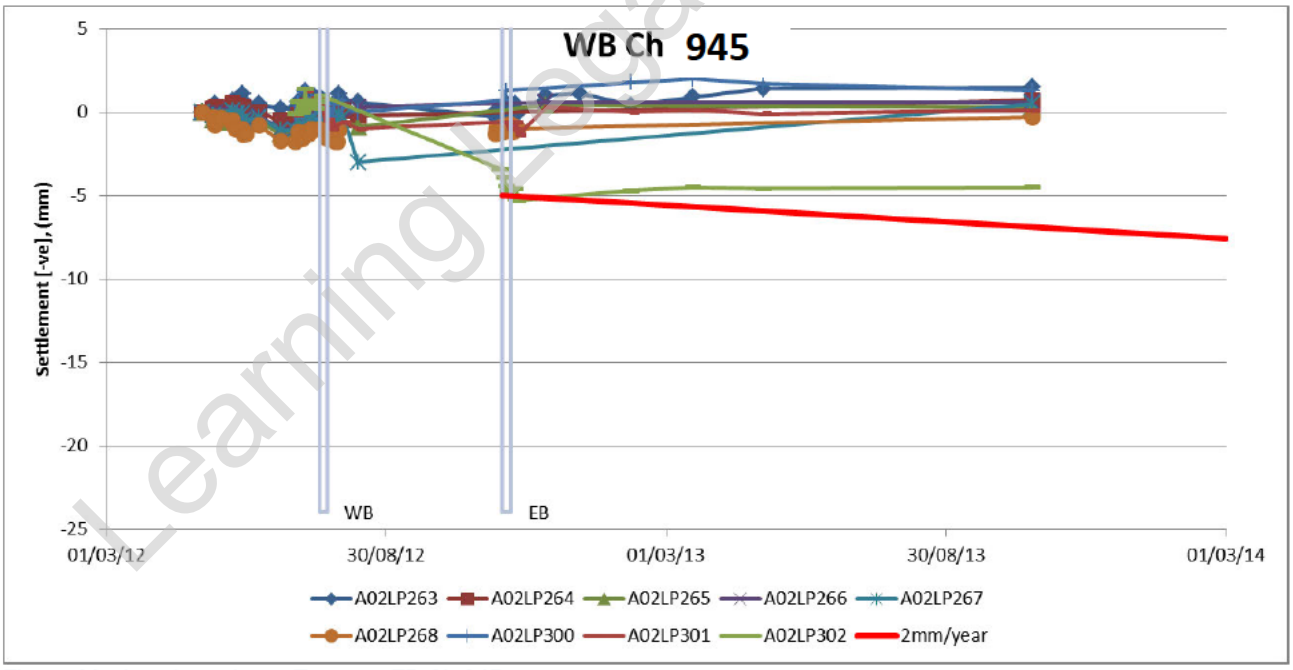


Figure 26: data time-plots – Transect EB Ch 945

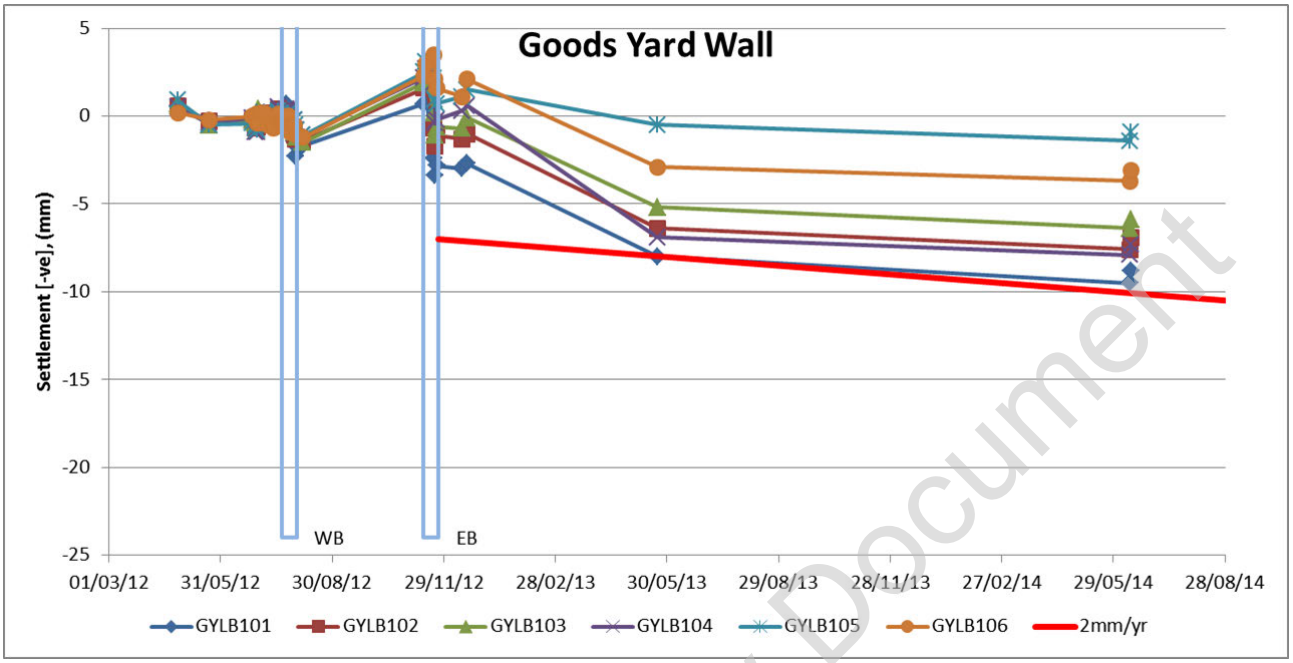


Figure 27: Good Yard Wall barcodes

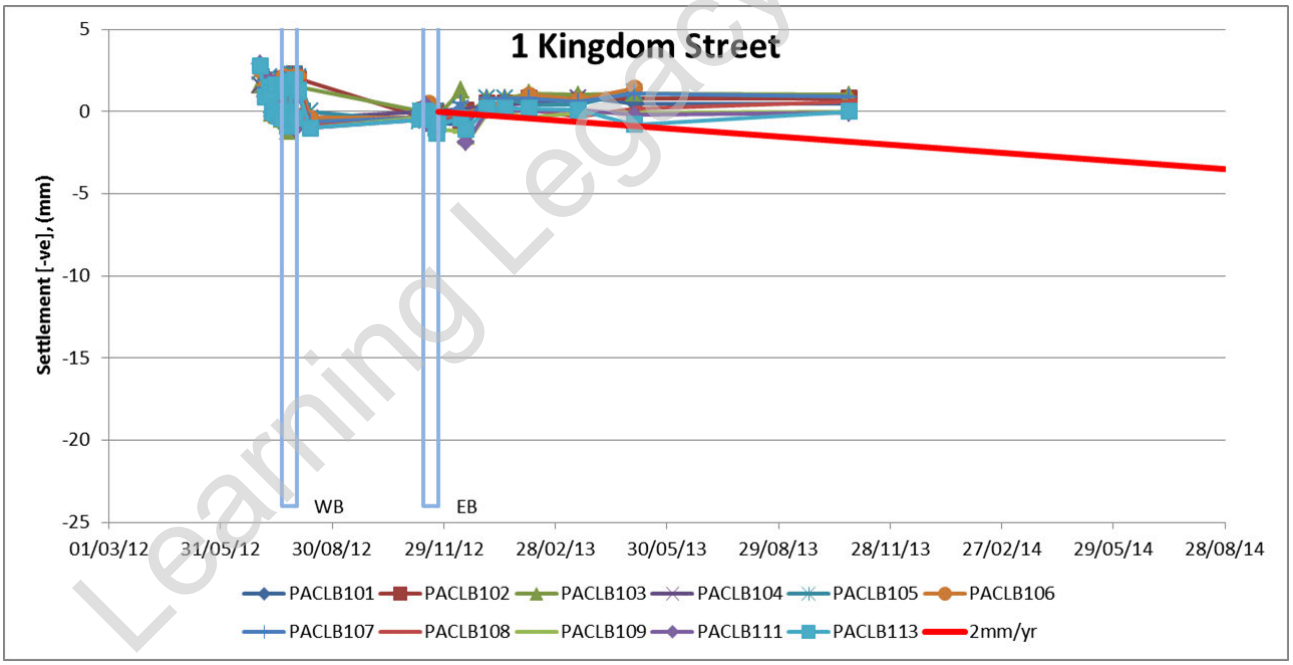


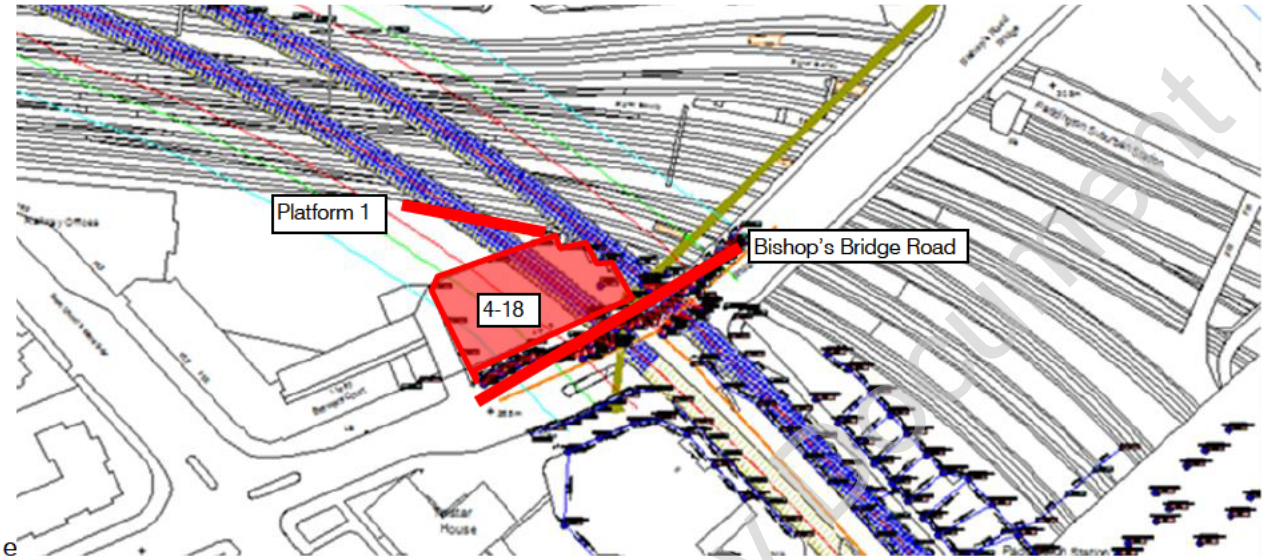
Figure 28 1 Kingdom Street barcodes

2.6.2. Comments

The measurement points presented in Section 2.6 show maximum settlement of approx. 10mm. No triggers have been breached. The residual risk associated with long-term settlements is considered to be negligible.

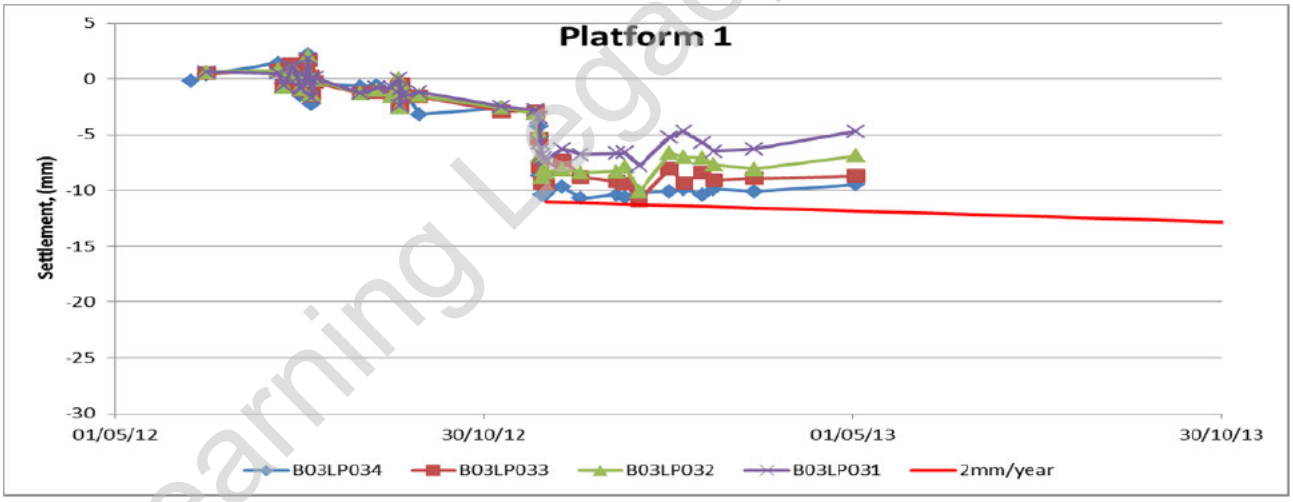
2.7. Bishop Bridge Road

2.7.1. Data



e

Figure 29: Location



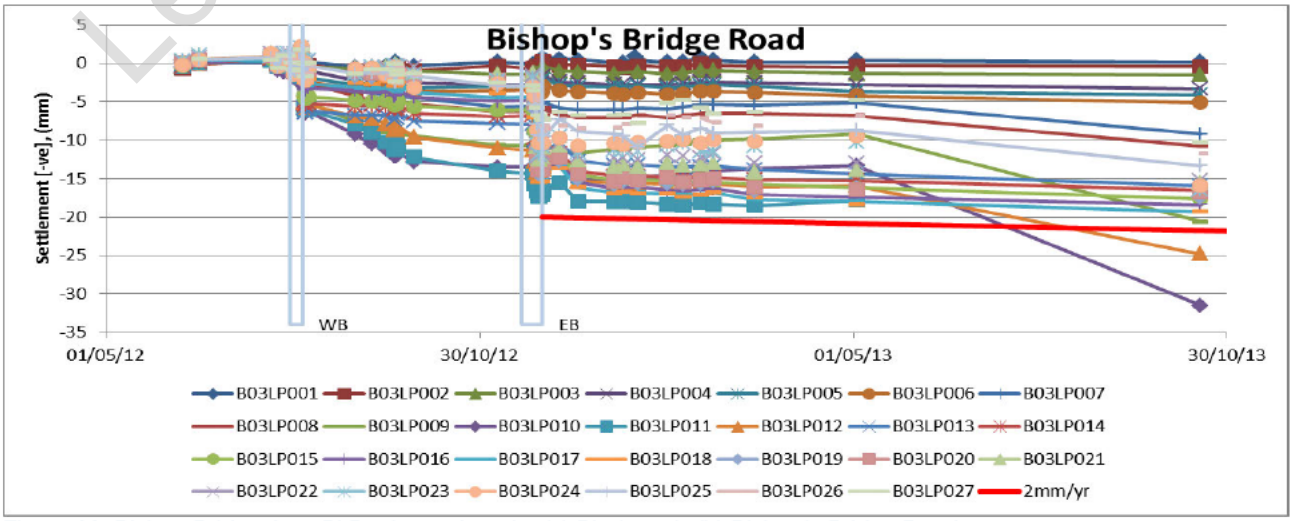


Figure 30: Bishop Bridge Area PLPs data – timeplot (a) Platform 1; (b) Bishop's Bridge Road

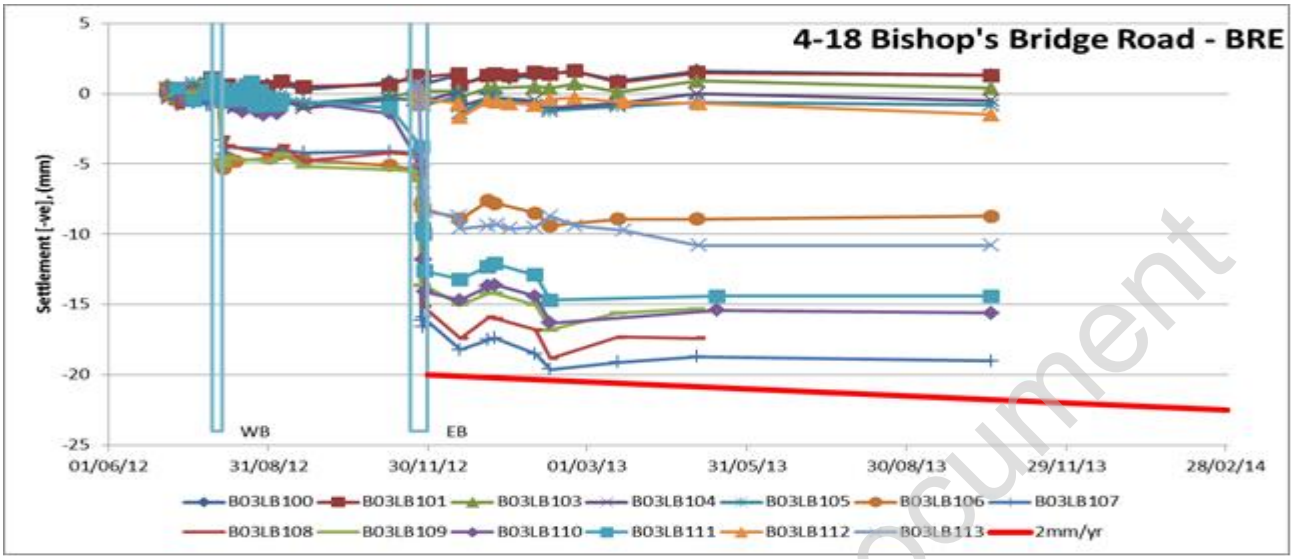


Figure 31: 4-18 Bishop Bridge Road BREs data – timeplot

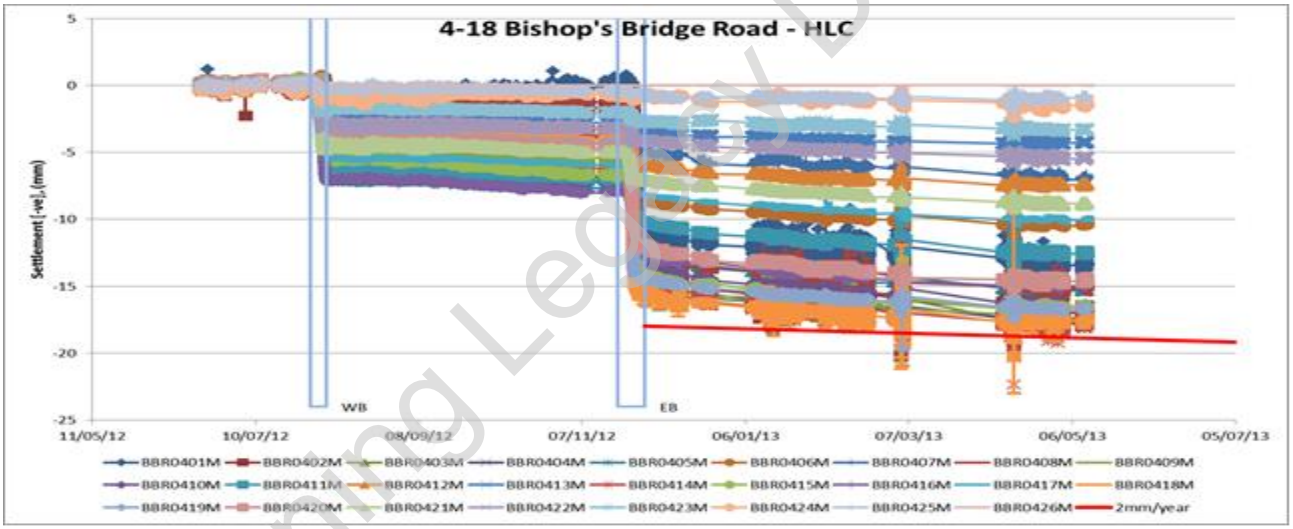


Figure 32 4-18 Bishop Bridge Road HLCs data – timeplot

Point Code	Point type	Trigger level
B03LP034	PLP	Green
B03LB107	BRE	Amber
B03LB108	BRE	Amber
B03LB109	BRE	Green

Table 4 Triggers

2.7.2. Comments

The measurement points presented in Section 2.7 show maximum settlement of approx. 20mm. One BRE and one PLP breached the green trigger and two BRE breached the amber trigger. Three adjacent PLPs over a distance of ~10m show significant settlements between the final two readings in May and October 2013. Given the stability of the data over a 6 month period following completion of the tunnelling and the lack of a similar response on the building monitoring, it is surmised that this is a localised effect due to works by others in the vicinity and is not a result of C300 works.

The residual risk associated with long-term settlements following the TBM drives is considered to be negligible.

2.8. London Underground Assets: H&C Line

2.8.1. Data

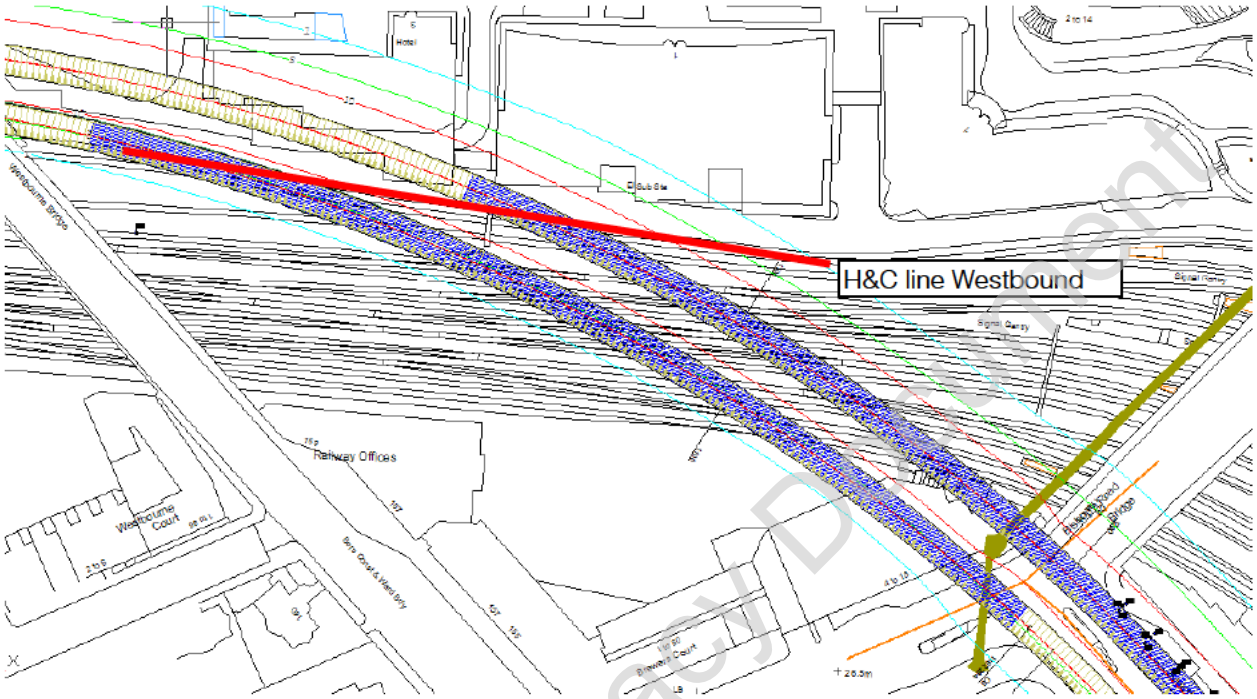


Figure 33: Location

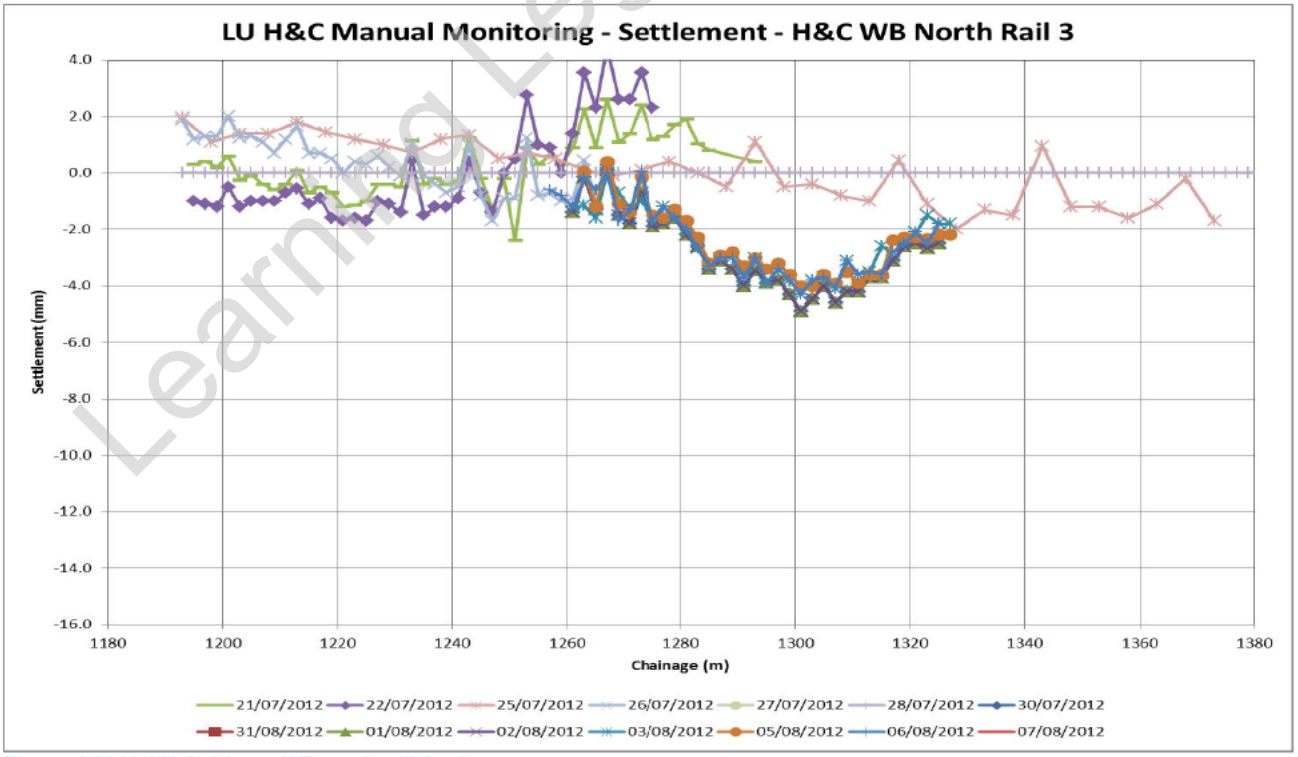


Figure 34 LU H&C Line - WB north rail Settlement

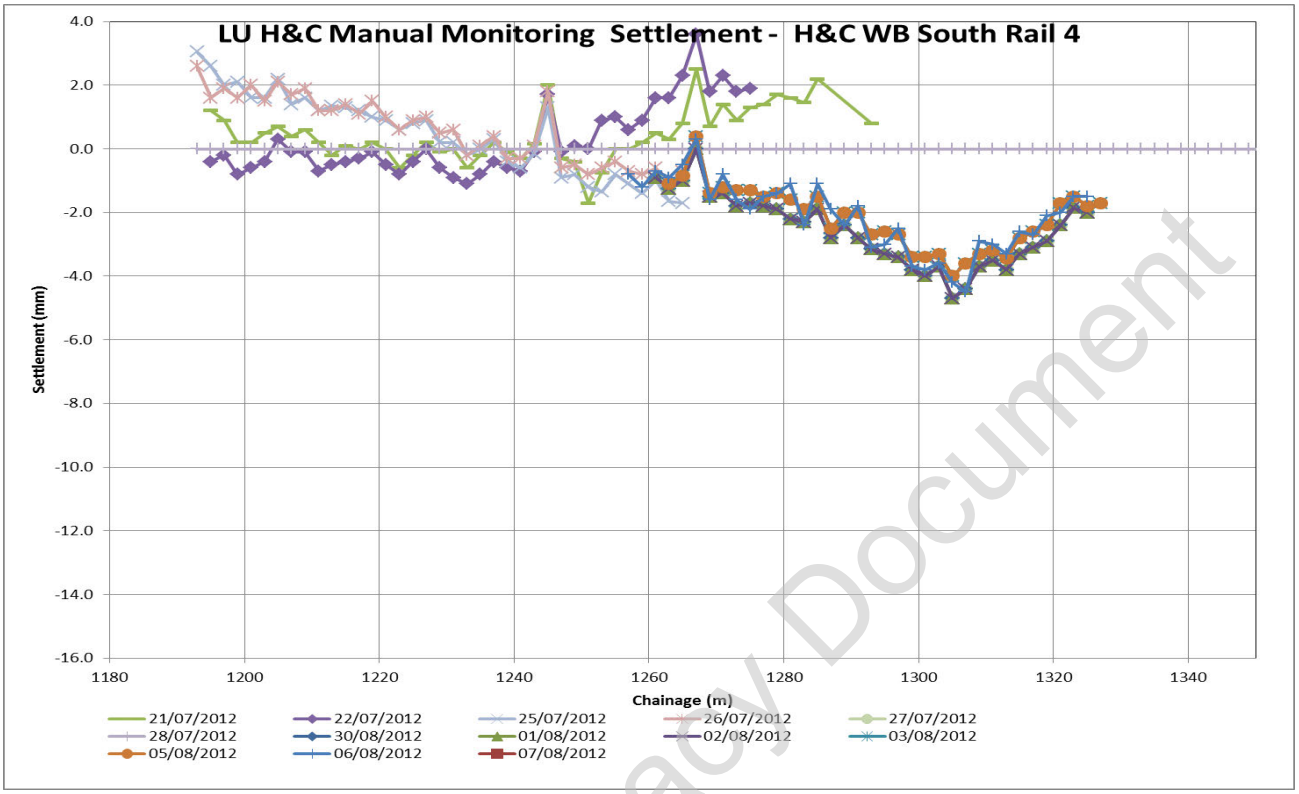


Figure 35 LU H&C Line - WB south rail Settlement

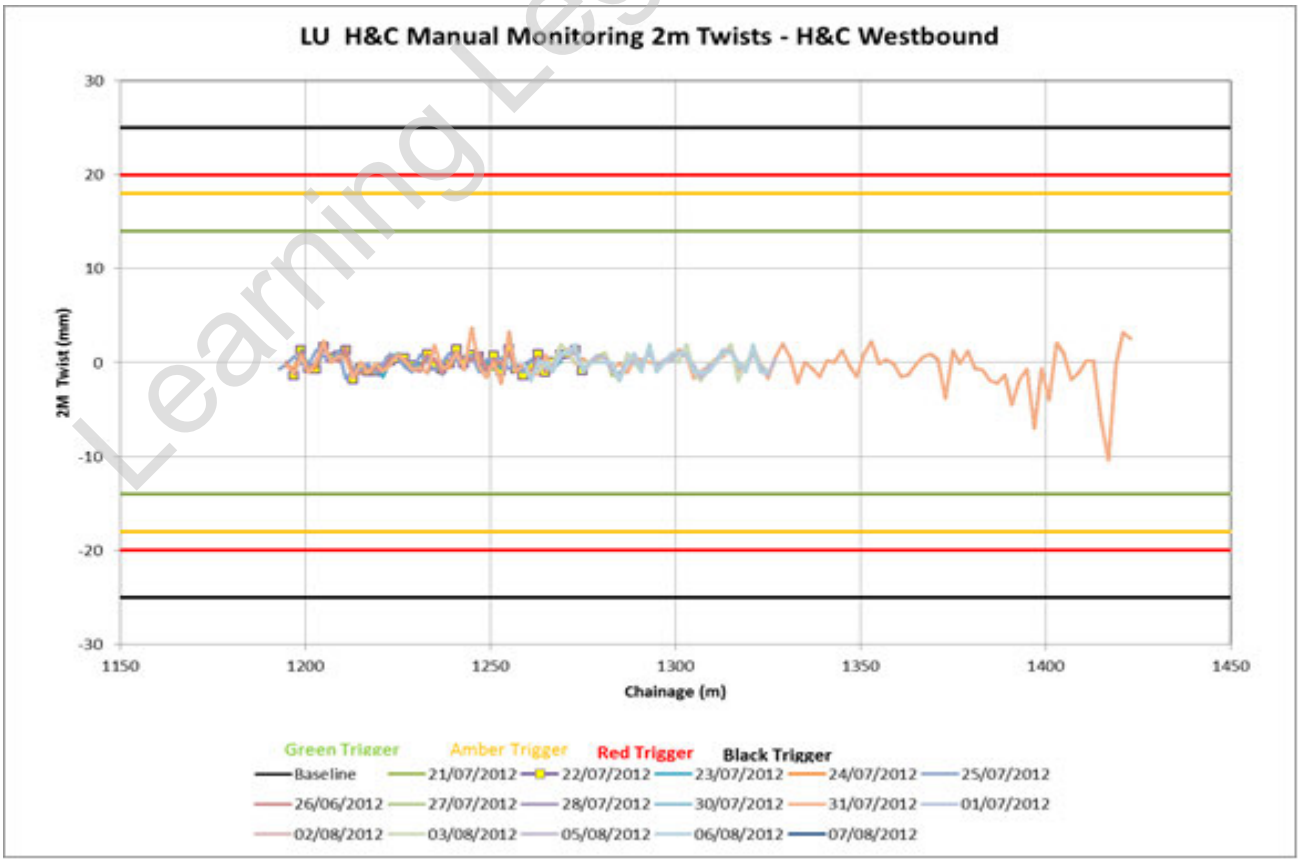


Figure 36 LU H&C Line - WB 2m twists

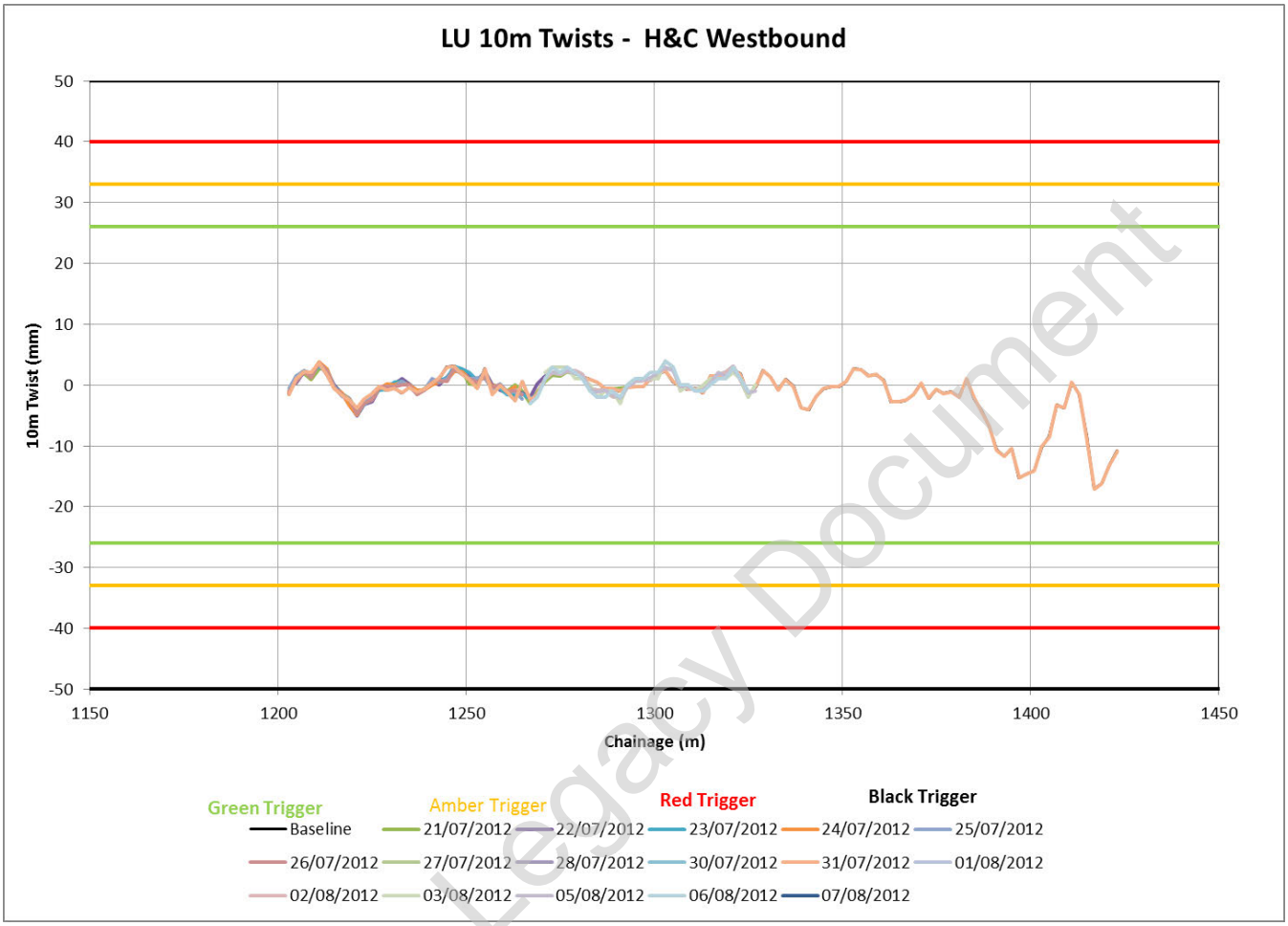


Figure 37 LU H&C Line - WB 10m twists

2.8.2. Comments

The measurement points presented in Section 2.8 show maximum settlement of approx. 5mm. The rail geometry (cant, twists) was not significantly affected by the TBMs passage. No triggers have been breached. The residual risk associated with long-term settlements is considered to be negligible.

2.9. Network Rail Assets

2.9.1. Data

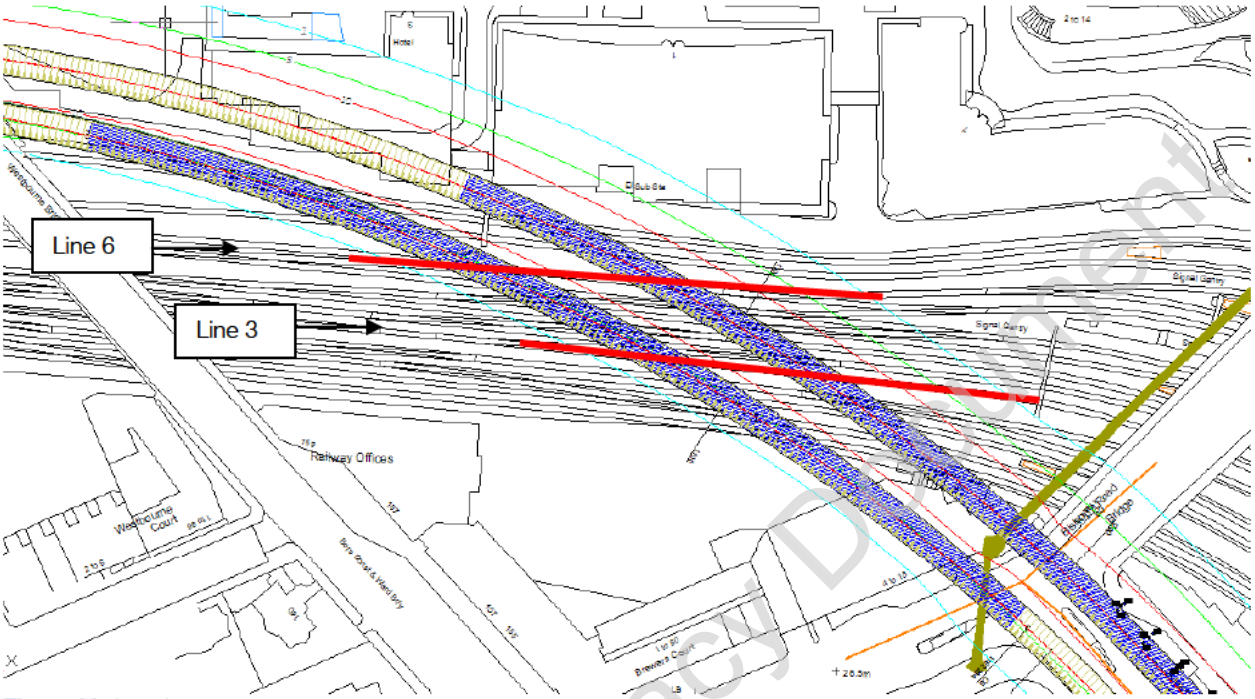


Figure 38: location

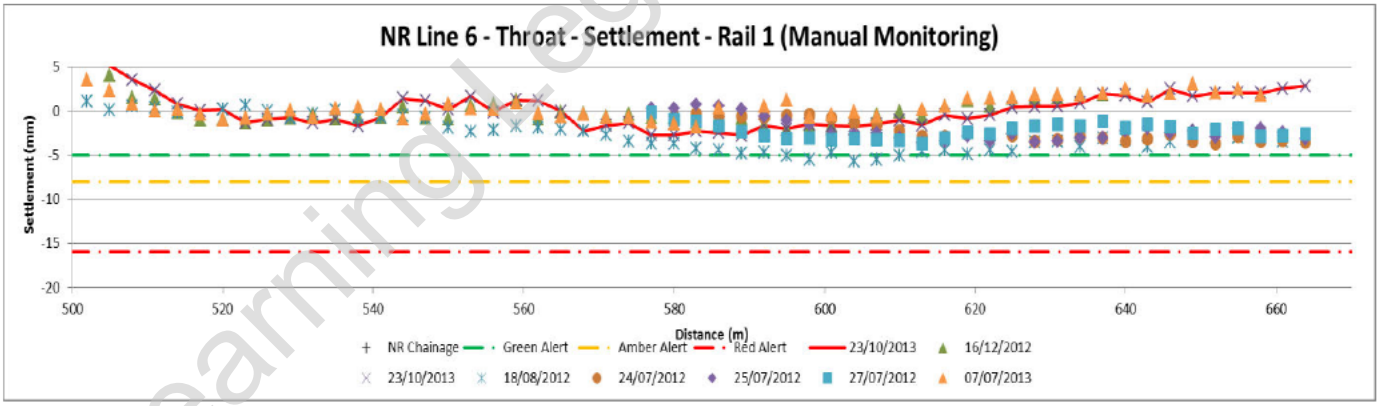


Figure 39 Line 6: settlement

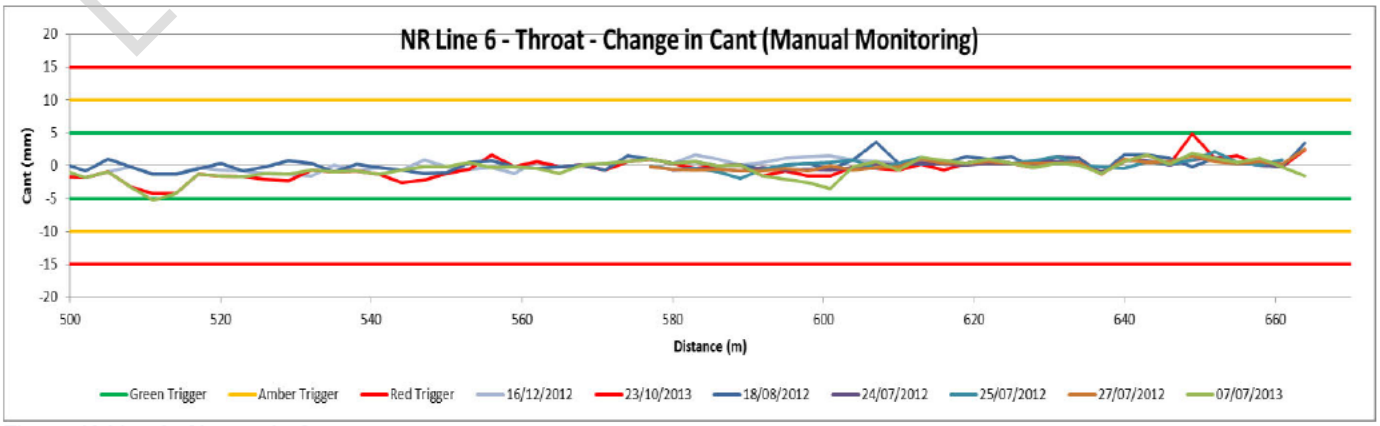


Figure 40 Line 6: Change in Cant

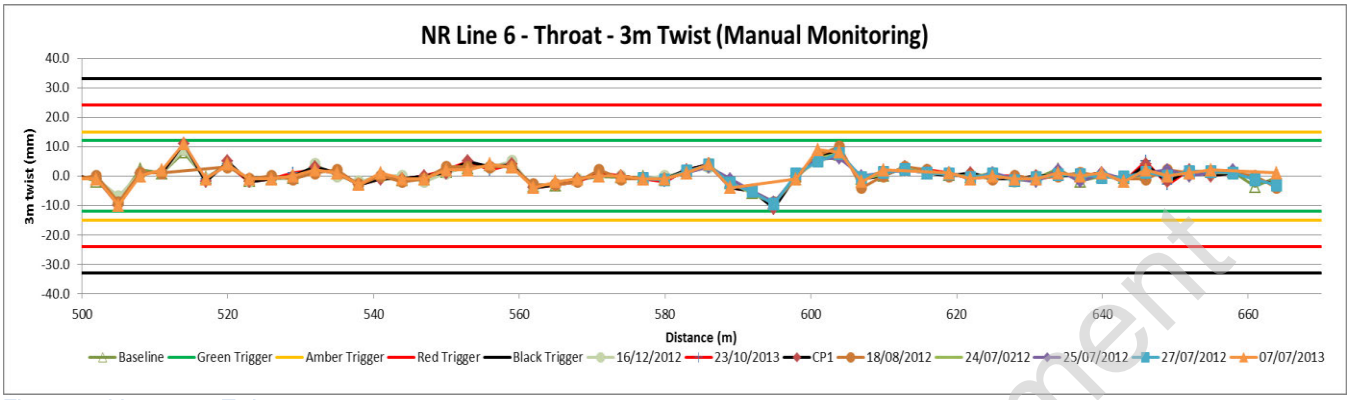


Figure 41 Line 6: 3m Twist

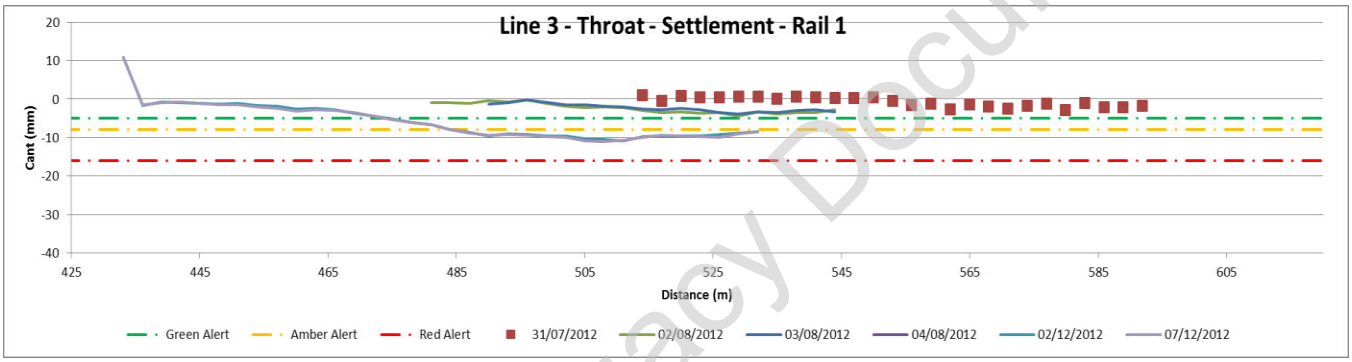


Figure 42 Line 3: Settlement

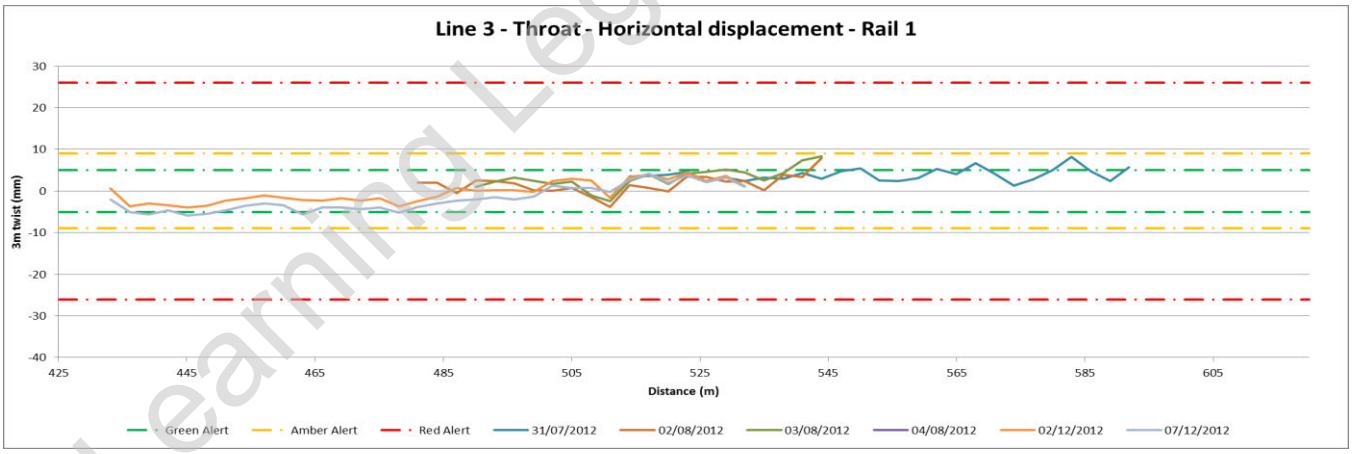


Figure 43 Line 3: Horizontal displacement

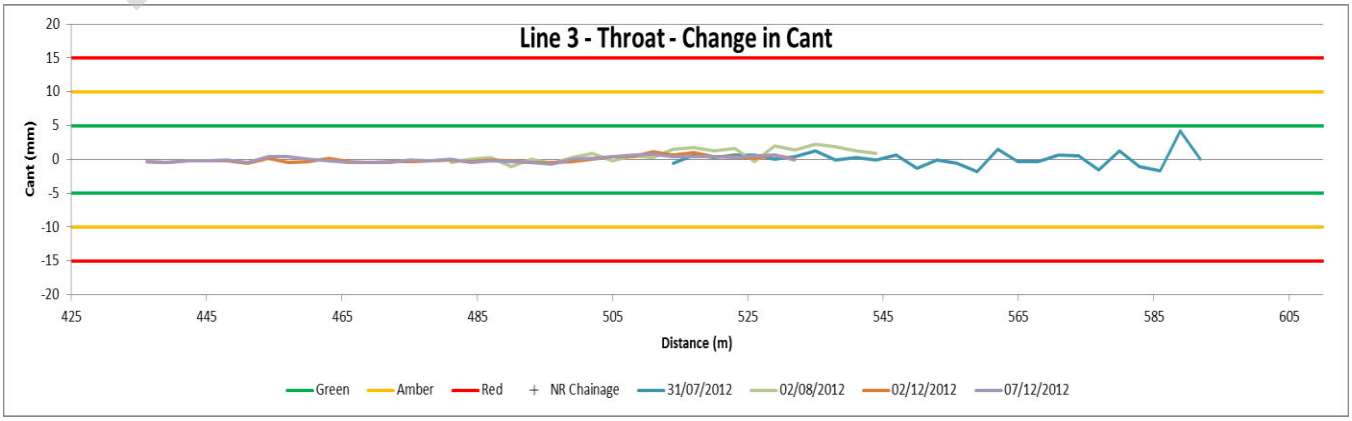


Figure 44 Line 3: Change in Cant

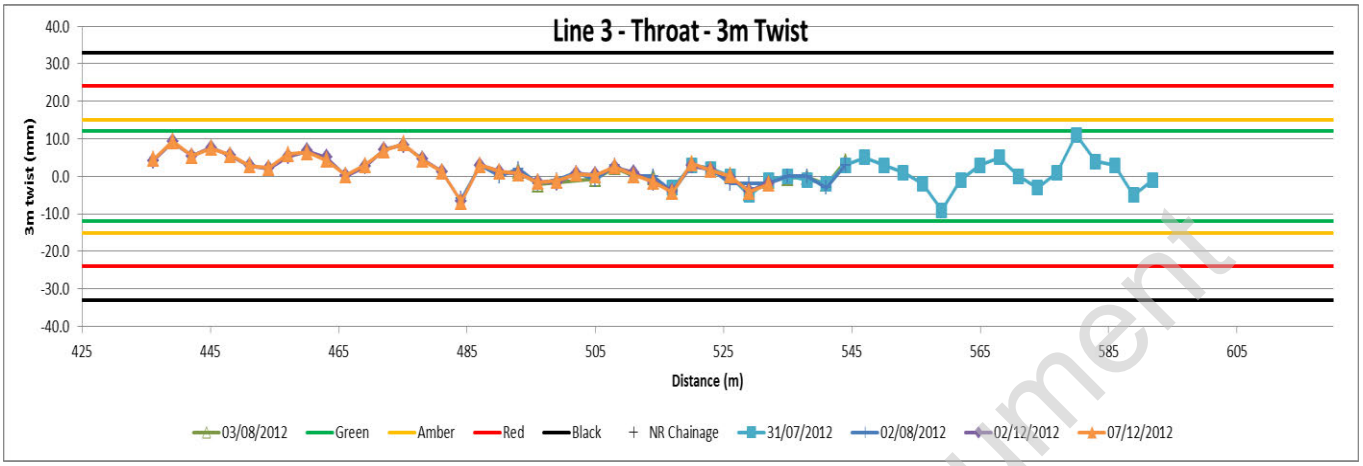


Figure 45 Line 3: 3m Twist

2.9.2. Comments

The measurement points presented in Section 2.9 show maximum settlement of approx. 10mm. The rail geometry (cant, twists) was not significantly affected by the TBMs passage. Amber triggers on settlement and Green triggers / alerts on horizontal displacement have been breached .The residual risk associated with long-term settlements is considered to be negligible.

2.10. Crosspassage 1

2.10.1. Data

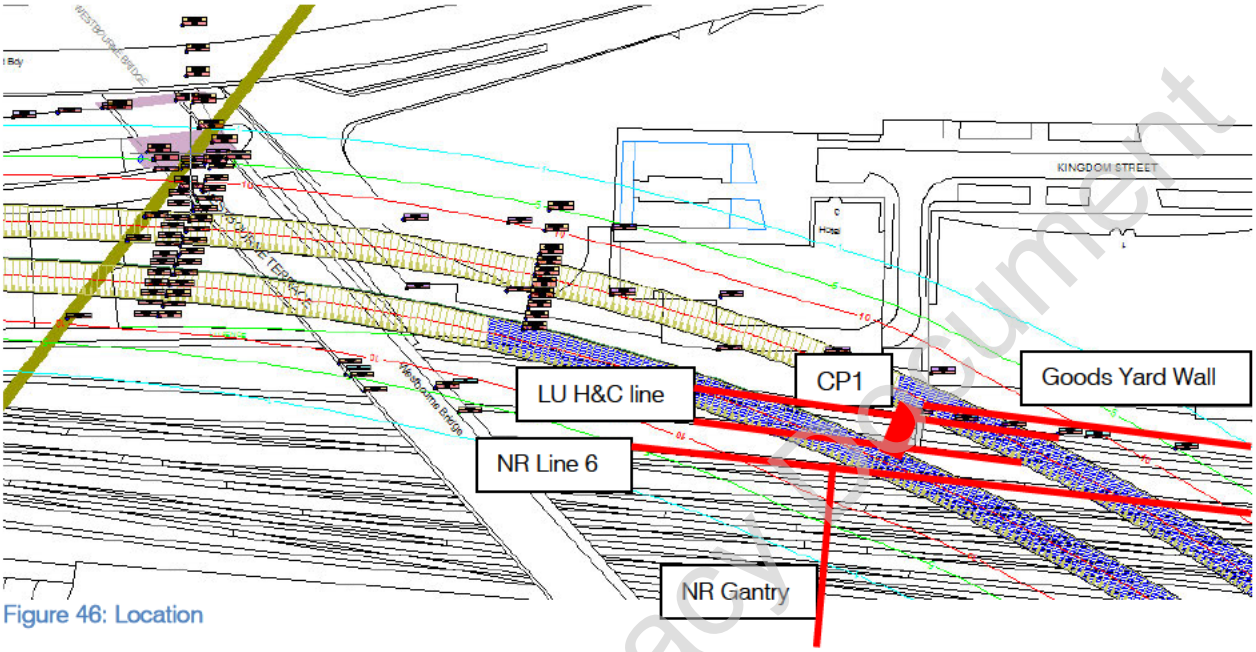


Figure 46: Location

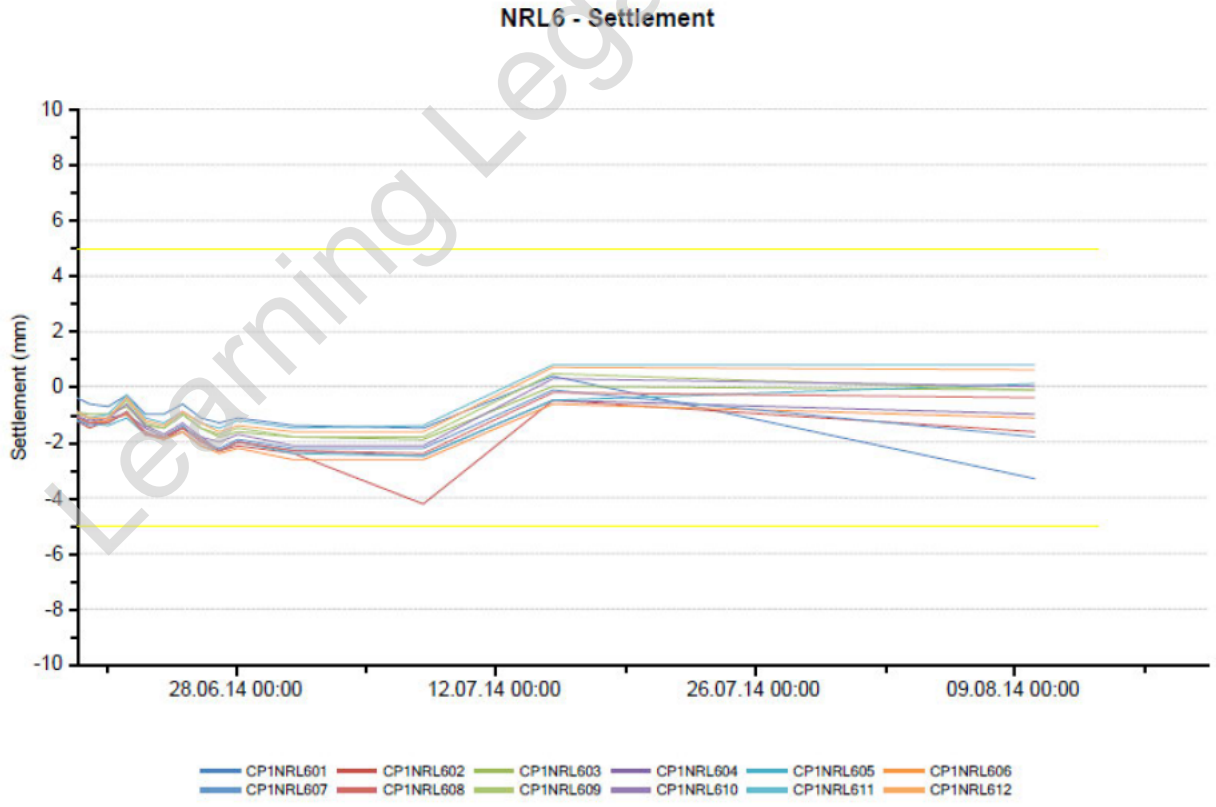


Figure 47: NR Line 6 prisms settlement

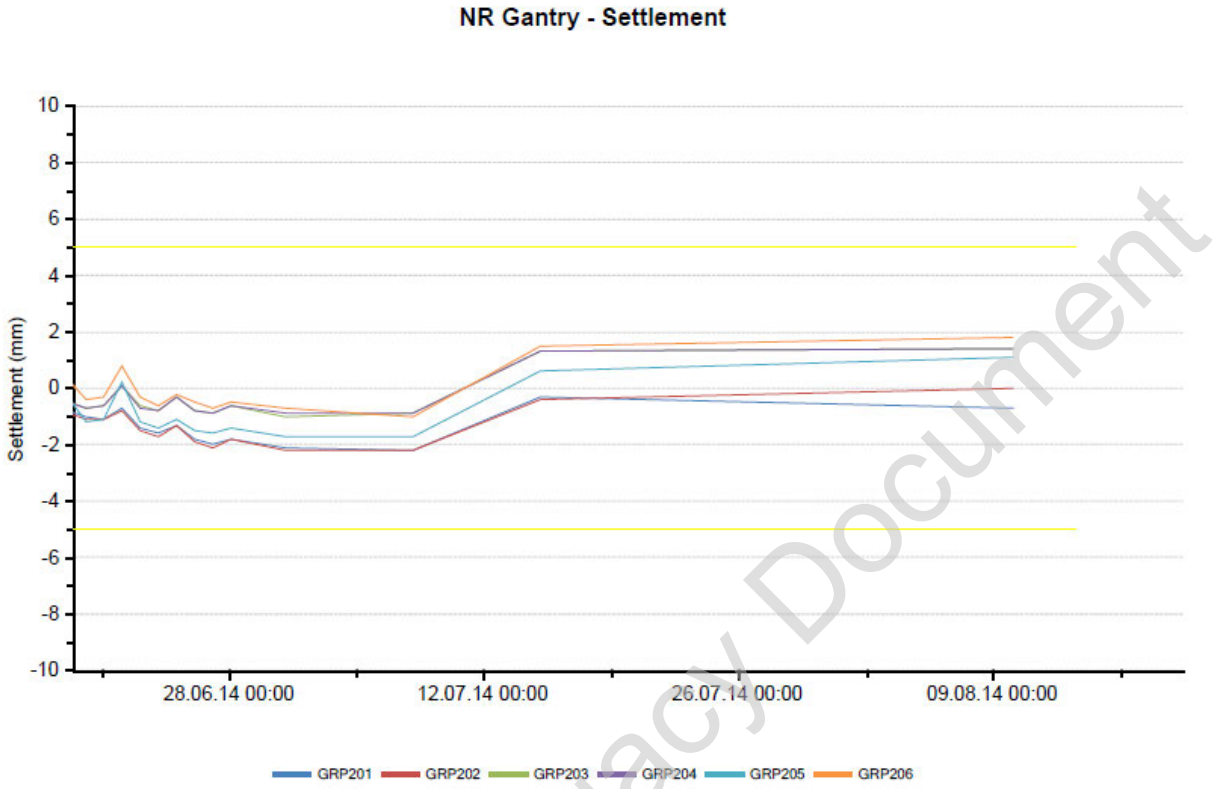


Figure 48: NR Gantry prisms settlement

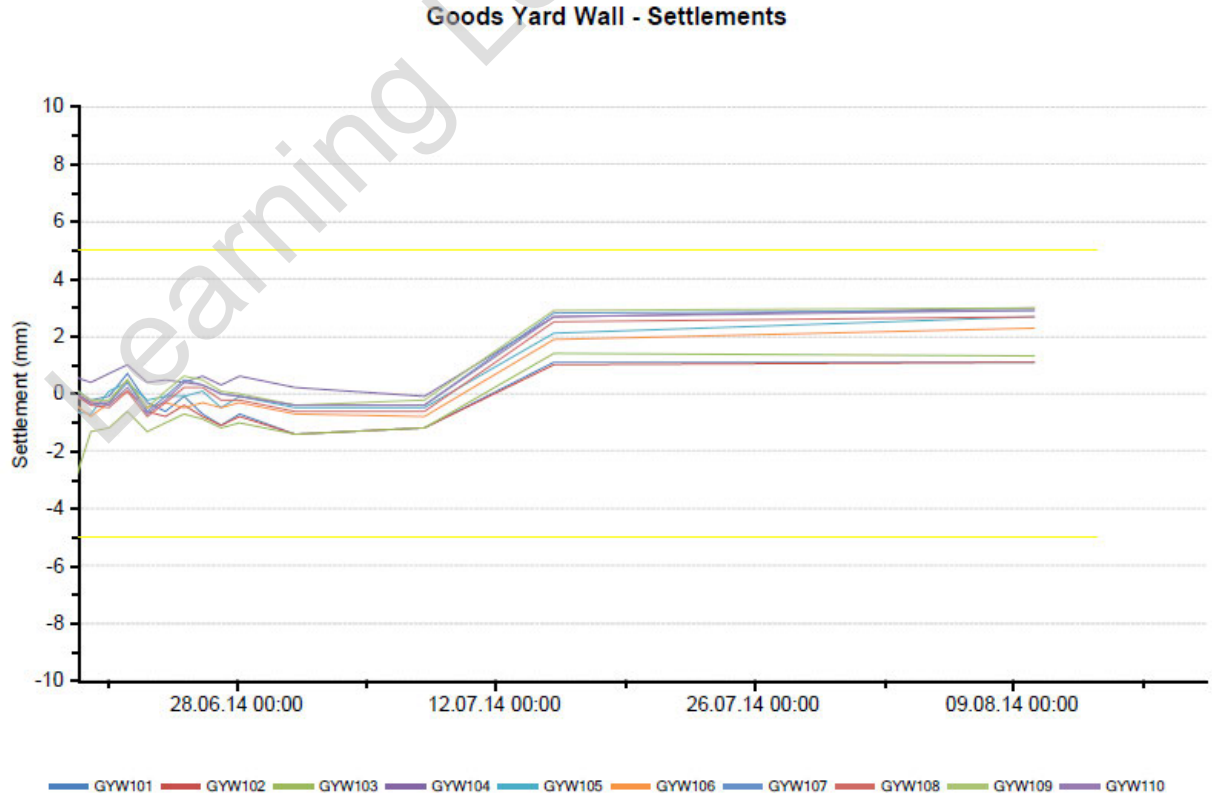


Figure 49: Good Yard wall prisms settlement

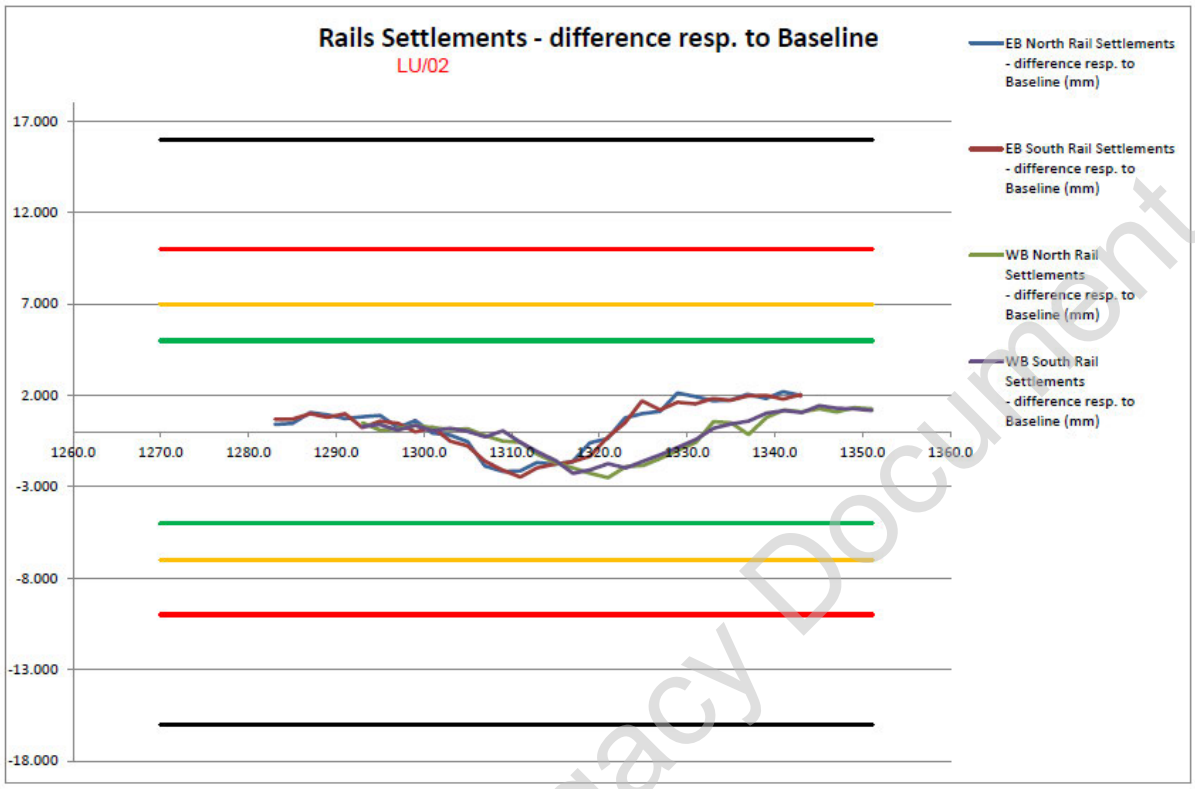


Figure 50: LU H&C line rails settlement

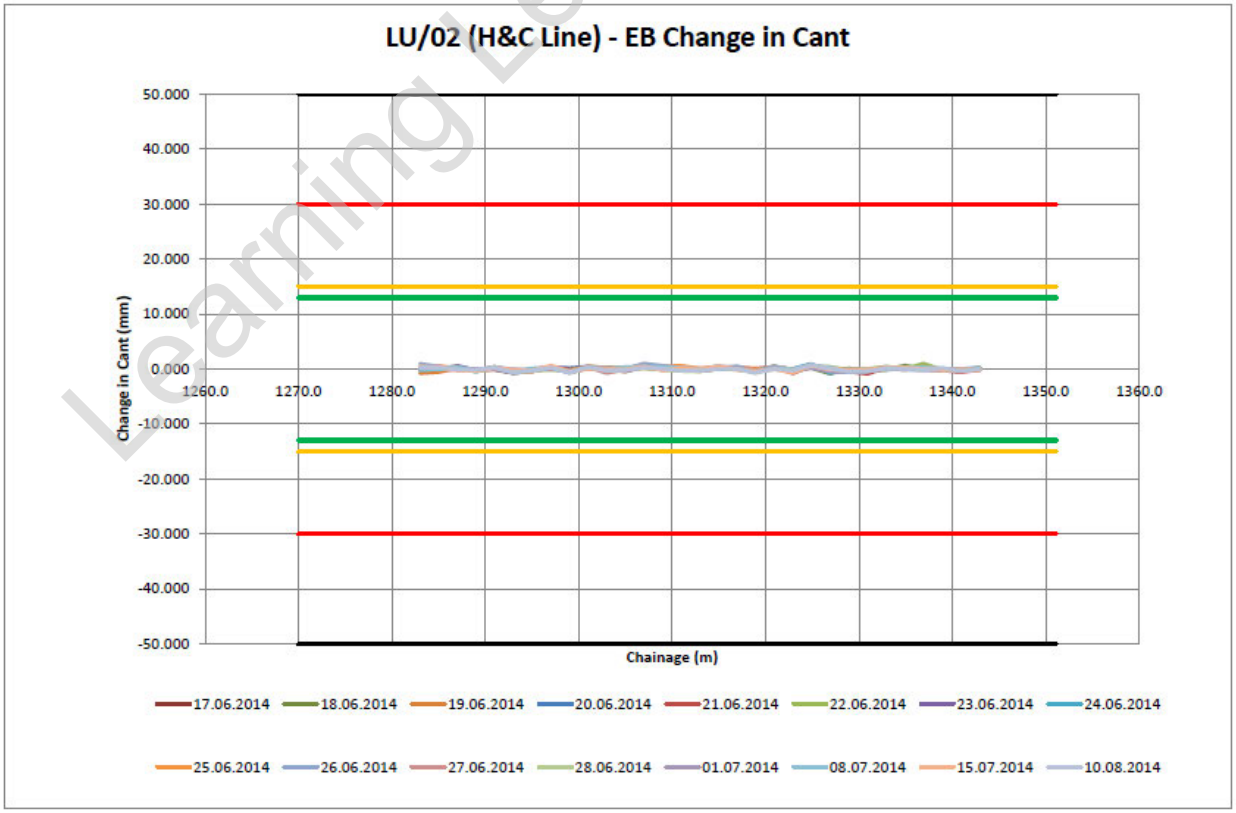


Figure 51: LU H&C line Eastbound Change in Cant

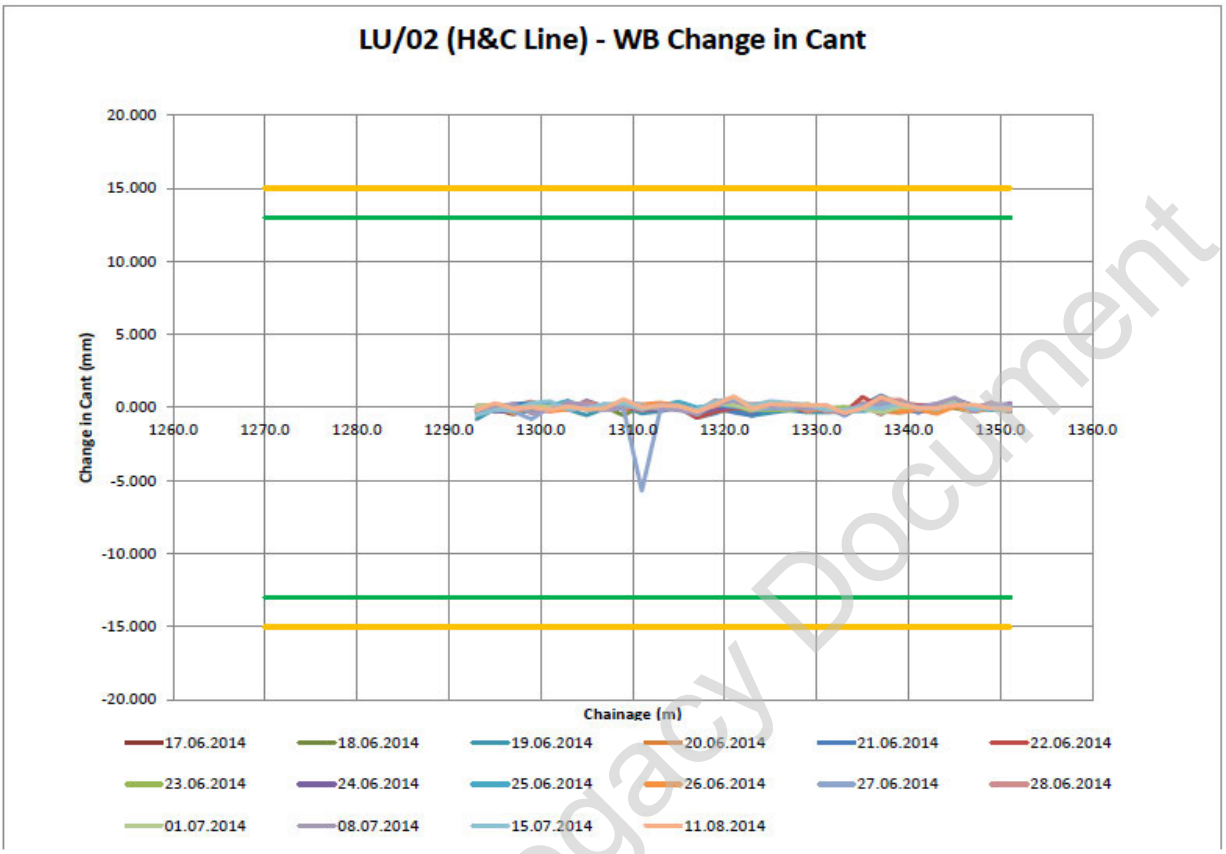


Figure 52 LU H&C line Westbound Change in Cant

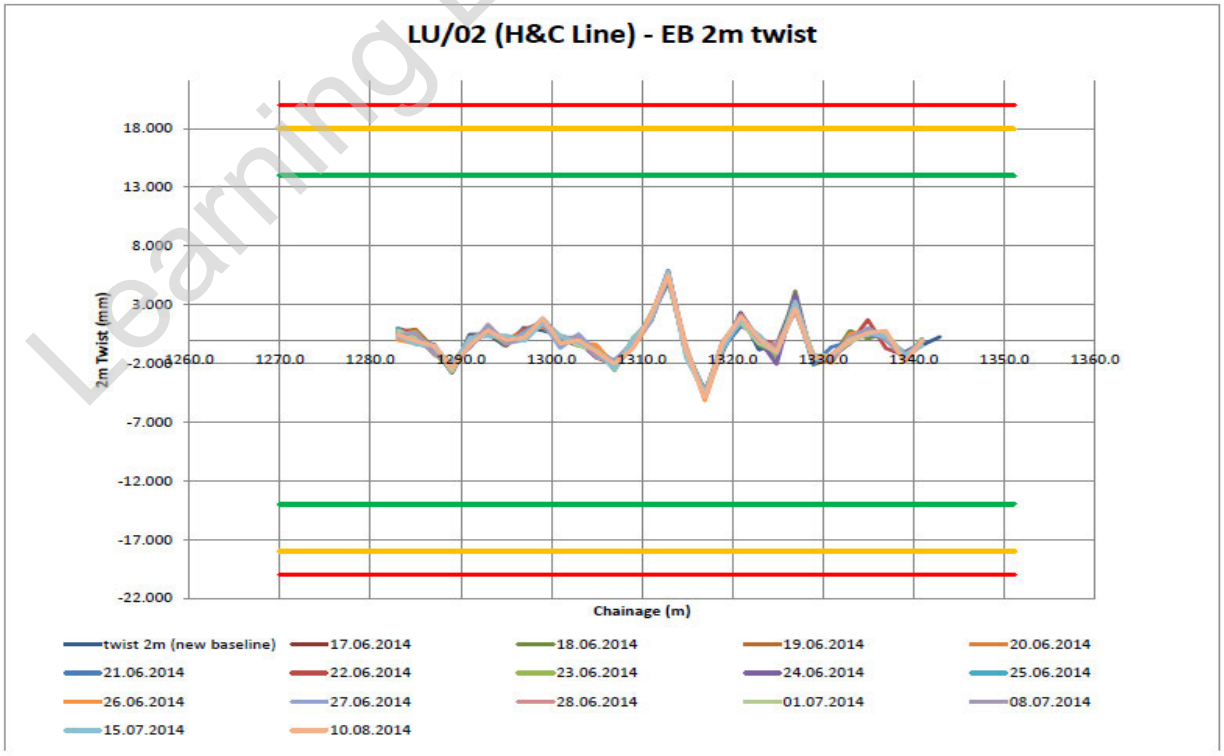


Figure 53 LU H&C line Eastbound 2m twists

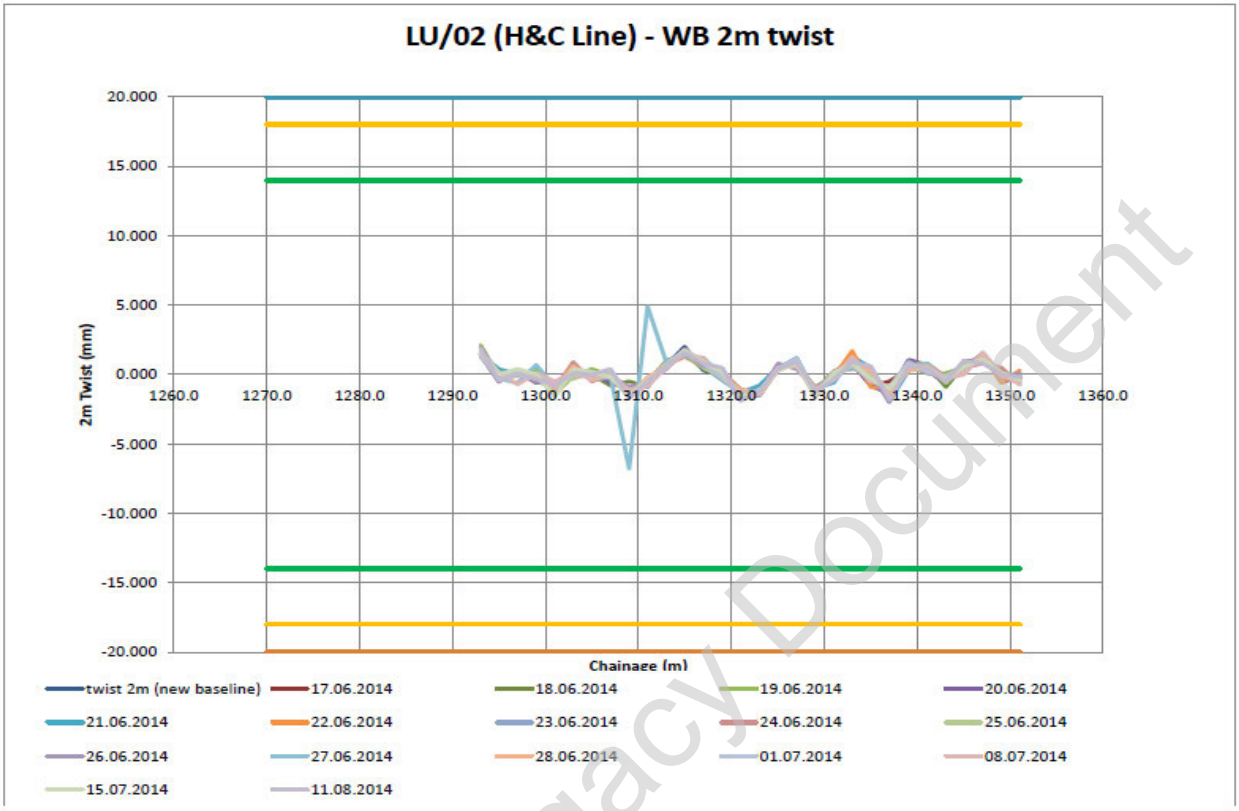


Figure 54 LU H&C line Westbound 2m twists

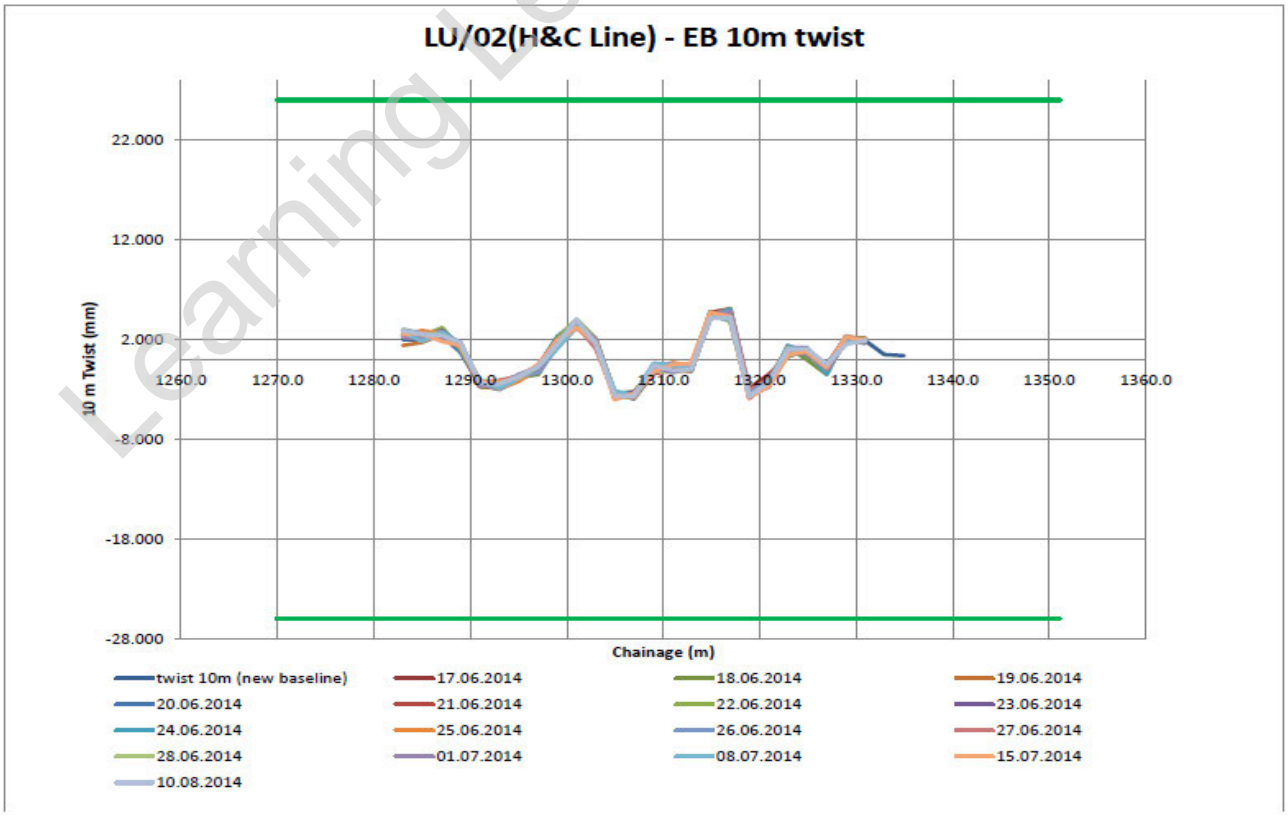


Figure 55 LU H&C line Eastbound 10m twists

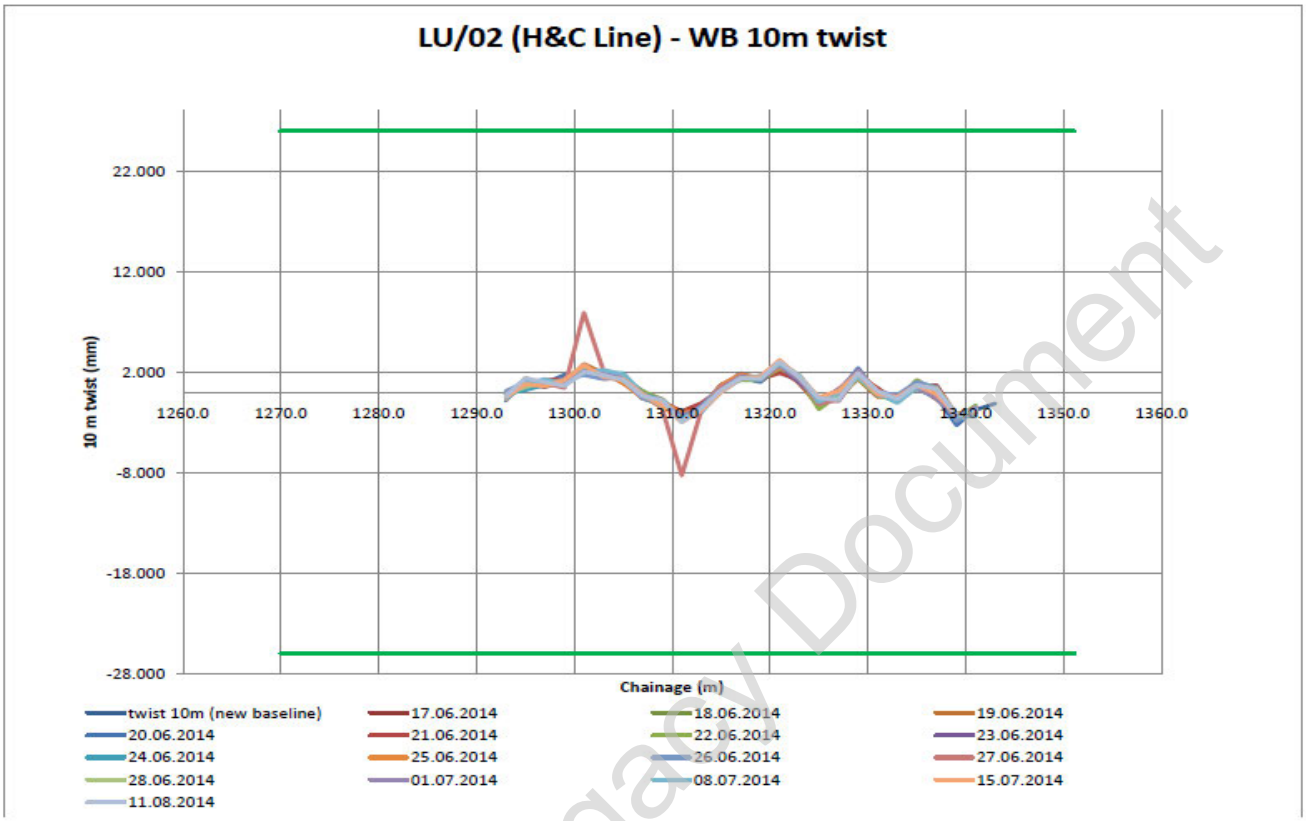


Figure 56 LU H&C line Westbound 10m twists.

2.10.2. Comments

The monitoring data for associated with construction of CP1 have been presented in this section. As expected, the higher settlement were measured on LU H&C line rails (up to 2-3mm), while no significant effects have been detected on NR rails. The maximum measured settlement was significantly less than the maximum calculated settlement for 1.5% Volume Loss (approx. 7mm).

2.11. Construction Control Instruments

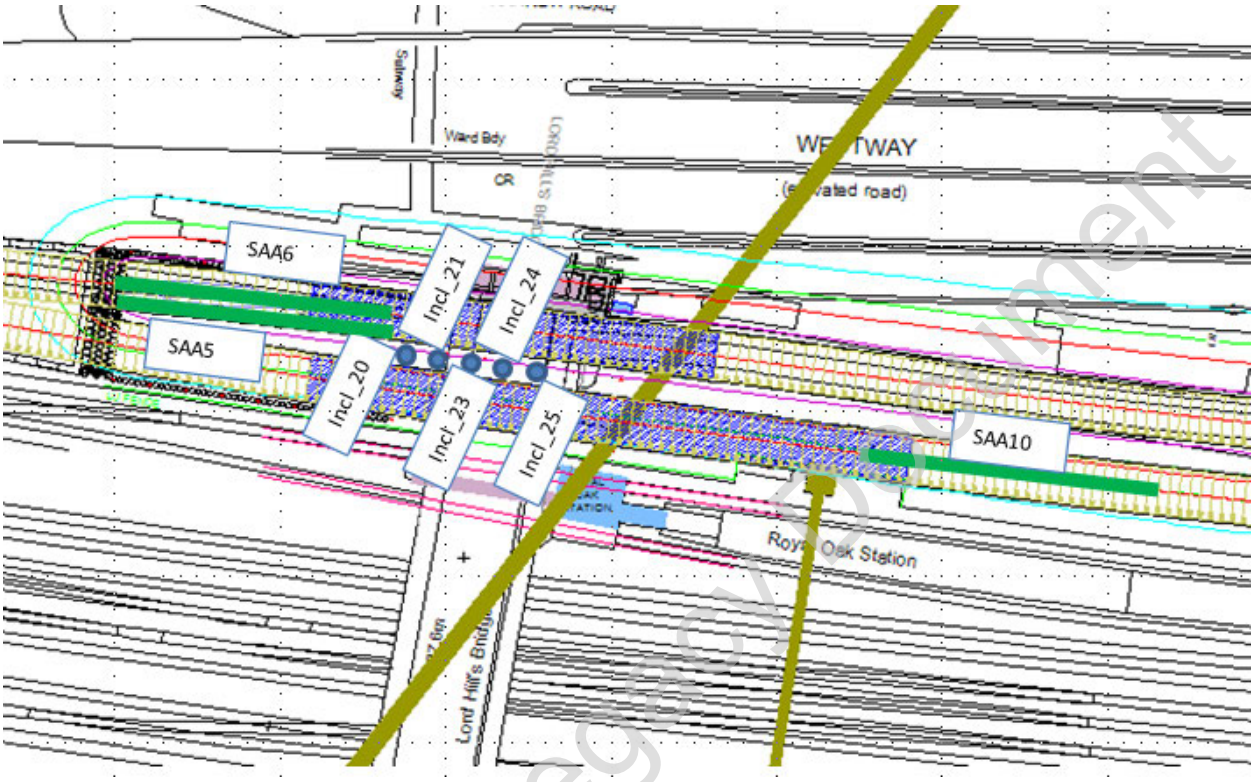


Figure 57 Location of instruments

Given the very shallow cover at the TBM launch from Royal Oak Portal, extensive protective works were required. These comprised a protective pile supported slab from the Portal to Lord Hill's Bridge (LHB). This structure was extended below LHB on the Westbound but, since the Eastbound passes partially below the north abutment a ground replacement solution was adopted (as described in Section 2.1).

Data from Horizontal Shape Accel Arrays installed below the slab (SAA6) and above the slab (SAA5 and SAA10) are presented, together with data from inclinometers in the north wall of the piled slab below LHB. The data show that there were large settlements (~140mm) below the slab about 11m after launch whereas the settlements of the slab itself were small (<5mm). Investigation showed that the earth pressure had not been maintained on the TBM: the responsible persons were removed from the project.

The inclinometers in the wall all show small movements (<5mm), which correlates well with the small movements noted on the surface structures (see Sections 2.1 and 2.2).

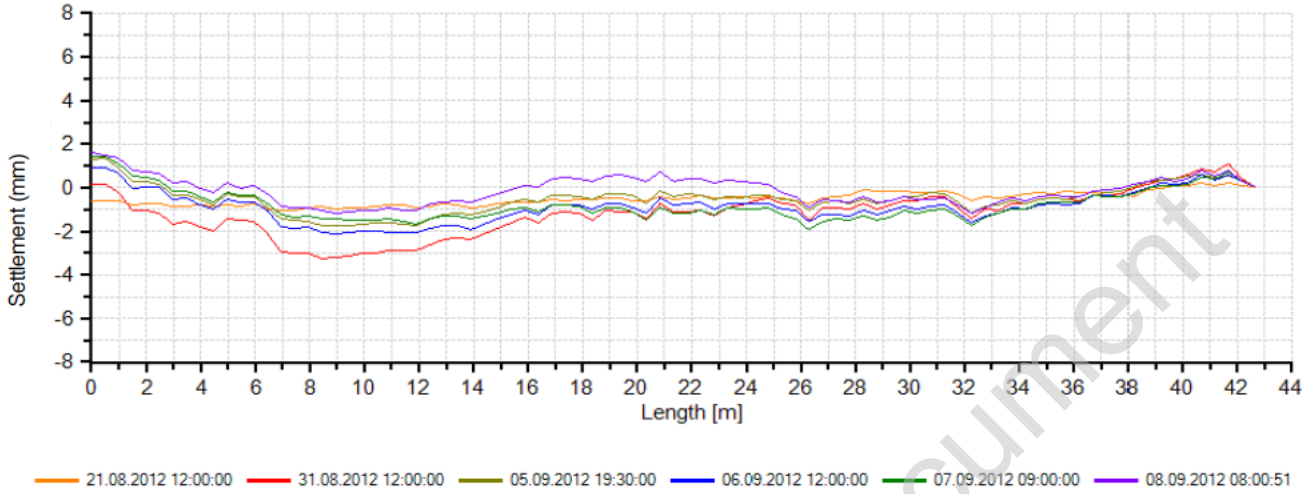


Figure 58 Data for SAA5 (0 "Length" at west end)

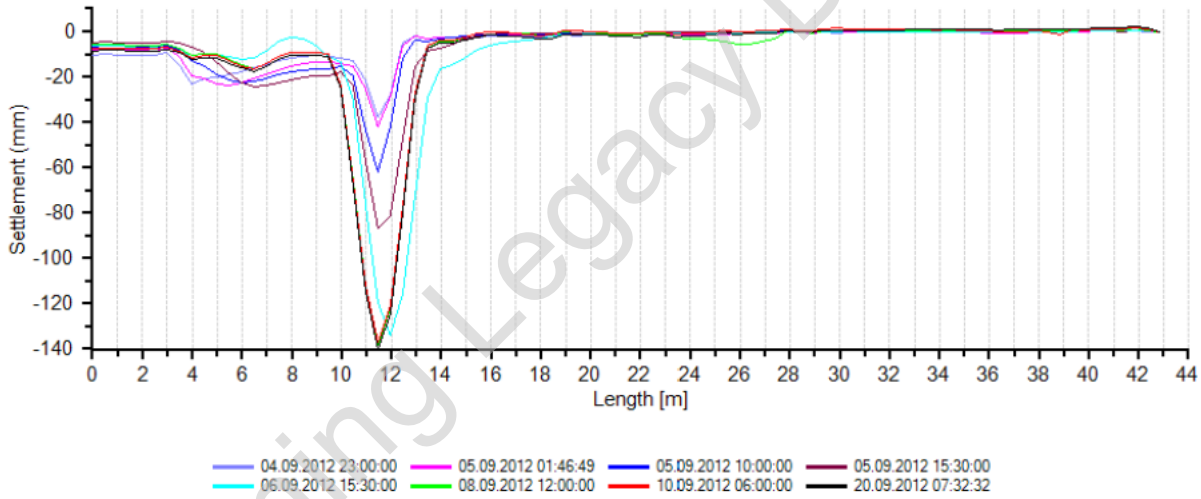


Figure 59 Data for SAA6 (0 "Length" at west end)

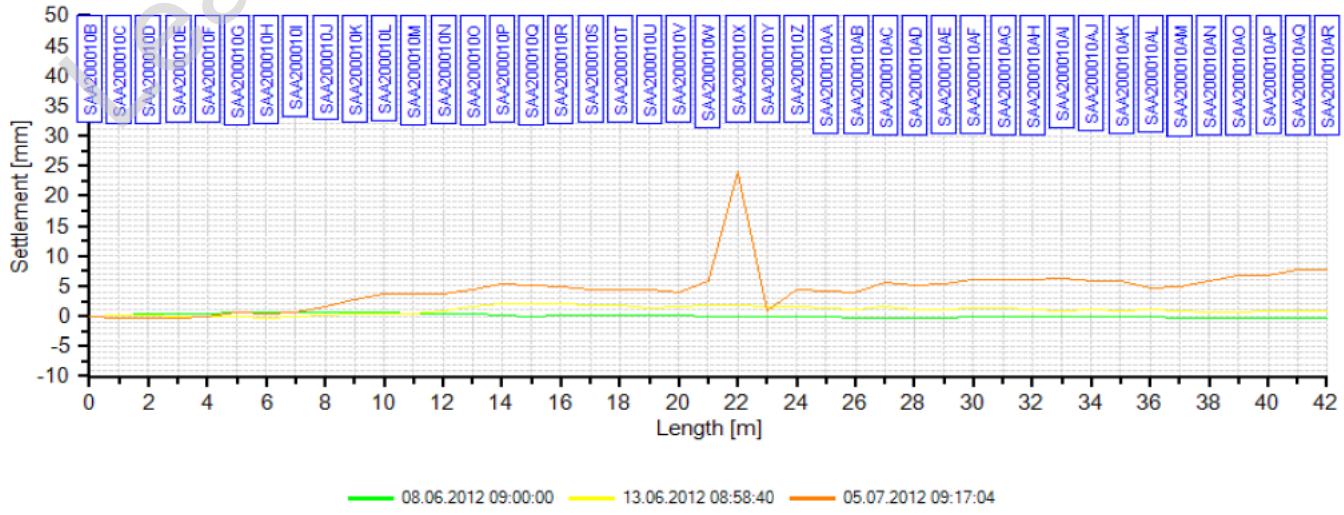
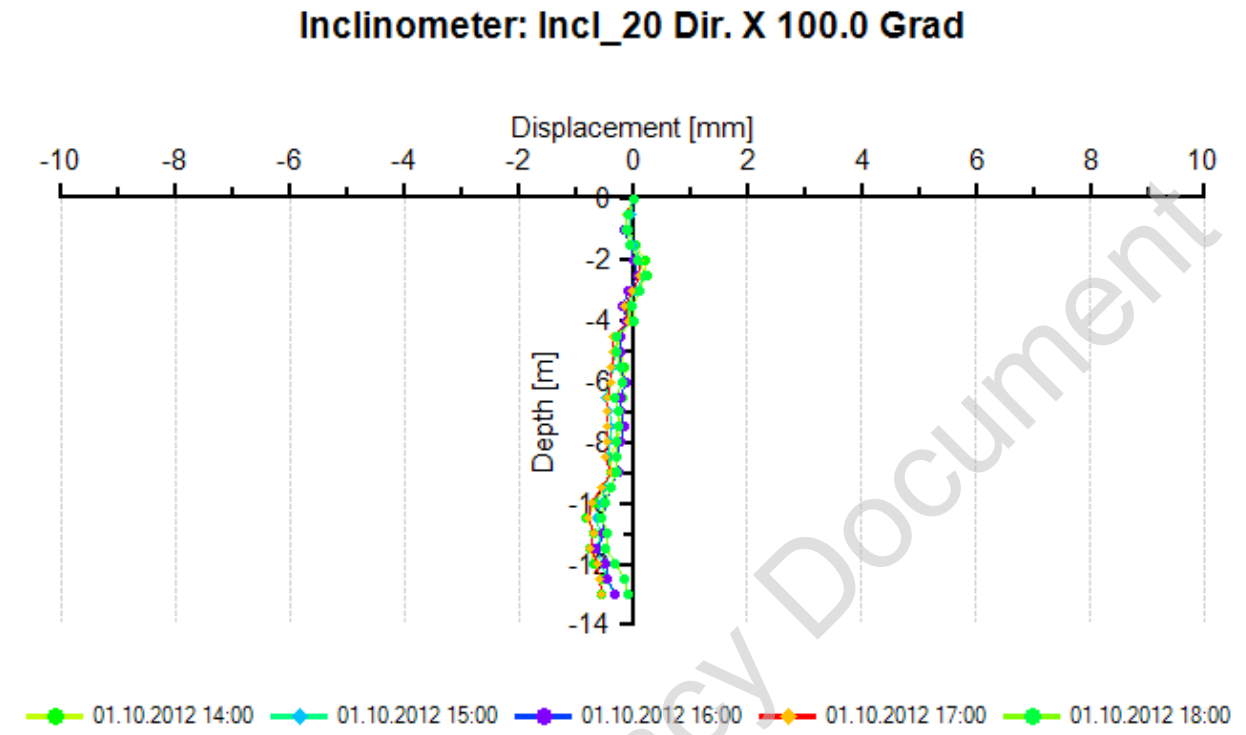


Figure 60 Data for SAA10 (0 "Length" at west end)



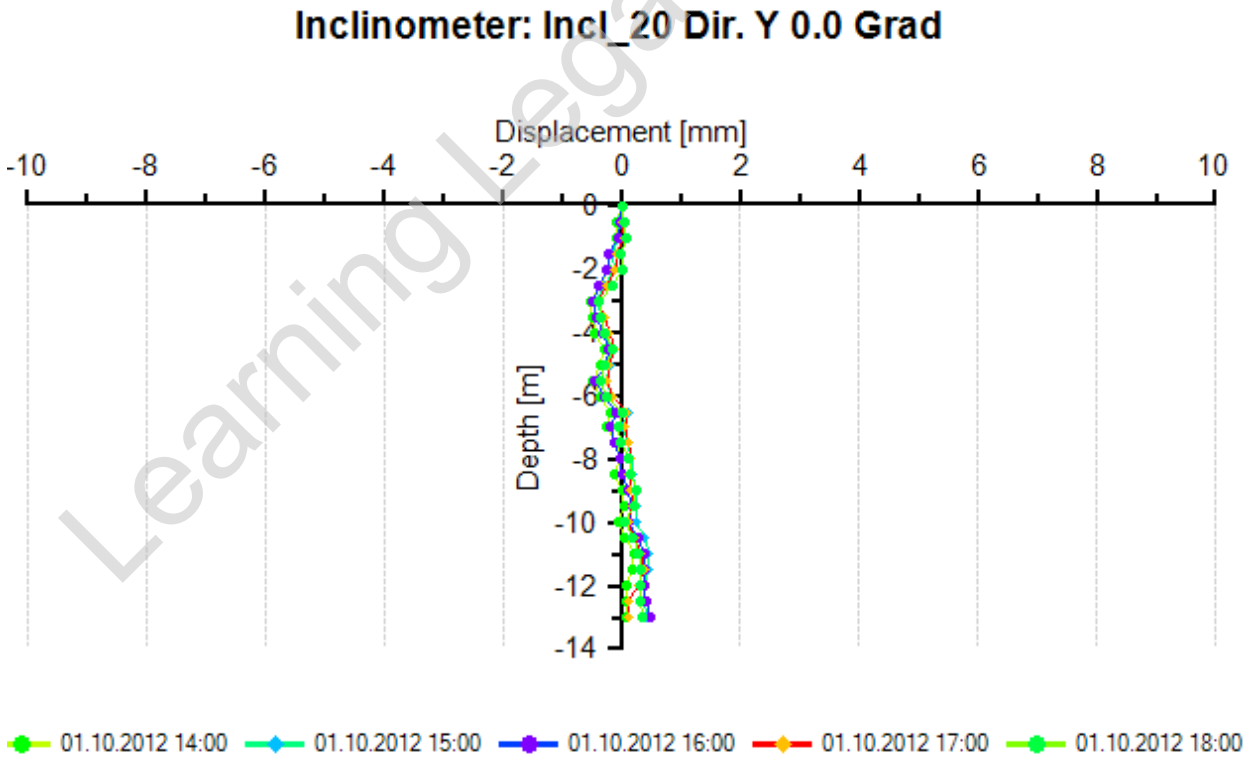


Figure 61 Data for Inclinometer 20

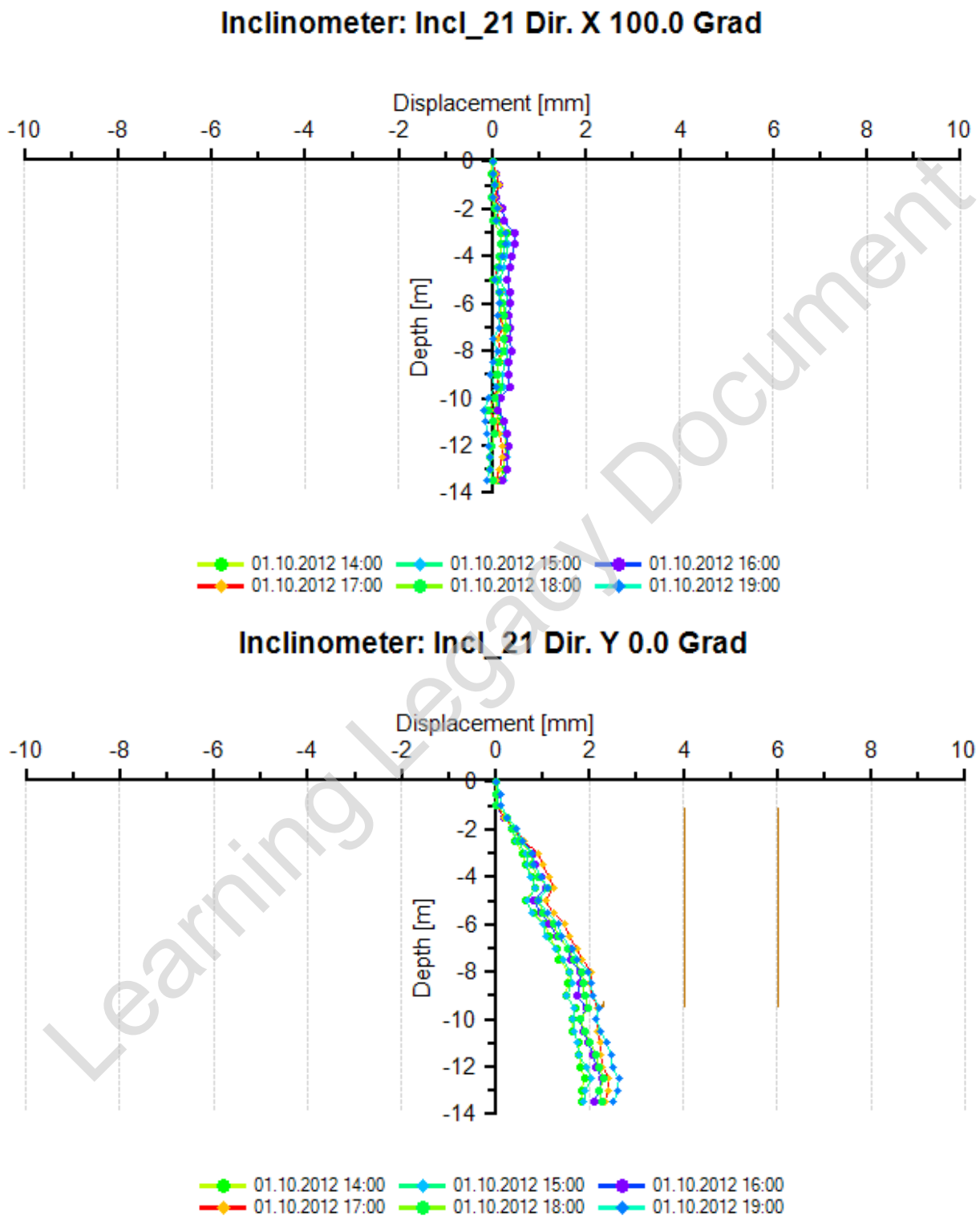


Figure 62 Data for Inclinometer 21

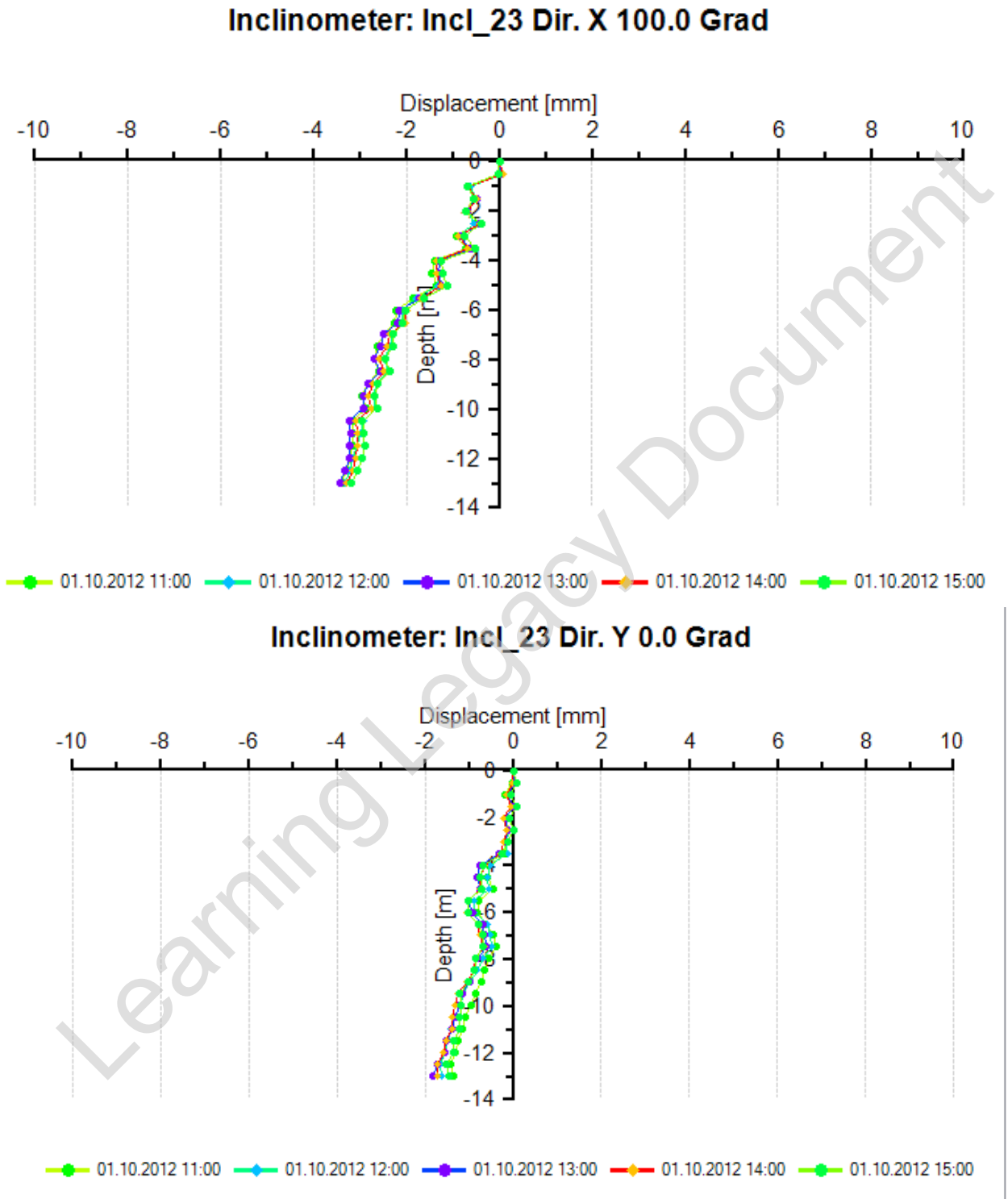
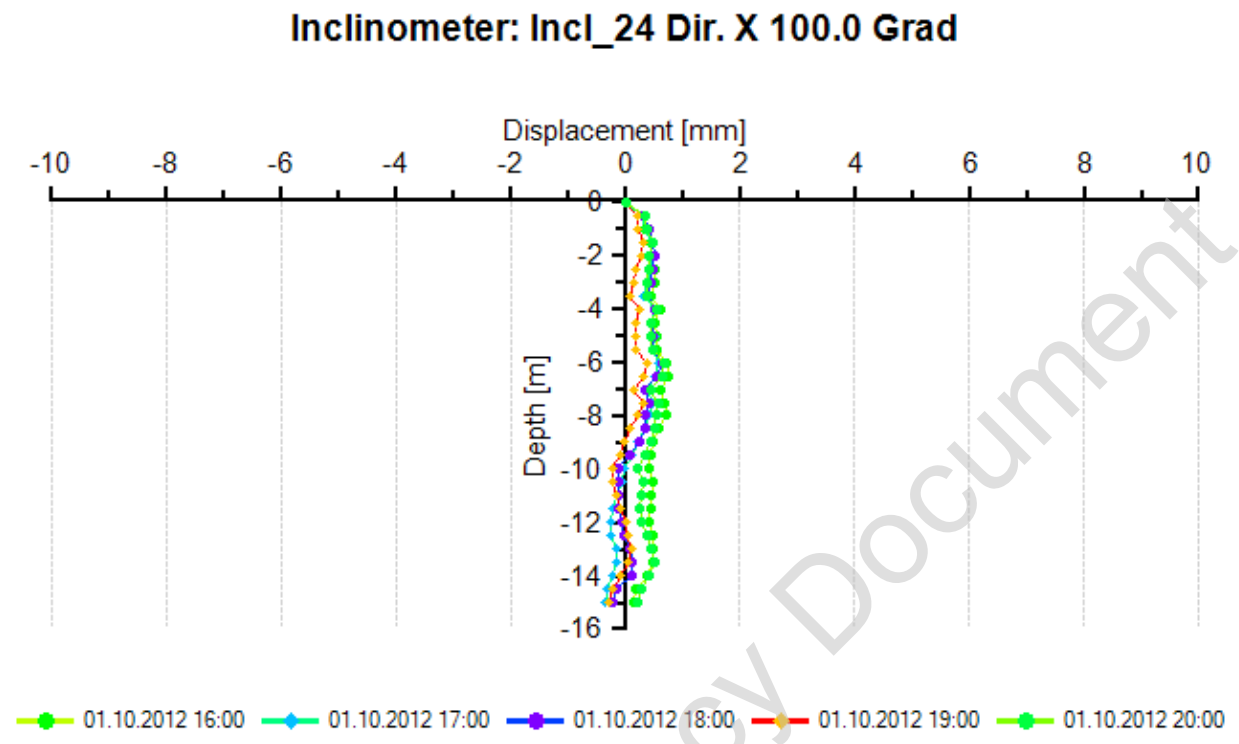


Figure 63 Data for Inclinometer 23



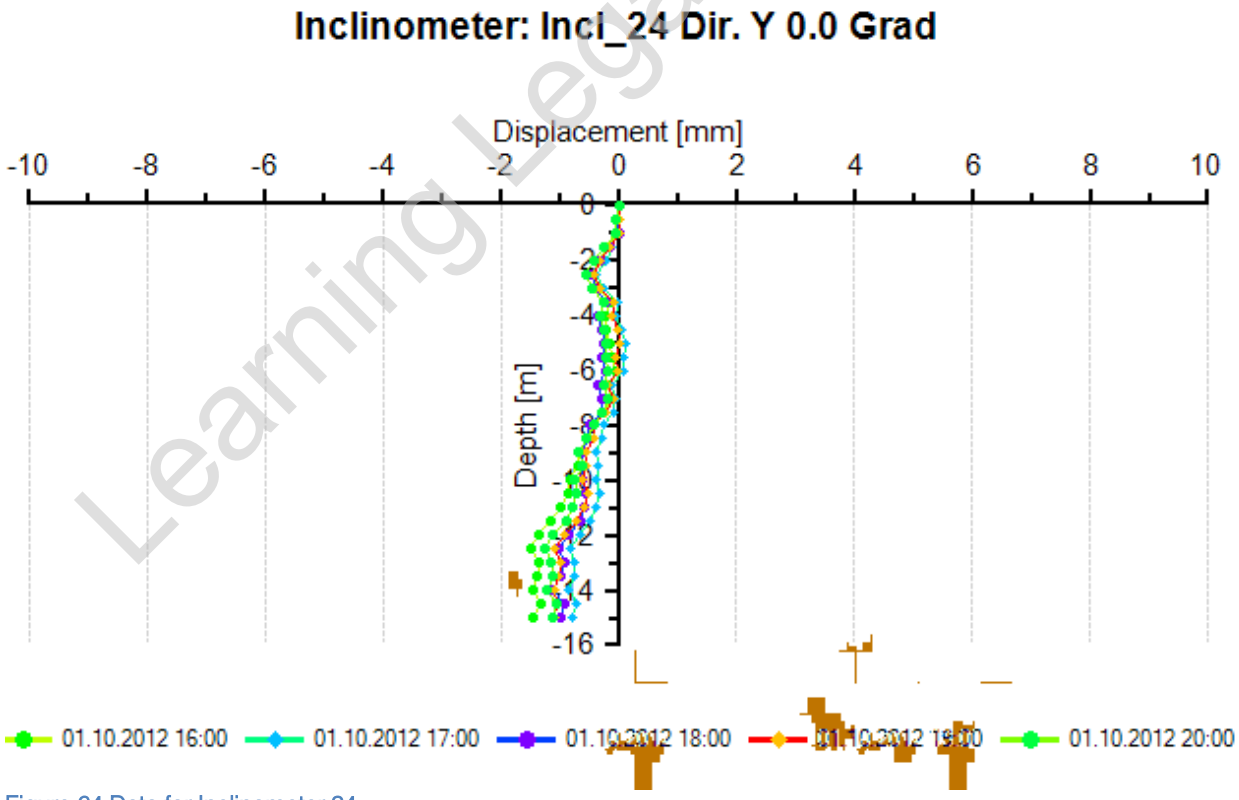
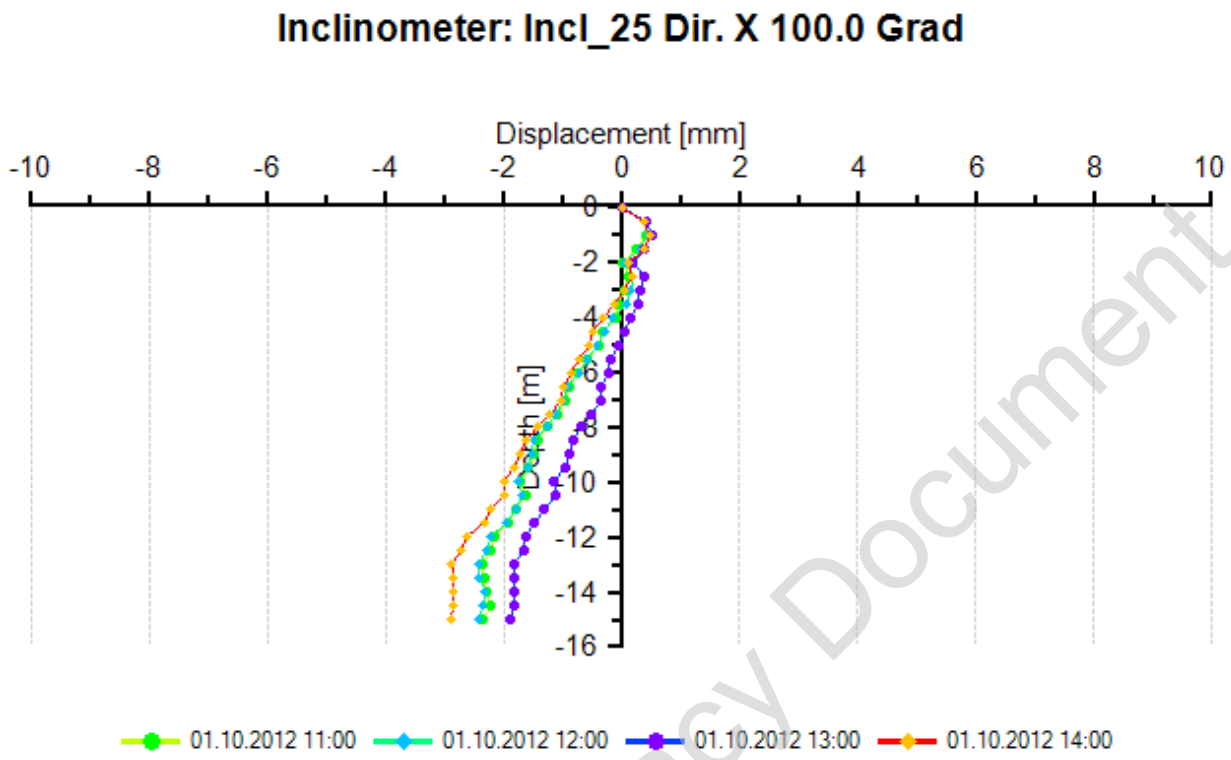


Figure 64 Data for Inclinometer 24



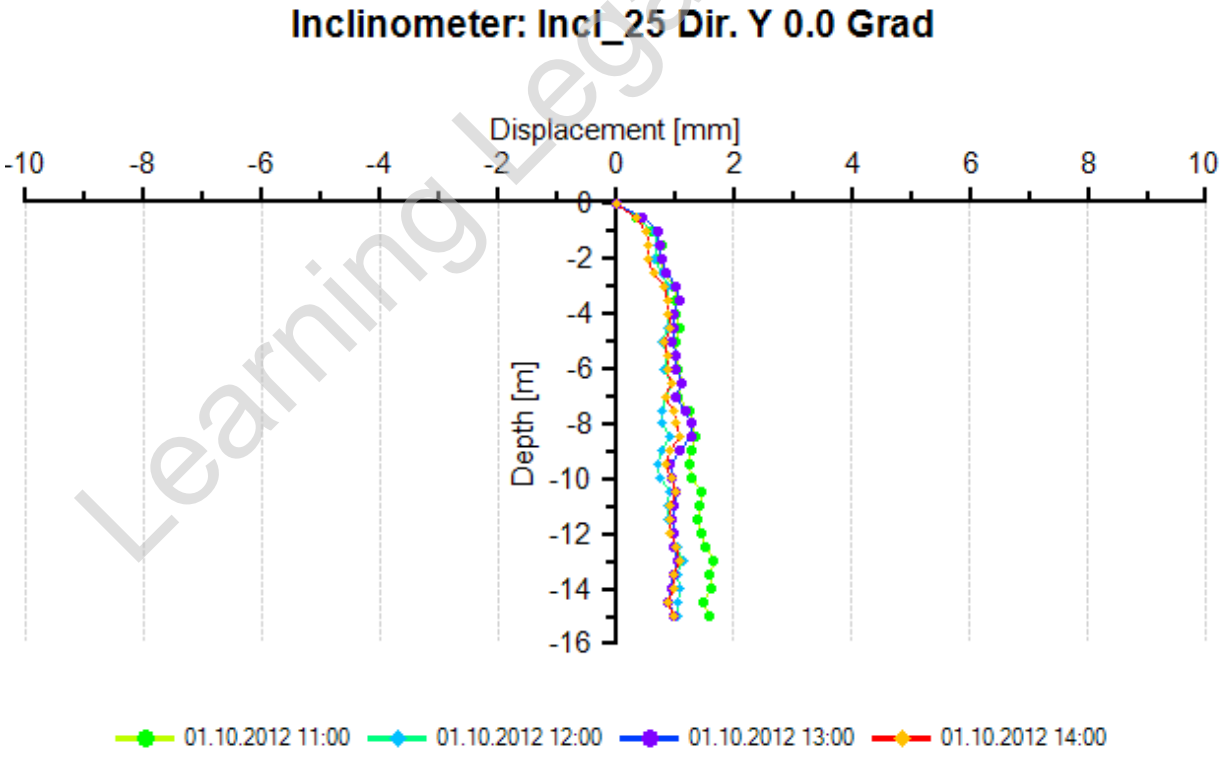
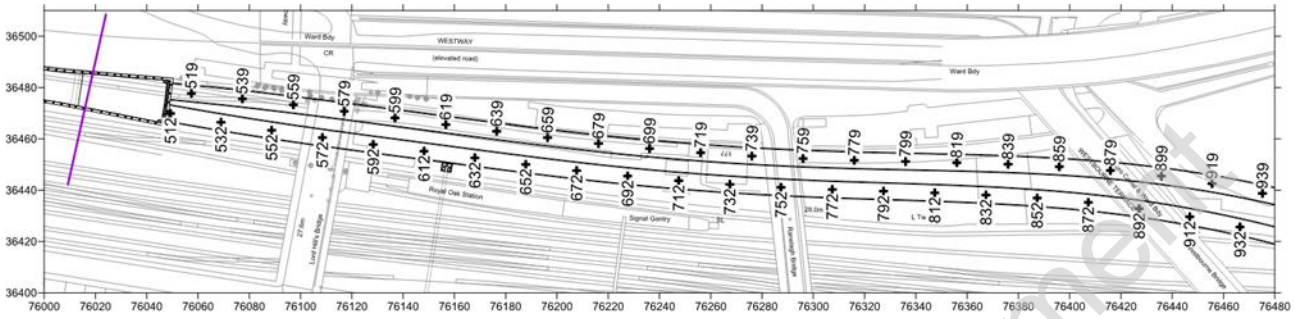
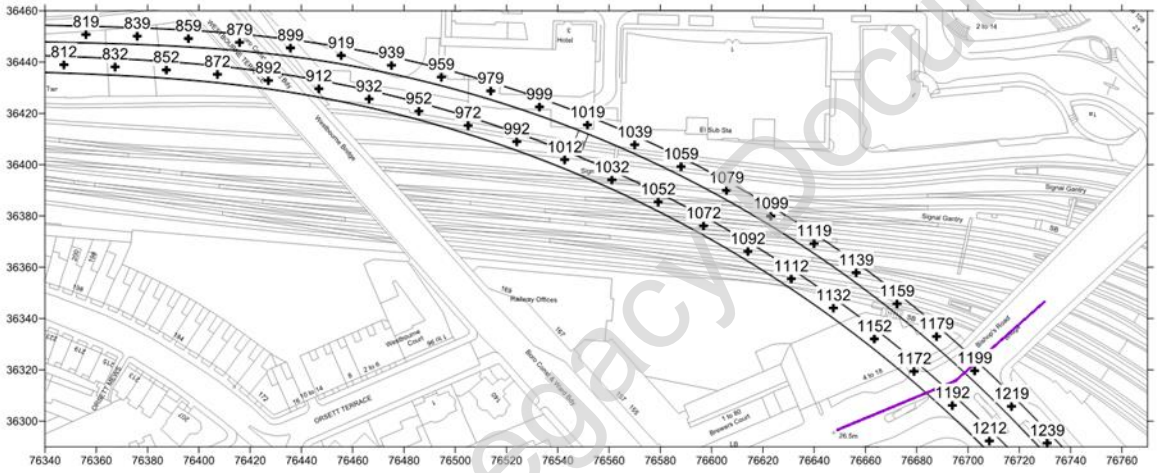
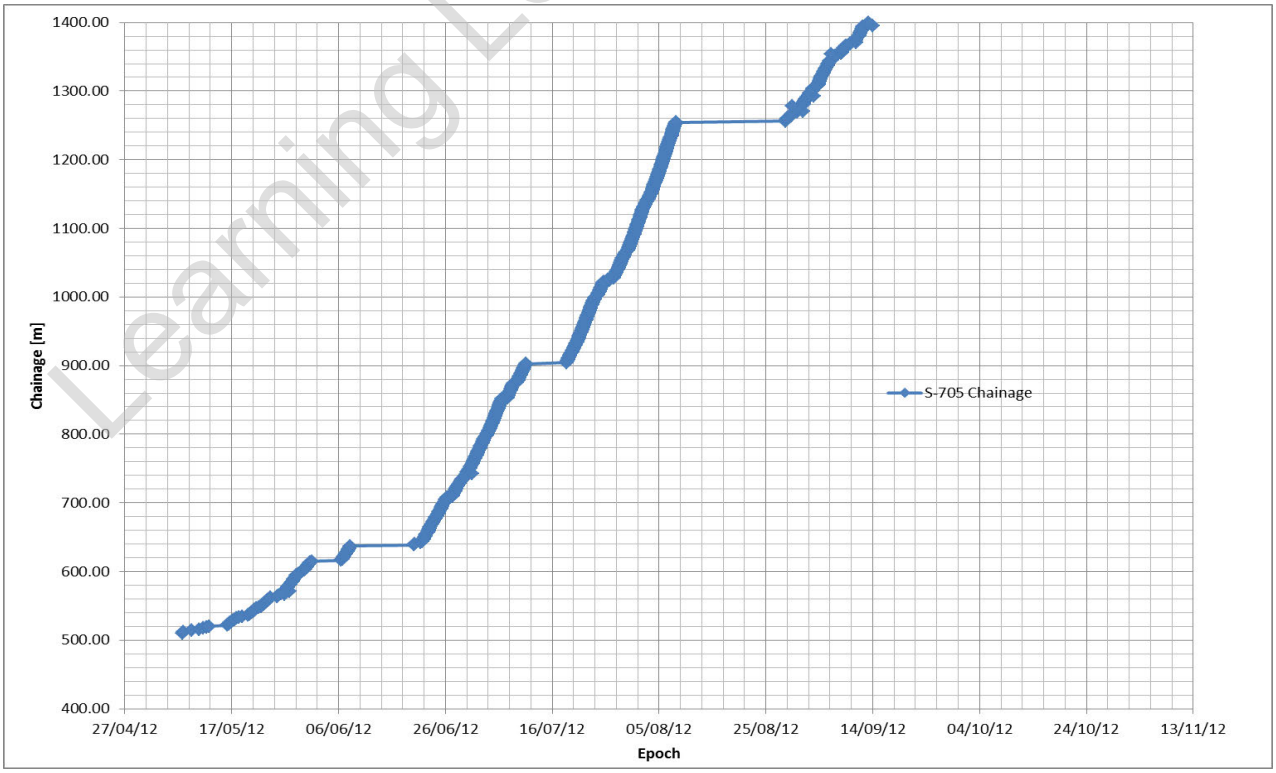


Figure 65: Data for Inclinometer 25

Appendix 1. TBMs time-chainage charts







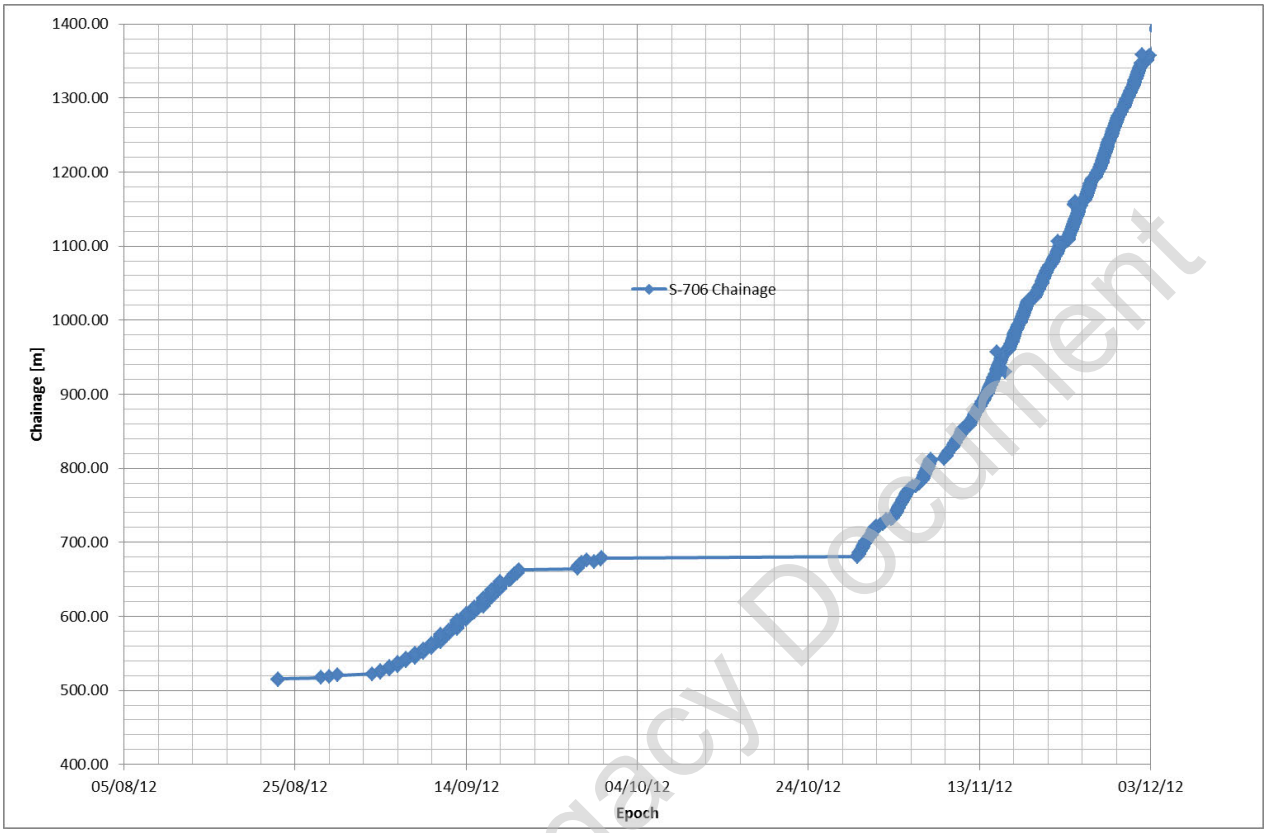


Figure 66: WB and EB TBMs progress on ROP-PAD drive

Table 5: Cross Passage 1 construction

Cross Passage 1	Excavation works took place from 17.06.2014 until 28.06.2014

Appendix 2. IDs, location coordinates and start/end monitoring dates for all instruments installed between ROP and PAD.

Appendix 3. List of relevant documents

Code	Document
C300-BFK-C4-STP-CRT00_ST005-50013	Management Plan for the Control of Ground Movements - Addendum 10 - TBM Drives 1 Royal Oak Portal to Paddington
C122-OVE-C2-RGN-CR076-50001	I&M Plan: LU/02 H&C Line
C122-OVE-C2-RGN-CRG01-50056	I&M Plan: Network Rail Assets NR/02 to NR/07 (PAD approaches)
C300-BFK-C4-RGN-CRT00_ST005-50399	Eastbourne Terrace I&M Subsurface Installation Report
C300-BFK-C4-RGN-CRT00_ST005-50401	Royal Oak portal I&M Subsurface Installation
C300-BFK-C4-RGN-CRT00_ST005-50503	Installation Report - Internal Monitoring of the Chilworth street sewer
C300-BFK-C4-RGN-CRT00_ST005-50504	Installation report of PLP's in Royal Oak to Paddington Area
C300-BFK-C4-RGN-CRT00_ST005-50517	Installation report for PLP's in Lords Hill Bridge to Royal Oak Portal
C300-BFK-C4-RGN-CRT00_ST005-50551	Lords Hill Bridge -Northern Abutment
C300-BFK-C4-RGN-CRT00_ST005-50581	Installation report for prisms in Royal Oak Portal to Paddington Area
C300-BFK-C4-RGN-CRT00_ST005-50703	Installation report for BRE's and Barcodes from Royal Oak to Paddington
C300-BFK-C4-RGN-CRT00_ST005-50768	Installation of Control Network Geodetic Prisms in the Paddington Approach Area
C300-BFK-C4-RGN-CRT00_ST005-50855	Installation Report for BRE's in Harrow Road wall Paddington
C300-BFK-C4-RGN-CRT00_ST005-50813	Installation of Barcodes in 4-18 Bishops Bridge Road (PMI 344) PAD
Installations within C405 Area	
C300-BFK-C4-RGN-CRT00_ST005-50637	Installation Report for Paddington Station Track Tiltmeters
C300-BFK-C4-RGN-CRT00_ST005-50638	Installation of Geodetic prisms and BRE's in Osbourne Tunnel, Plant Room Paddington Station (PMI 327)
C300-BFK-C4-RGN-CRT00_ST005-50639	Instrumentation and Installation Report - Installation of Geodetic Track Prisms Lines 1-3 and Platform edge Geodetic Prisms Platforms 1-4 - Paddington Station

Appendix 4. Thames Water Assets summary table

Area	Type	Sewer Name	Address	Alert Value (mm)	Deflection Alert Value	Deflection Amber Trigger Value	Deflection achieved (average of 3 values)
ROP - PADD	Sewer	TW02 Ranelagh Sewer	Ranelagh Bridge	-	1 in 5000	-	
	Water Main	Ranelagh Bridge Water mains	Ranelagh Bridge	Same as bridge	-	-	
	Water Main	Westbourne Bridge Water mains	Westbourne bridge	Same as bridge	-	-	
	Sewer	TW04 Bishop's Bridge Road & Eastbourne Terrace	Bishop Bridge Road	-	1 in 5200	-	1 in 6600

Appendix 5. Summary Plots: Distribution of final settlement measurements