Balfour Beatty VINCI Working in partnership with HS2

Instrumentation and Monitoring Feedback on Ground Movement Response during tunnelling activity through Mercia Mudstone Group Strata, on HS2 Project (Area North)

Geological Society of London - West Midlands Regional Group
February Talk

Mr Ioannis Papadatos - Geotechnical Manager / Tunnels

Presentation includes:

- **HS2 project overview**
  - **Long Itchington Wood Tunnel**
    - Tunnel overview
    - Ground conditions
    - Instrumentation and Monitoring
    - Ground inspections during TBM excavation (Cutterhead Interventions)
    - Ground inspection during Cross Passage SCL excavation
    - Monitoring summary and volume Loss
  - **Bromford Tunnel**
    - Tunnel overview
    - Ground conditions
    - Key asset owners within tunnel influence zone
    - Design approach
    - Instrumentation and Monitoring system applied
    - Greenfield monitoring records and Volume Loss (VL)
    - Borehole extensometer records
    - Borehole inclinometer records
- **Conclusions**

HS2 Project Overview

- HS2 is Britain's new high speed railway line being built from London to the West Midlands

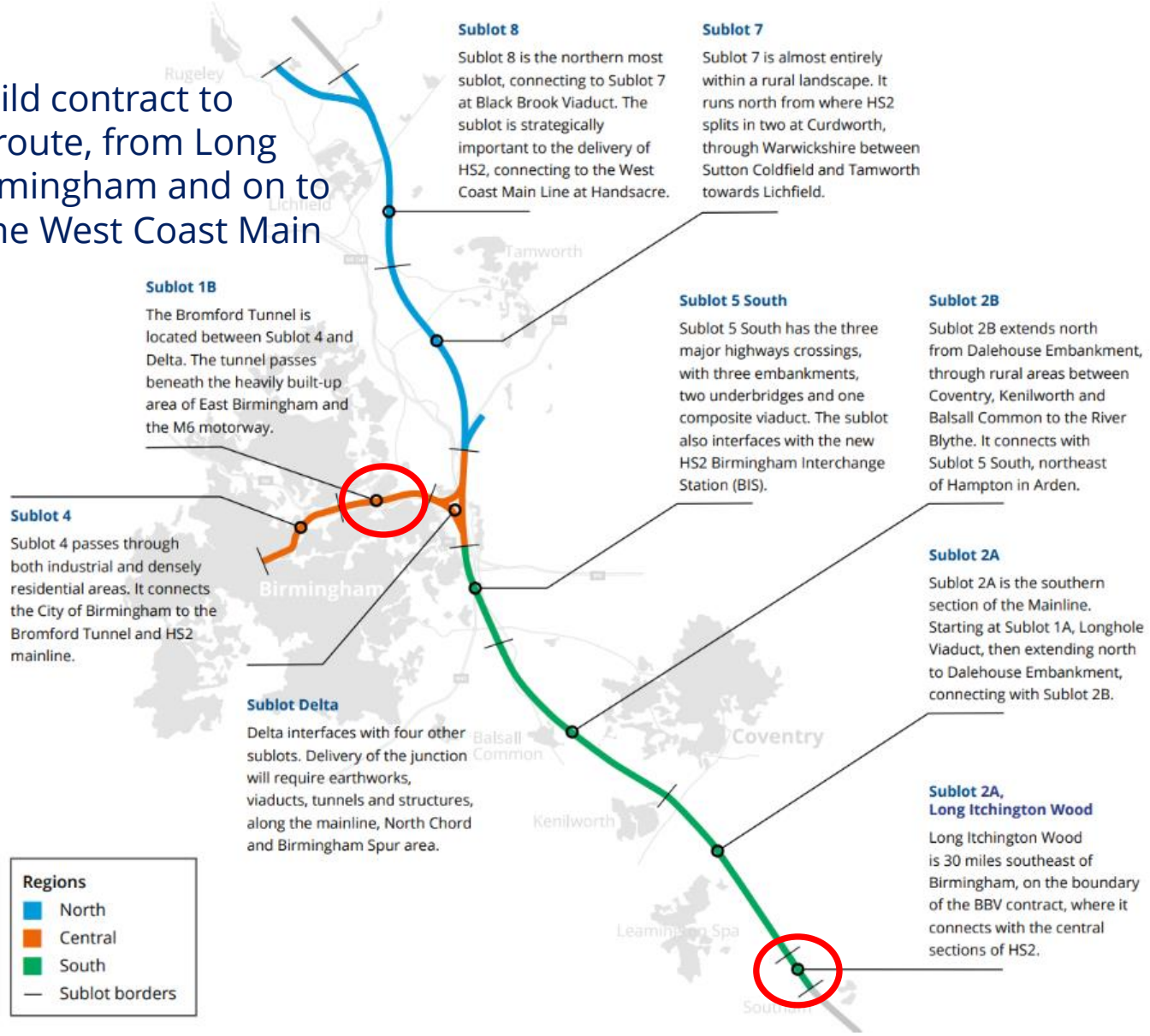
- The route construction comprises:
  - 140-miles (224 km) of track,
  - 4 brand new stations,
  - 2 major depots,
  - 32 miles of tunnels &
  - 500 bridging structures.

HS2 Project Overview

- **Balfour Beatty VINCI JV (BBV)** Design and build contract to construct the northernmost 90km of the HS2 route, from Long Itchington in Warwickshire to the centre of Birmingham and on to Handsacre in Staffordshire, where it will join the West Coast Main Line.

The contract includes :

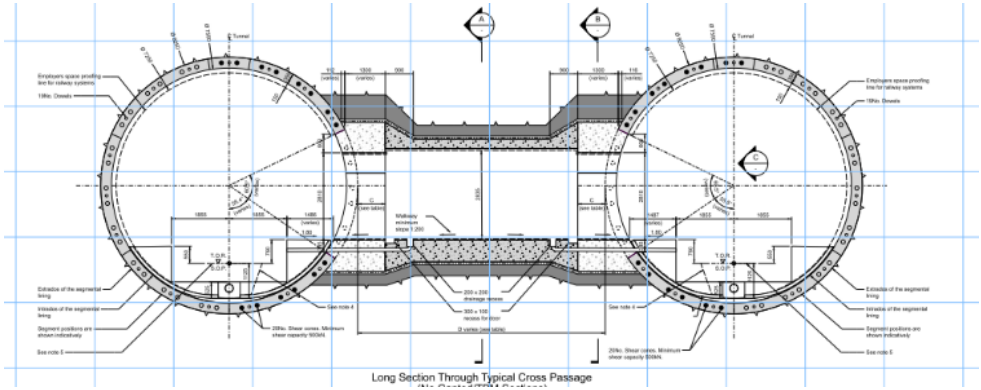
- 90km of track
- 11km of viaducts
- 62 overbridges
- 28 underbridges
- 62 embankments
- 34 cuttings
- 11 underpasses
- **2 tunnels (twin bore)**
  - **Long Itchington Wood (LIW)**
  - **Bromford Tunnel**



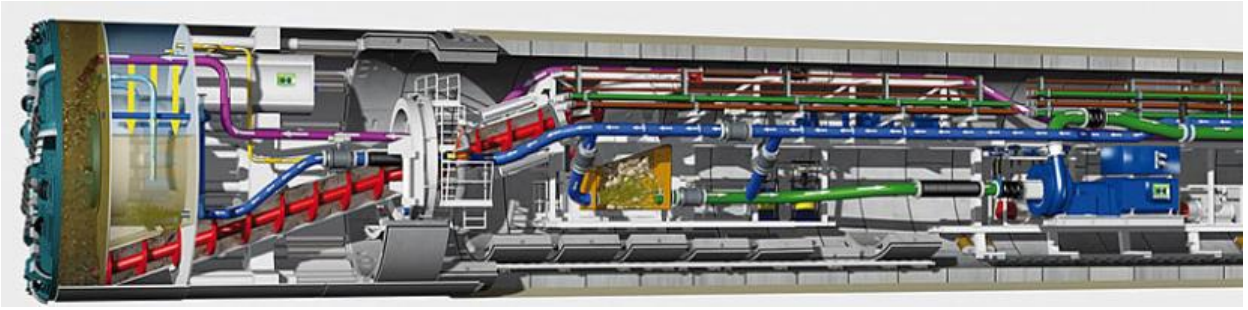
Long Itchington Wood (LIW) Bored Tunnels

Tunnel Overview

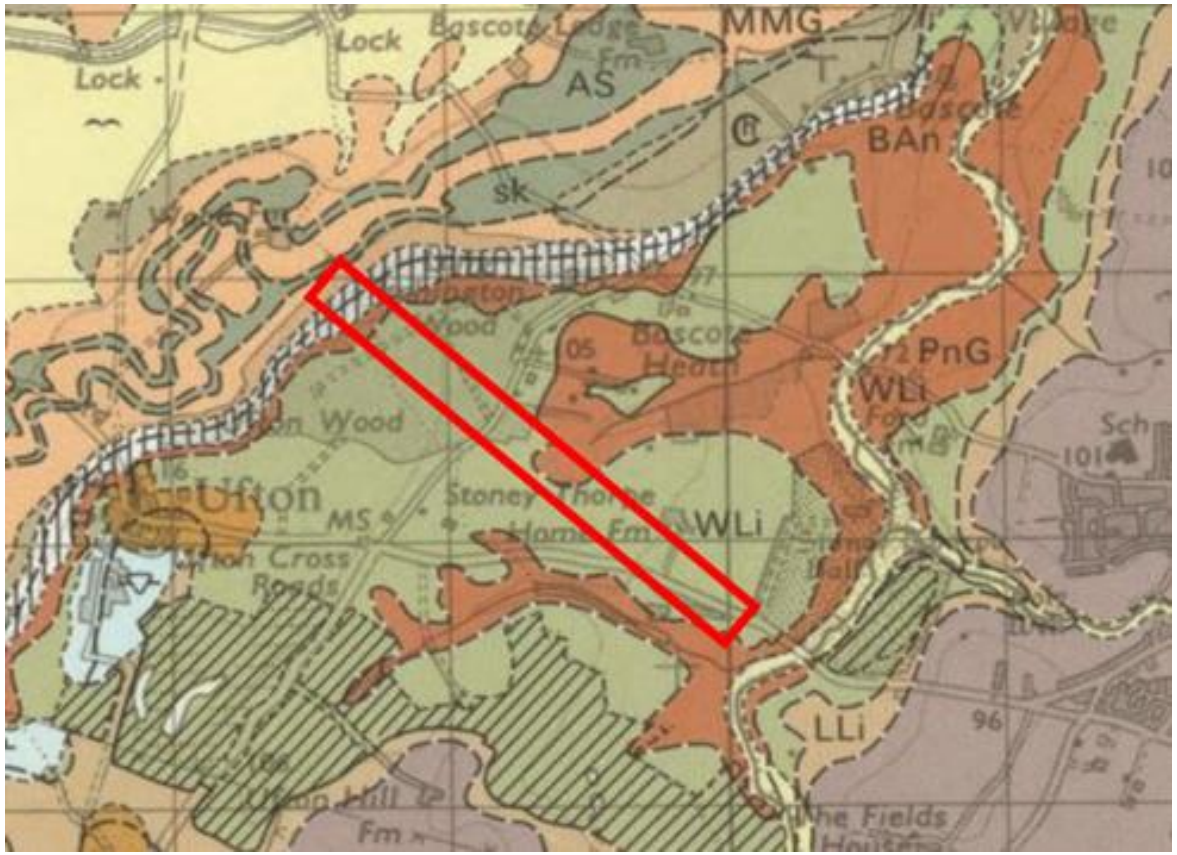
- 2no.single bore 1.6km (total 3.2km)
- 3no cross passages, connecting UP/DN Bore
- 1no.TBM (Variable Density®)-Dorothy
- Excavation diameter (TBM) 9.99m
- Internal diameter 8.80m
- Segmental lining 400mm thick of 2000mm nominal ring length
- Tunnel ring includes 7 + 1 (key) Steel fibre reinforced segments
- The construction of both Upline and Downline bored tunnels as well as the 3 SCL Cross passages is completed



Long Section Through Typical Cross Passage



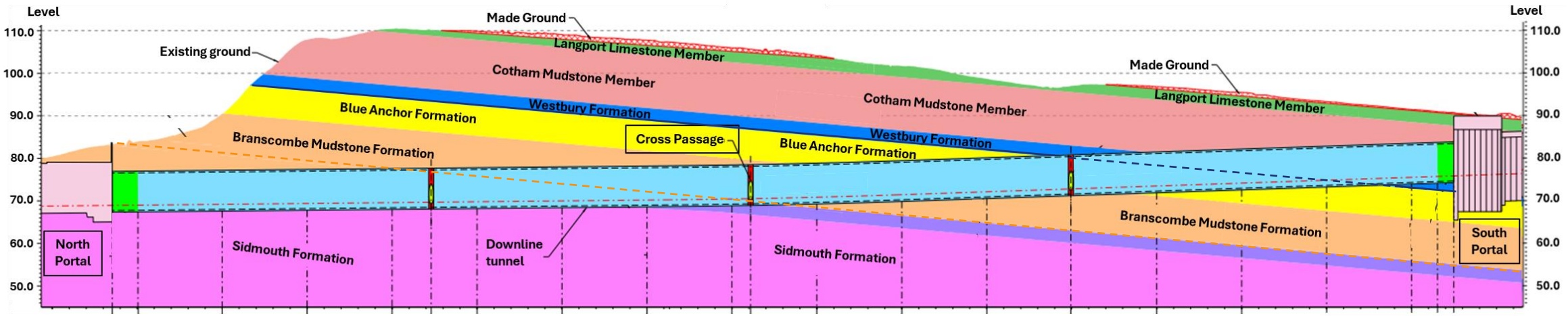
Long Itchington Wood (LIW) Ground Conditions



Extract of the BGS 1:50,000 scale geological map

Period	Group	Formation	Member	Typical description
Triassic	**Penarth** Group (PnG brown)	Lilstock Formation	**Langport** Limestone (WLi)	Thinly bedded limestone with calcareous mudstones and siltstones
			Cotham Member (CTM)	Calcareous mudstones and shales
		Westbury Formation (WBY)		Black pyritic shaly mudstone
Triassic	**Mercia Mudstone** Group	**Blue Anchor** Formation (BAn, light blue)		Greenish grey siltstones
		Branscombe Formation (BCMU, included within undifferentiated MMG)		Brownish red siltstones, mudstones and sandstones
		Sidmouth Formation (SIM, included within undifferentiated MMG)		Brownish red and greenish grey mudstones with sandstone skerries and gypsum veins.

Long Itchington Wood (LIW) Ground Conditions



- Tunnelling boring activity for both TBM drives, performed from **North to South Portal**
- Ground conditions composed on the longest part of tunnel by **Mercia Mudstone Group (MMG**) and more particular by **Sidmouth, Branscombe and Blue Anchor** strata.
- Formation described as brownish red mudstones with frequent bands of green - grey siltstones. The rock mass generally described as **weak to very weak** and **variably weathered**.
- From CP3 passes into Penarth Group including **Cotham Mudstone Member & Westbury Formation**
- On overlaying **Penarth group**, mudstones were found extremely weak to weak, more distinctly weathered with a laminated and closely bedded rock mass.
- **Two different aquifers were encountered**, the deeper one during most of the drive and the shallow one on Penarth Group close to South Portal.

Long Itchington Wood (LIW) Ground Conditions

Design Geotechnical Parameters on MMG Strata

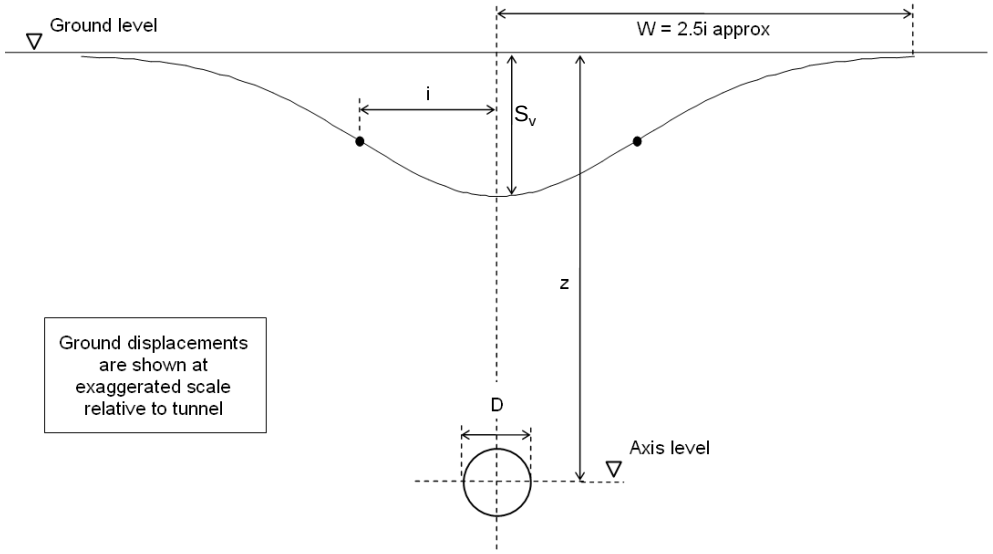
- Geotechnical parameters derived from lab tests, in-situ tests and adapted
- Soil and rock mass permeabilities evaluated using in-situ permeability tests and correlations with published data
- Wide ranges of permeability coefficients introduce uncertainties in ground behaviour during the tunnel excavation and TBM cutter head interventions.

Parameter		Made ground	Langport Limestone member	Cotham Mudstone Member and Westbury formation (soil)	Sidmouth Formation (soil)	Unit
Unit weight	γ	19	20	20.5	20	kN/m^3
Effective cohesion	c'	0	0	5	3 - 15	kPa
Effective friction angle	φ'	25	30	25	29	°
Undrained shear strength	c_u	-	-	100	75	kPa
Undrained Young modulus	E_u	-	-	400 c_u	500 – 700 c_u	MPa
Drained Young modulus	E'	10	15	0.87 E_u	0.87 E_u	MPa
Poisson's ratio	v	0.35	0.35	0.35	0.35	-
Coefficient of earth pressure at rest	K_0	0.5	0.5	1.0 – 1.5	1.5	-

Parameter		Cotham Mudstone Member and Westbury formation (rock)	Blue Anchor Formation	Branscombe Mudstone Formation	Sidmouth Formation (rock)	Unit
Uniaxial Compressive Strength	UCS	0.5	3.2	4.5	2.0	MPa
Geological Strength Index	GSI	30	60	58	55	-
Intact Rock Constant	m	4	7	7	4	-
Rock mass Modulus	E_m	150	800	800	400	MPa
Poisson's ratio	v	0.2	0.2	0.2	0.2	-
Coefficient of earth pressure at rest	K_0	1.5 - 2.0	1.5 - 2.0	1.5 - 2.0	1.7 – 2.0	-

Long Itchington Wood (LIW) Ground Conditions

Ground Movement Assessment



8.2.3	A value of trough width parameter, K = 0.5 shall be adopted in London Clay, a value of K = 0.4 shall be adopted in other geologies shown in Table 1. K values for "sands" should consider differences above and below the water table. Values of up to 0.5 can occur for wet sands.
8.2.4	Table 1 provides values of volume loss for various ground conditions and tunnel construction methods.

Volume Loss

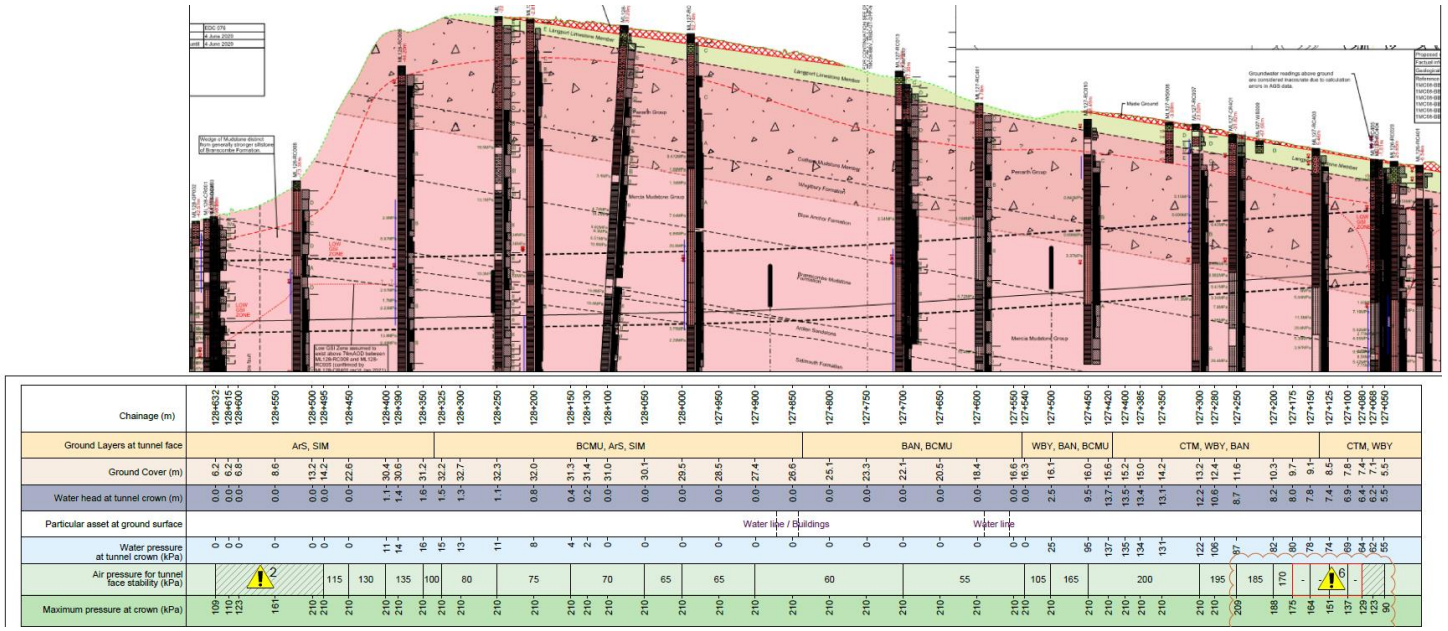
Tunnel construction methods	London Clay	Lambeth Group	Chalk	Mercia Mudstone
Closed face tunnelling (earth pressure balance machine (EPBM) or slurry Tunnel Boring Machine (TBM)	1%	1%	1%	1%
Open face tunnelling	2%	2%	2%	2%
Sprayed concrete lining (SCL)	1.5%	1.5%	1.5%	1.5%

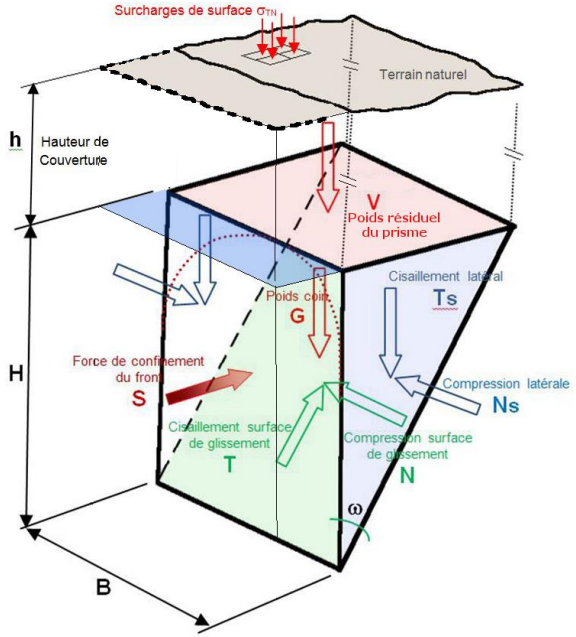
- The **ground surface settlement** induced by tunnel construction is commonly described by a Gaussian inverted curve in the transverse direction (by O'Reilly & New, 1982) and a cumulative Gaussian curve in the longitudinal direction (by Attewell & Woodman, 1982) has been calculated in line to HS2 technical Standards.
- A **volume loss of 1%** has been assumed for the TBM bored tunnels and 1.5% for the SCL cross passages.
- A **trough width parameter of 0.4** is adopted for all tunnel elements.

Long Itchington Wood (LIW) Ground Conditions

TBM Confinement Pressure

- **Equilibrium of the ground wedge and water pressure** at the tunnel face has been calculated through out the TBM drive
- Objectives of the design : Define the **lower and upper bounds of TBM face pressure** to apply during the excavation
- Analyses conducted both in **drained and undrained conditions**, regarding the uncertainty of ground permeabilities.
- **Upper bound** of support pressure conservatively set to the **vertical total stress above the tunnel**, reduced by a tolerance on the applied pressure.
- **Lower bound** of support pressure defined for the tunnel face stability.





Instrumentation and Monitoring

Levelling Studs for Hard and Soft Ground

Levelling stud
installed hard paved areas

Levelling stud
installed soft Ground
pavers

Survey anchor for Soft Ground to mitigate seasonal variations
Depth can vary between 0.4m and 1m

Instrumentation and Monitoring

Borehole Instrumentation

Borehole inclinometer (IM) : instrument designed to measure the horizontal deformations at depth.

Borehole extensometer (XM) : instrument designed to measure the vertical displacements at depth.

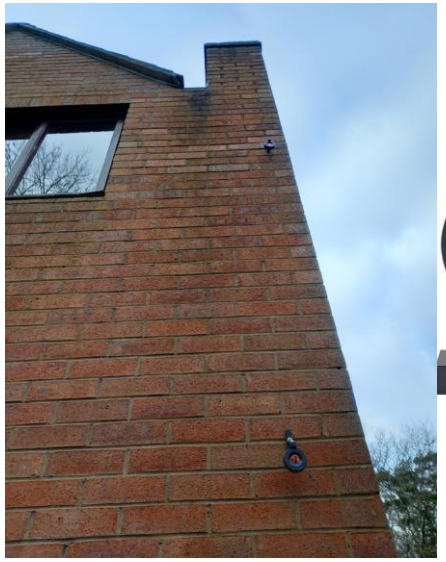
Standpipe piezometer (PS) : open tube / well installed in the ground and allowing to measure directly the ground water level.

Fully-grouted borehole piezometer (PV) : grouted borehole equipped with one to 4 piezometer sensor(s) installed at several depths.

Most of borehole Instruments were set **as Automated** transferring monitoring data through Gateways to the project online Monitoring Database.

Instrumentation and Monitoring

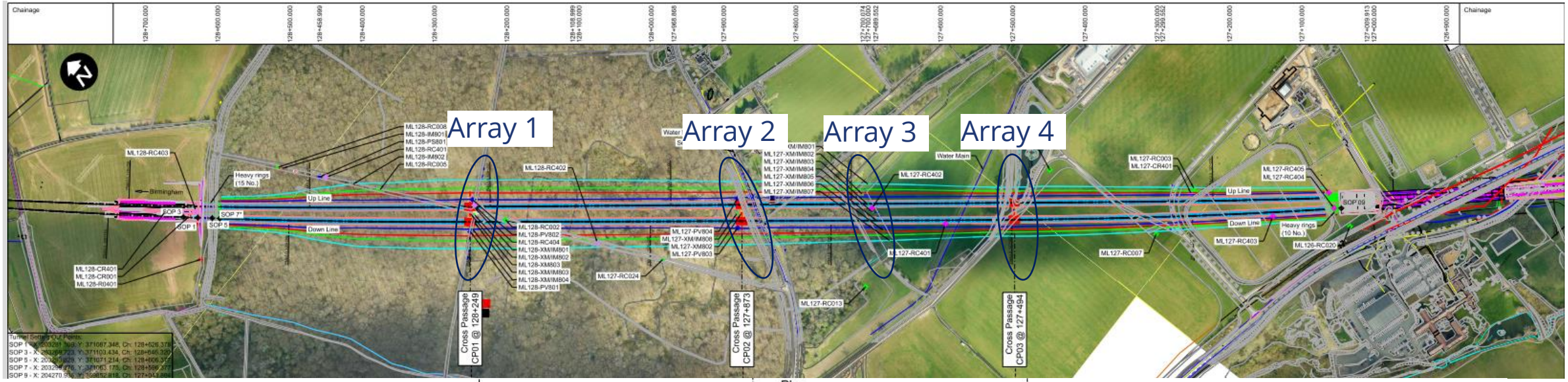
Building Monitoring for asset protection



- Levelling studs at buildings lower walls
- Prisms at building façades
- Crack meters (where cracks identified)
- Triaxial automated Tilt Meters

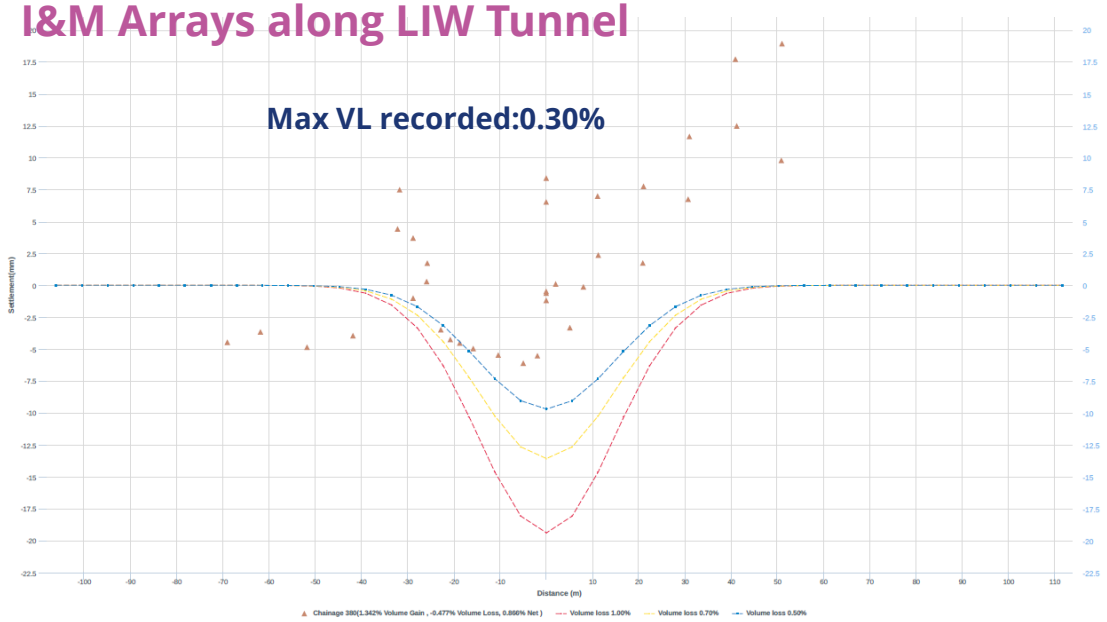
Instrumentation and Monitoring

I&M Arrays along LIW Tunnel

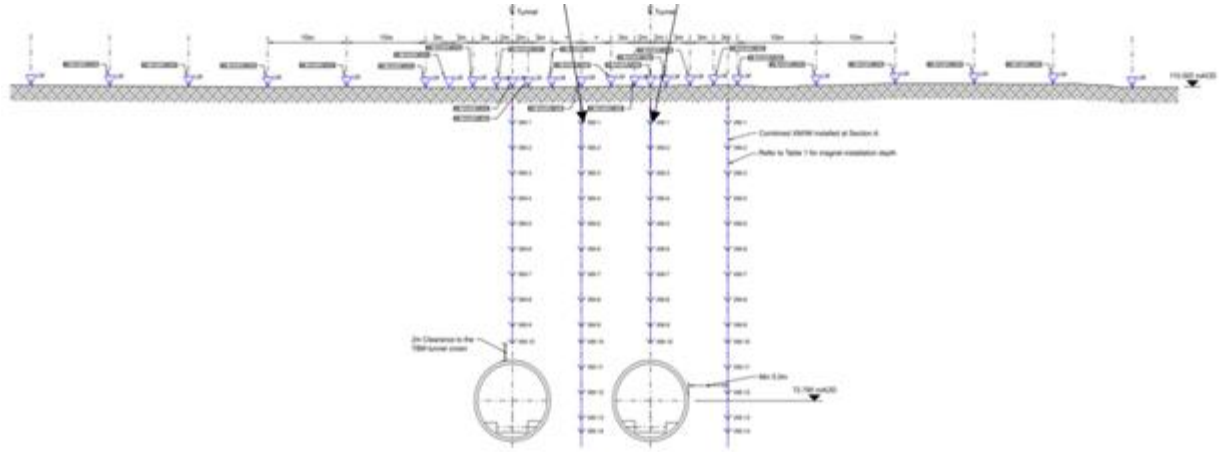


Instrumentation and Monitoring

I&M Arrays along LIW Tunnel



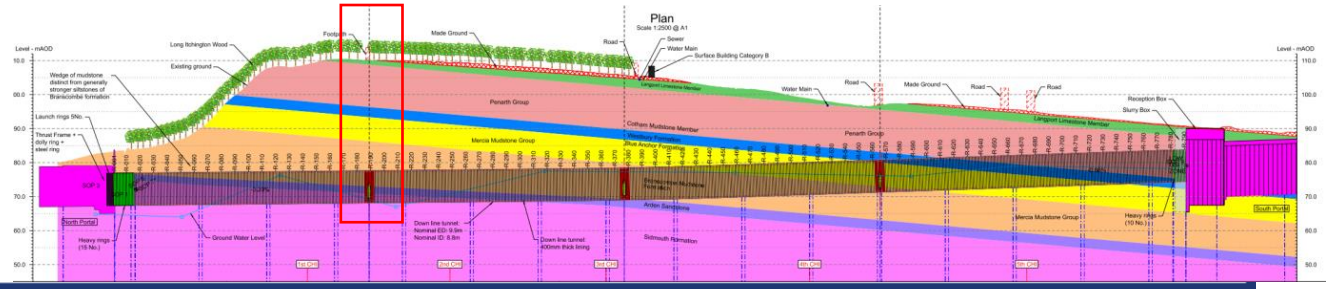
Typical Monitoring array with:
(a) **Levelling points** (b) **Extensometers** (c) **Inclinometer** (d) **Piezometers**



Layout of CP1 location

CP1 location Chainage : 128+254

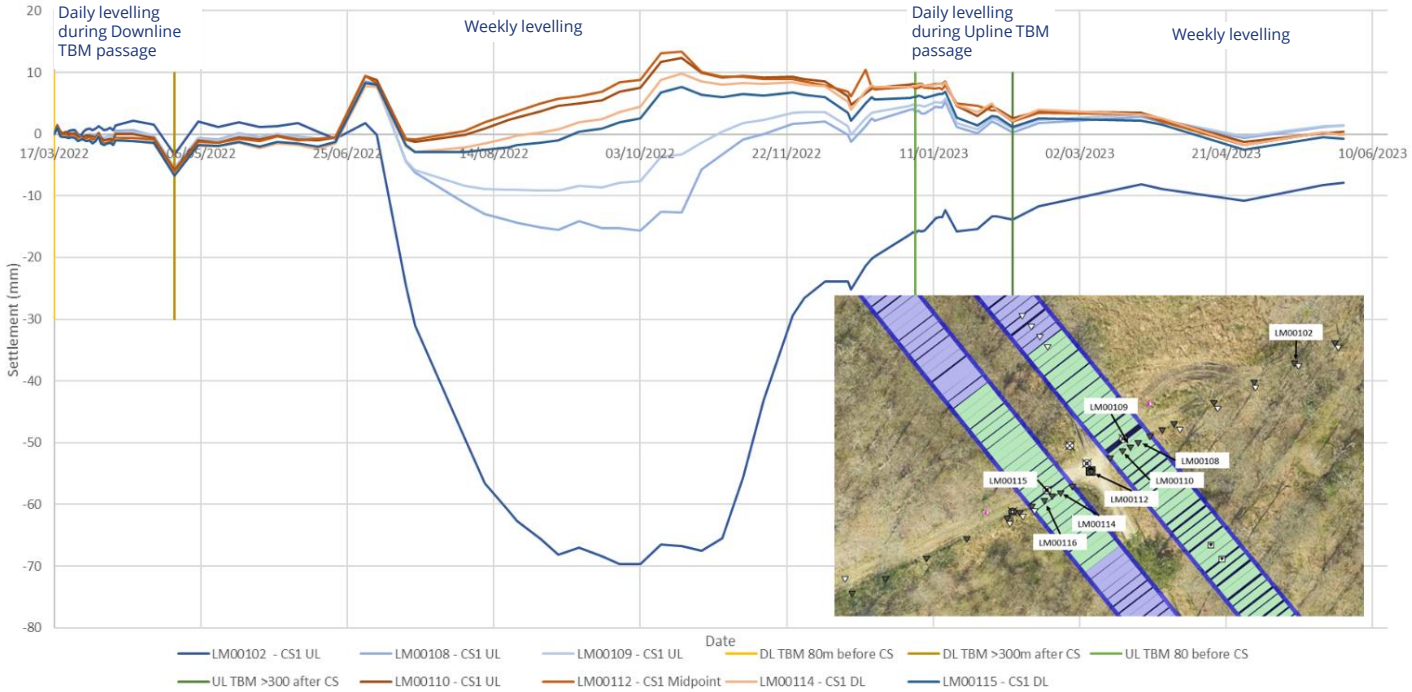
CP1 location Simplified Geological Section
CP1 location
Cover: 33m
Geology: MMG (mix conditions Sidmouth/Arden/Brancombe)



Instrumentation and Monitoring

I&M Arrays along LIW Tunnel

CP1 location Chainage : 128+254

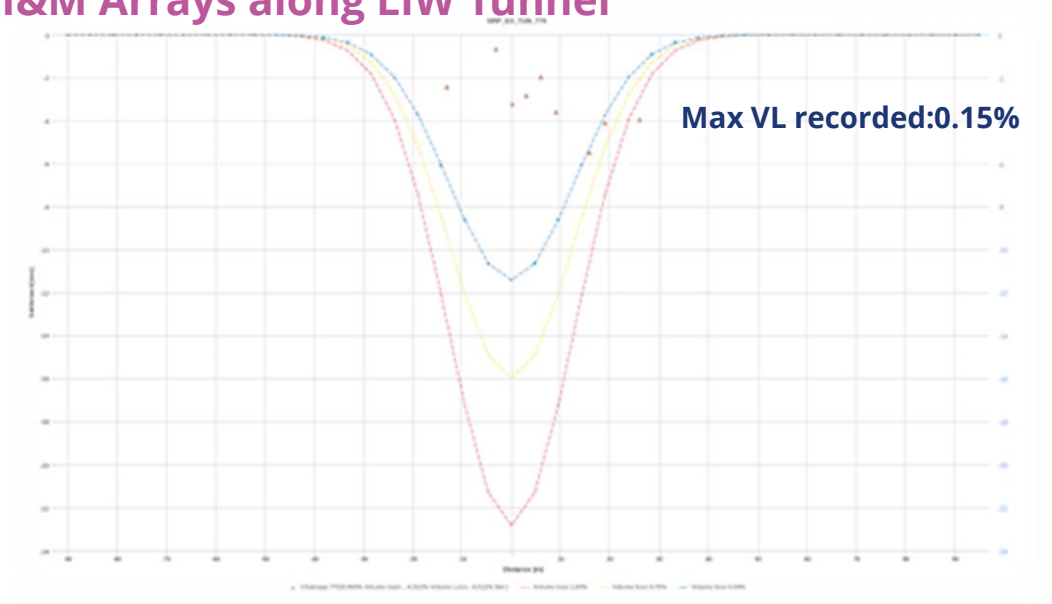


Seasonal Variation of surface soft ground

- On Ancient Woodland more than a year of levelling at CP1 - indicates that the impact of the shrink-swell behaviour is significant, and of a much larger magnitude than the tunnelling induced movement.
- To mitigate that deep survey anchors were added for TBM2 and also implemented on Bromford Tunnel

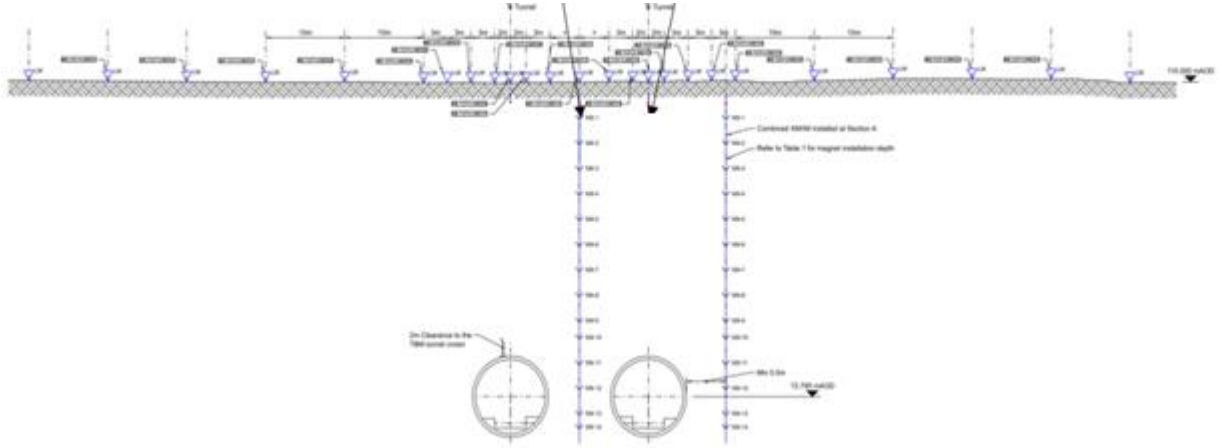
Instrumentation and Monitoring

I&M Arrays along LIW Tunnel



Max VL recorded:0.15%

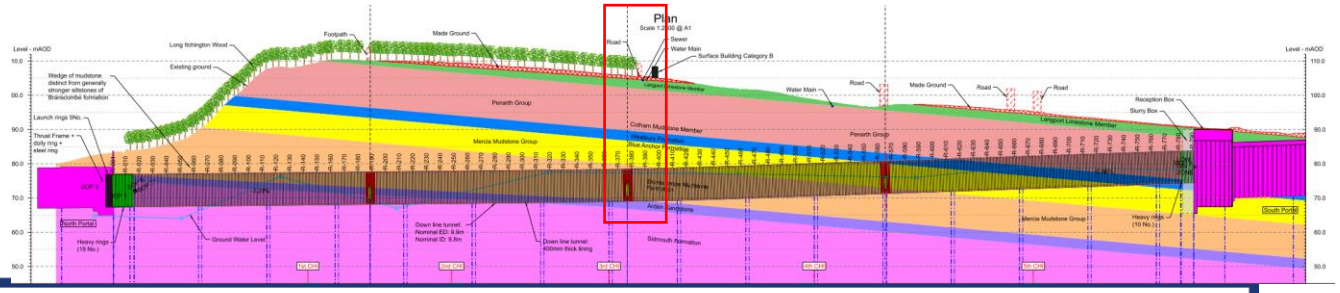
Typical Monitoring array with:
(a) **Levelling points** (b) **Inclinometer** (c) **Piezometers**



Layout of CP2 location

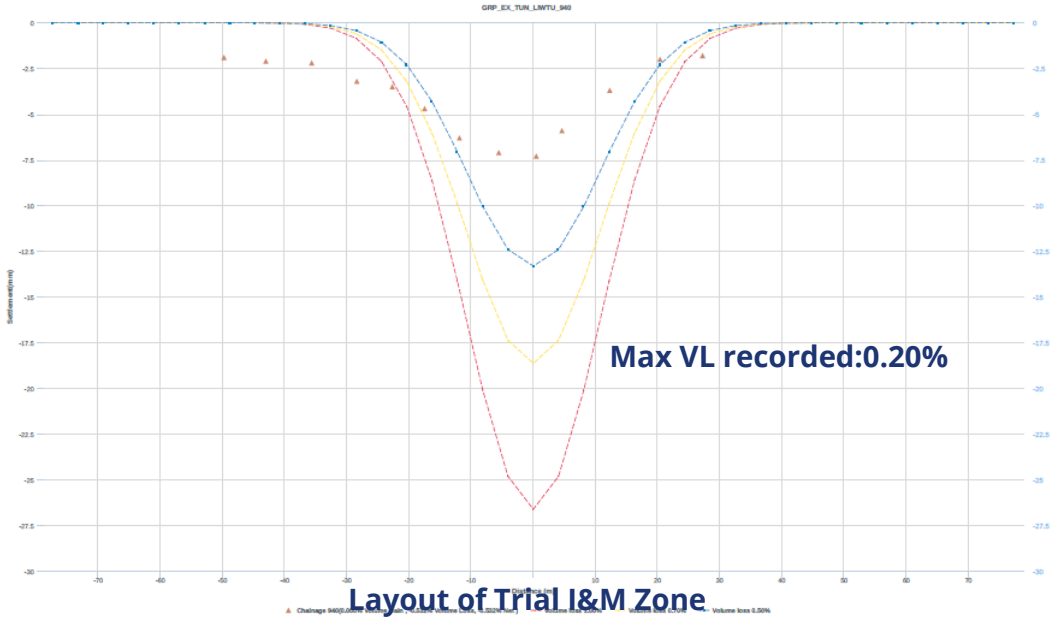
CP2 location Chainage : 127+878

CP2 location Simplified Geological Section
CP2 location
Cover: 27m
Geology: MMG (Brancombe)

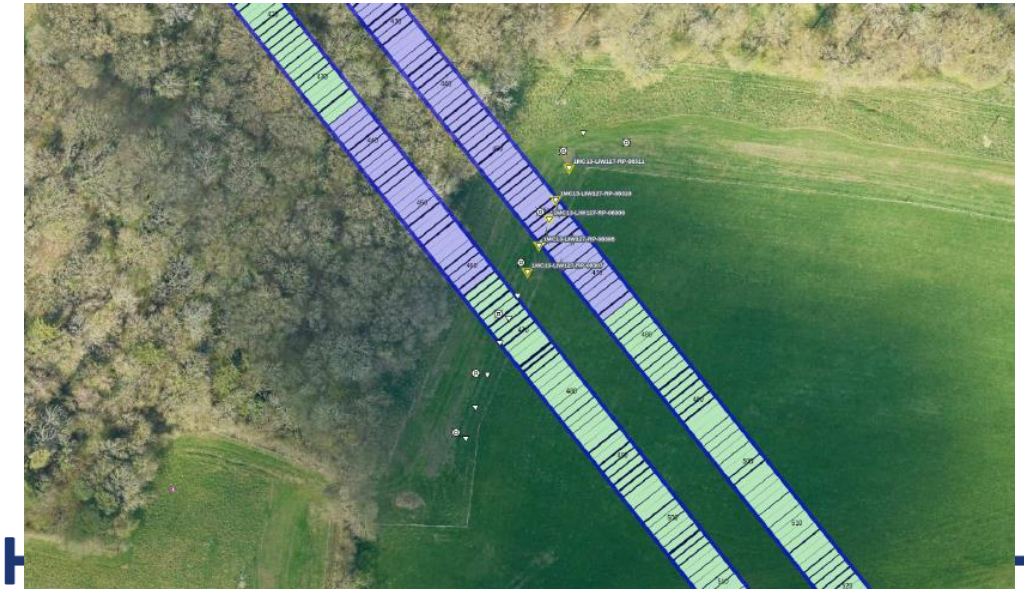


Instrumentation and Monitoring

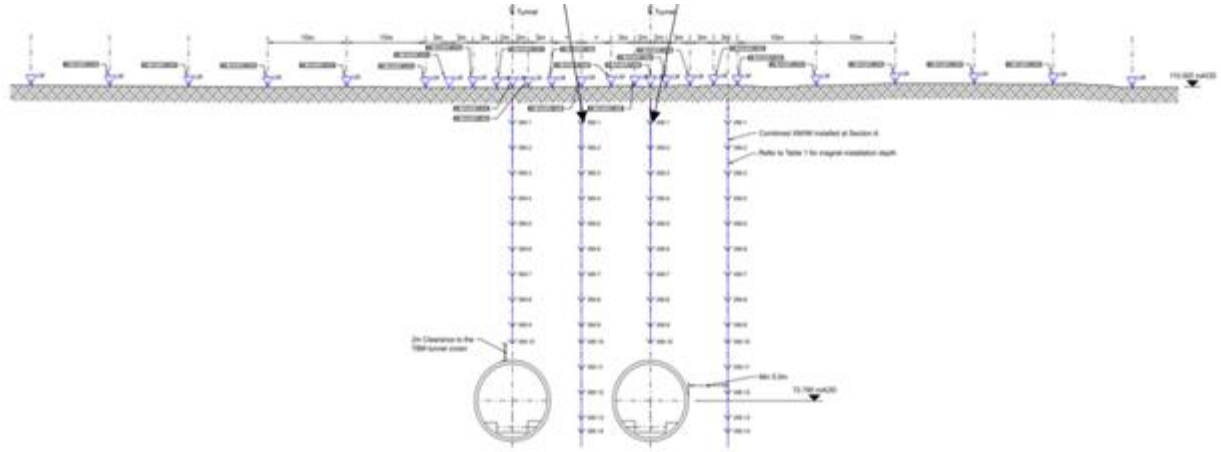
I&M Arrays along LIW Tunnel



Layout of Trial I&M Zone

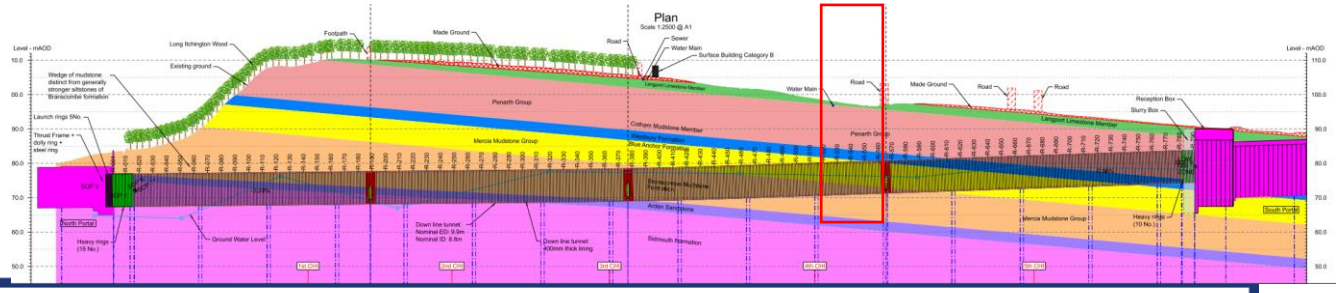


Typical Monitoring array with:
(a) **Levelling points** (b) **Extensometers** (c) **Inclinometer** (d) **Piezometers**



Trial Monitoring Zone Chainage : 127+600

Trial Zone Simplified Geological Section
Trial I&M Zone location
Cover: 19m
Geology: MMG (mix conditions Brancombe/Blue Anchor)

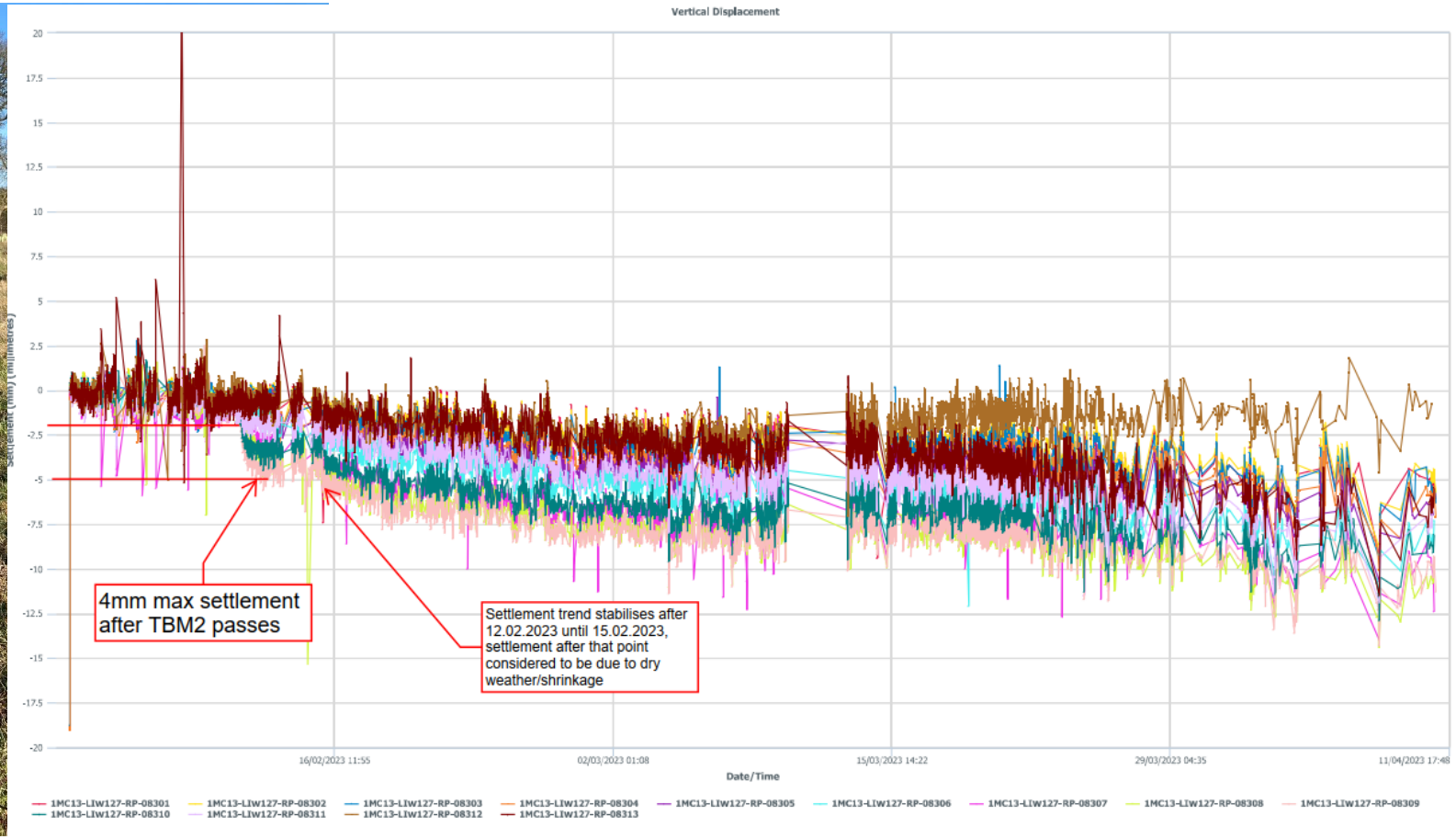


Instrumentation and Monitoring

I&M Arrays along LIW Tunnel

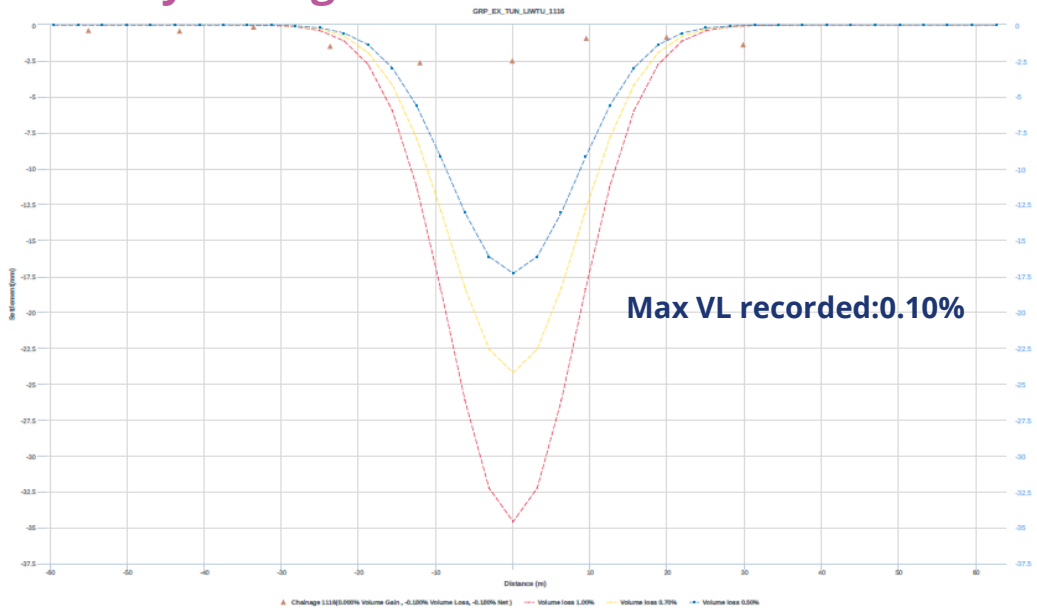
Trial Monitoring Zone Chainage : 127+600

Automated Total Station (ATS) with hourly data monitoring frequency transferring data online to Monitoring Database



Instrumentation and Monitoring

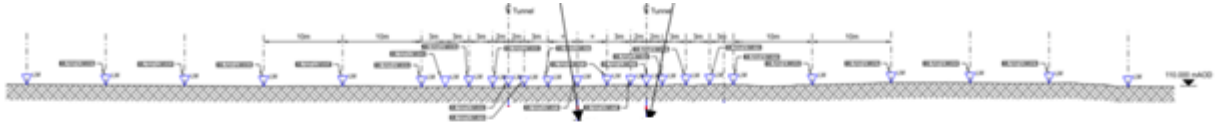
I&M Arrays along LIW Tunnel

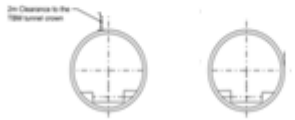


Max VL recorded:0.10%

CP3 Layout

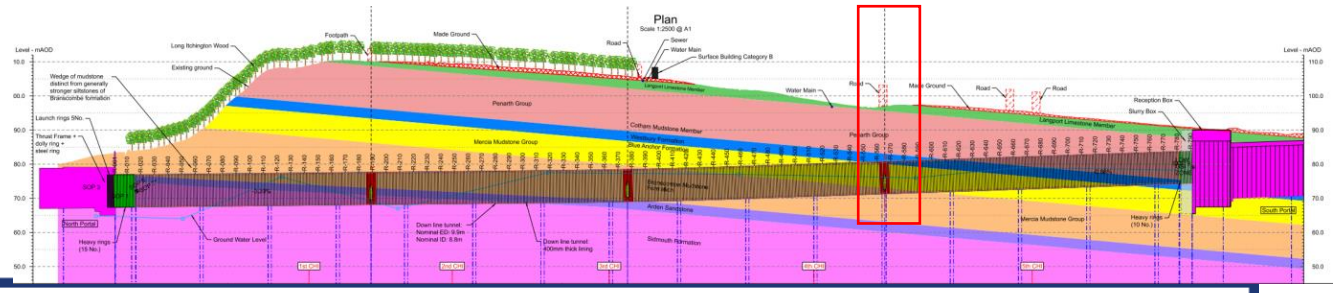
Typical Monitoring array with:
Levelling points



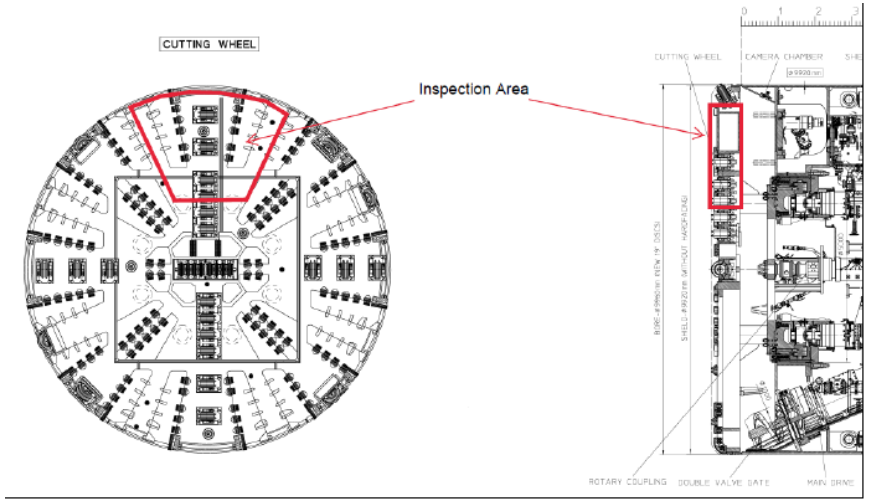


CP3 Chainage : 127+501

Simplified Geological Section
CP3
Cover: 16m
Geology: MMG (mix conditions Branscombe/Blue Anchor)

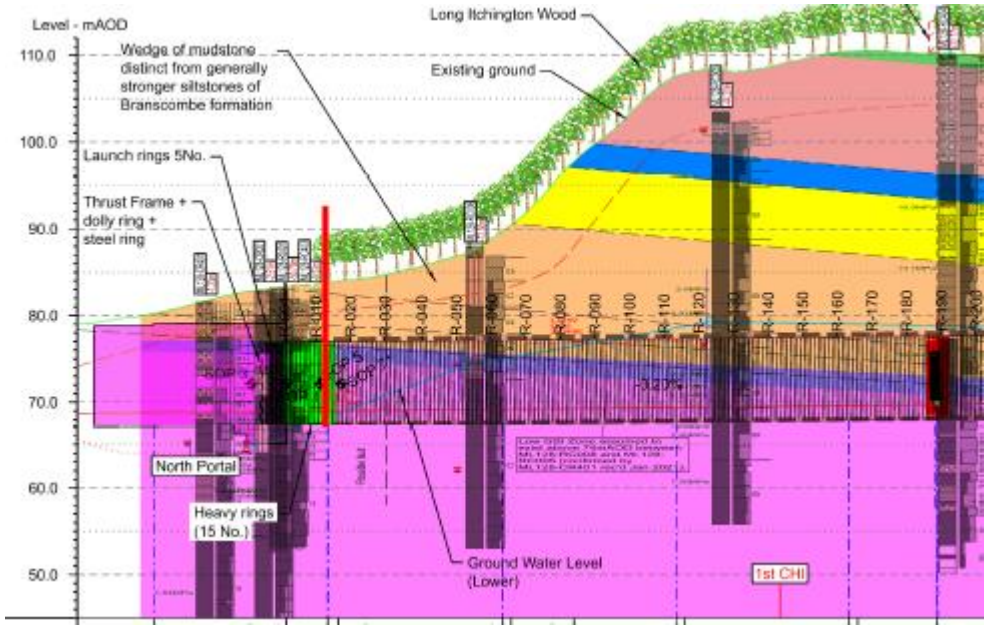


Ground Inspections during TBM Excavation (CHI)

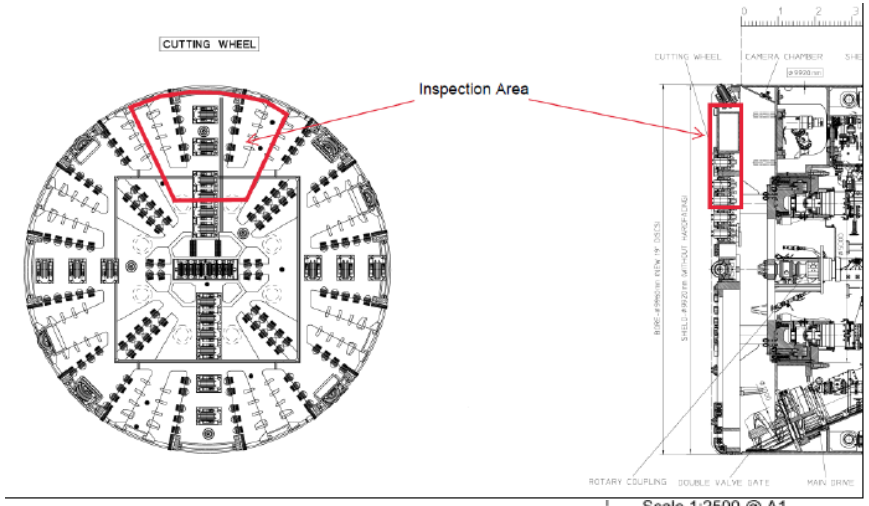


Chainage : 128+600
Ring: 12
Cover: 8m

Geology:
MMG mix conditions
Sidmouth formation and on top Arden sandstone

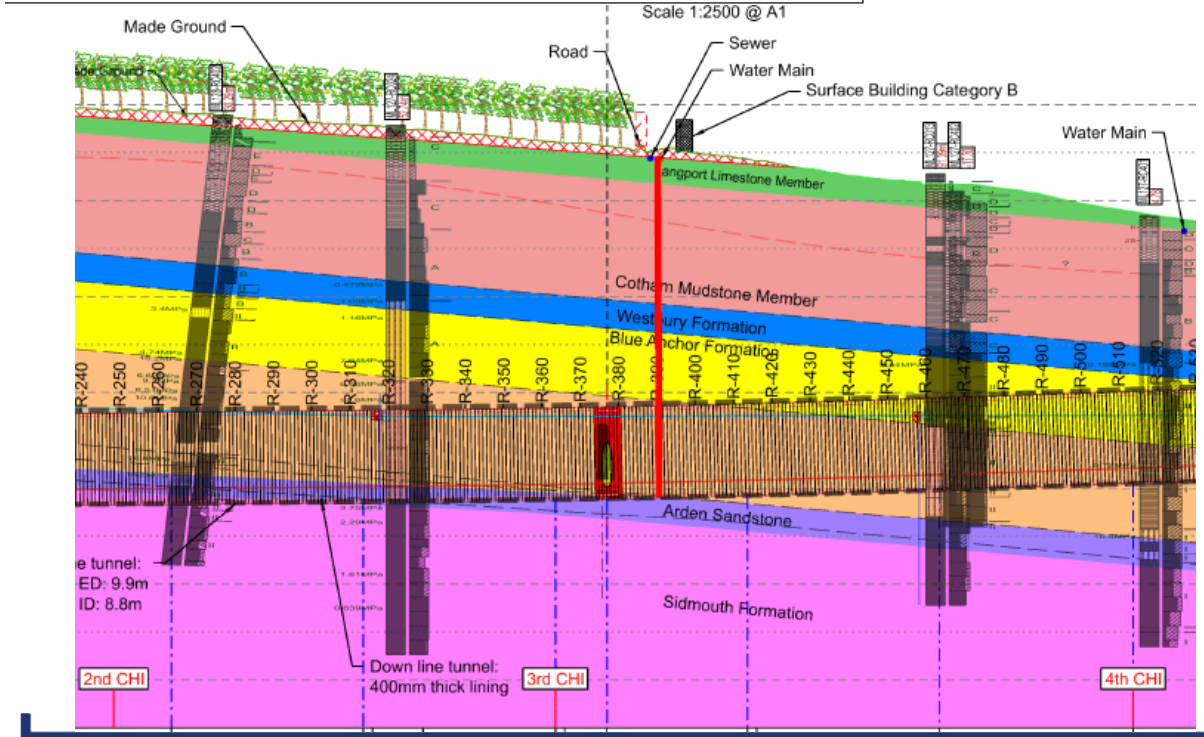


Ground Inspections during TBM Excavation (CHI)

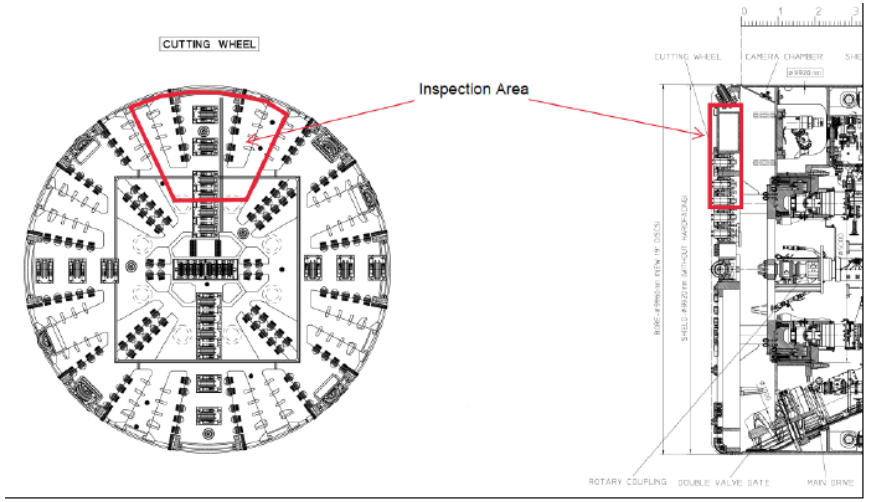


Chainage : 128+850
Ring: 390
Cover: 27m

Geology:
MMG Branscombe formation

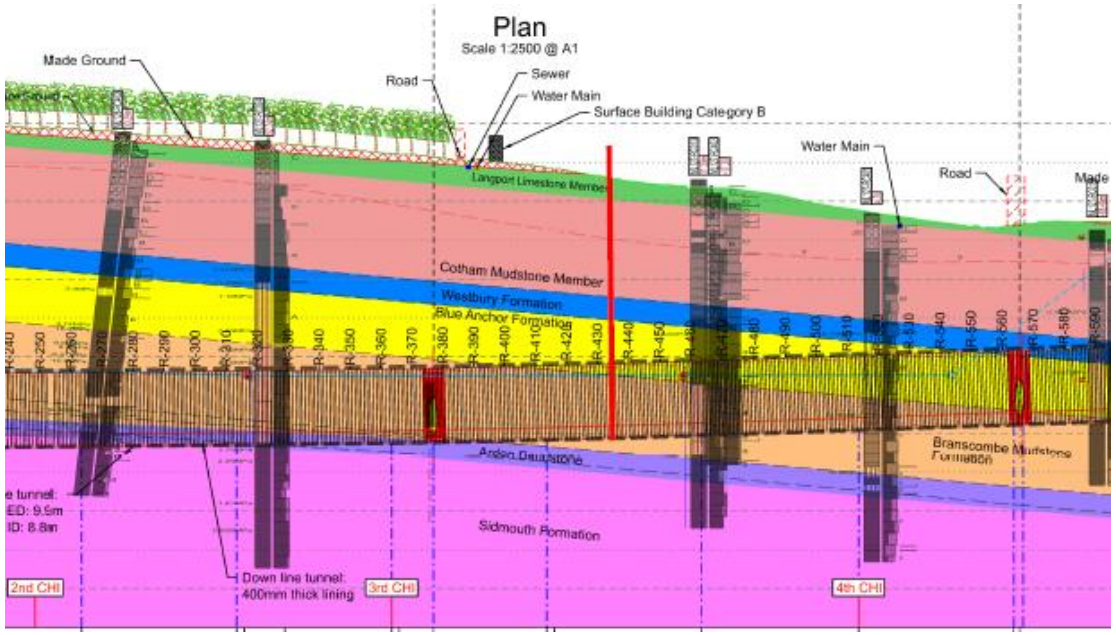


Ground Inspections during TBM Excavation (CHI)



Chainage : 127+780
Ring: 434
Cover: 24m

Geology:
MMG mix conditions
Blue Anchor on top
Branscobe Mudstone below

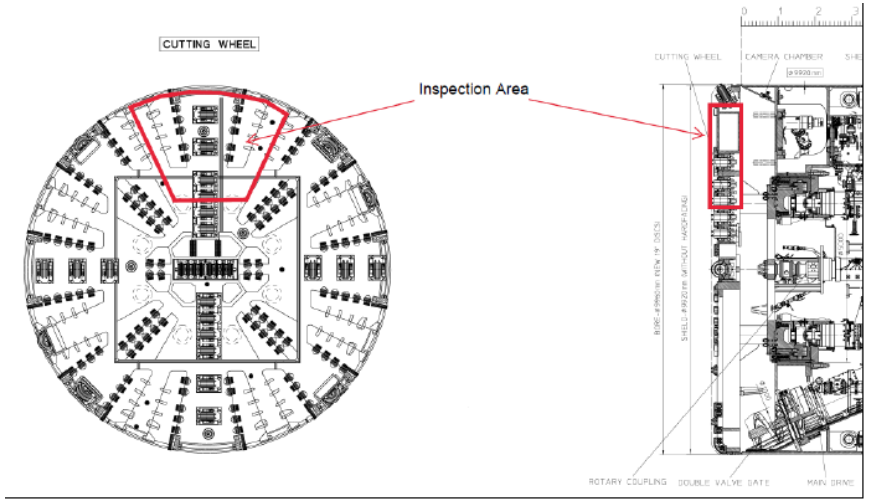


LIW Tunnel – Cutterhead Intervention Photos

Blue Anchor Formation / Wet conditions

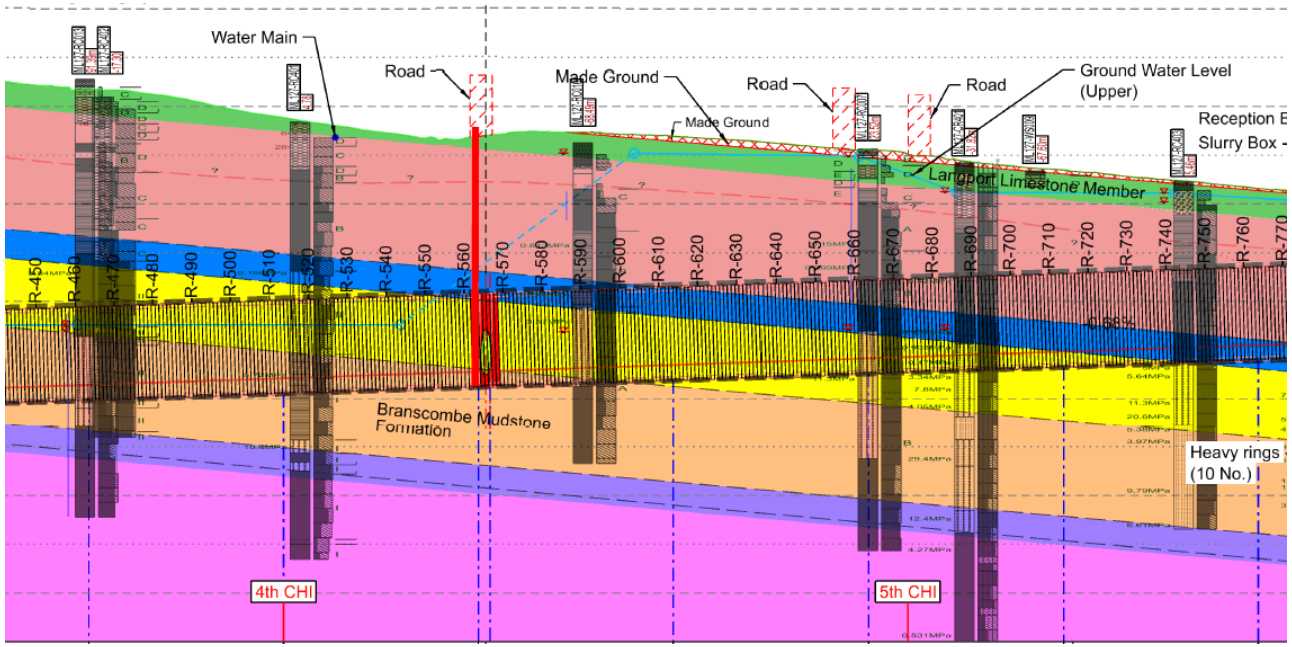
Top and Middle Cutterhead levels
Blue Anchor and Branscombe Formation

Ground Inspections during TBM Excavation (CHI)

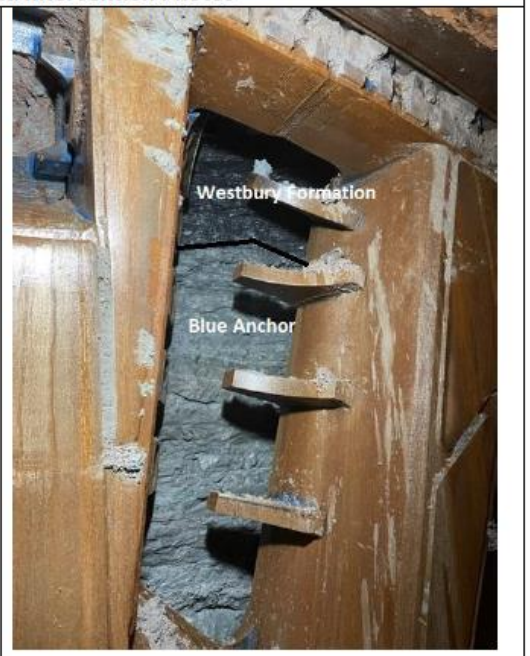


Chainage : 127+780
Ring: 564
Cover: 21m

Geology:
MMG mix conditions
Blue Anchor on top
Branscobe Mudstone below



LIW Tunnel – Cutterhead Intervention Photos



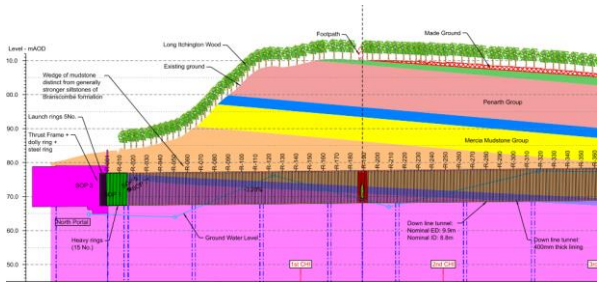
Westbury Formation – Blue Anchor Contact

Ground Inspections Cross Passage during SCL Excavation

CP1 location Chainage : 128+254

Cover: 33m

Geology:
MMG mix conditions
Arden Sandstone on top
Sidmouth Mudstone below



Balfour Beatty VINCI Working on behalf of HS2

1MC08-BBV-DS-PRO-N001-000002

PAGE: 1 OF 3 Rev: 0

GEOTECHNICAL LOGGING SHEET - SCL EXCAVATION

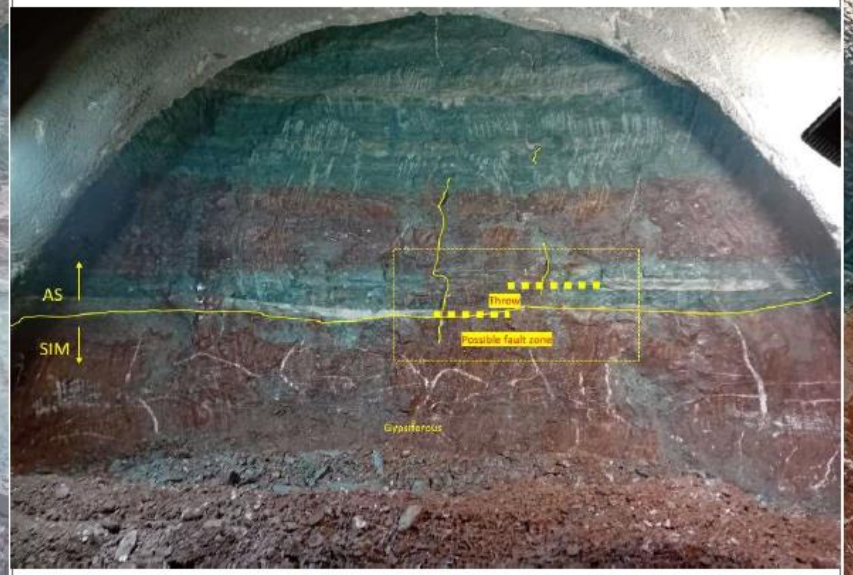
PROJECT TITLE:			HS2 - Area North									
RESS:	CP01-05 Rev01	Structure:	Long Itchington Wood Tunnel - Cross Passage 1	Date:	27/07/2024	Time:	12:30	03:00	1m	Chainage:	128,270	Advance ID:	Advance 10

FACE PHOTOGRAPHS / SKETCHES

CROWN

LEFT SIDE

FACE



RIGHT SIDEWALL

Ground Conditions Description (Intact rock and discontinuities):

Moderately weak thickly laminated to thinly bedded bluish-grey non-calcareous SILTSTONE becoming moderately weak thickly laminated to thinly bedded reddish-brown non-calcareous MUDSTONE. With thin white fine calcareous sand strangled ripple laminations.
(CIRIA WEATHERING GRADE II)
(ARDEN SANDSTONE FORMATION - AS); over

Moderately weak thickly laminated to thinly bedded reddish-brown gypsiferous non-calcareous MUDSTONE.
(CIRIA WEATHERING GRADE II)
(SIDMOUTH MUDSTONE FORMATION - SIM)

Observations and recommendations:

The section appears to be through the anticipated Arden Sandstone Formation and Sidmouth Mudstone Formation, as per the ground model. RMR assessment has not distinguished between these strata.
RMR increased to 49 based on sample recovery demonstrating clean fracture surfaces.
Possible fault in centre of the face.

Groundwater inflow or seepage:

Groundwater was not encountered.

Overbreak:

No obvious overbreak was noted. Crown and sides were finished with the miller.

Probe holes / investigation holes:

Probe holes are not visible

Obstructions or man-made features:

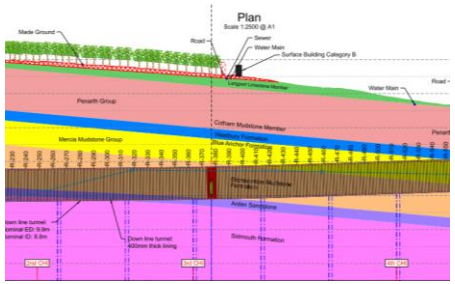
No obstruction or man-made features were encountered.

Ground Inspections Cross Passage during SCL Excavation

CP2 location Chainage : 127+878

Cover: 27m

Geology:
MMG Branscombe Mudstone



Balfour Beatty VINCI Working on behalf of HS2

1MC08-BBV-DS-PRO-N001-000002

PAGE: 1 OF 3 Rev: 0

GEOTECHNICAL LOGGING SHEET - SCL EXCAVATION

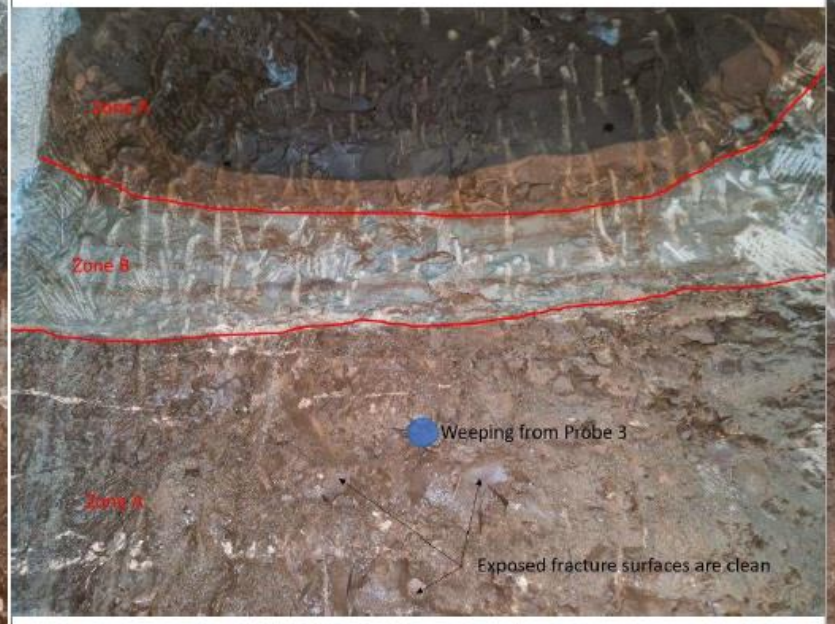
PROJECT TITLE:			HS2 - Area North									
RESS:	RESS CP02 - 03	Structure:	Long Itchington Wood Tunnel - Cross Passage 2	Date:	02/06/2024	Time:	14:15	Advance length:	1m	Chainage:	127,902	Advance ID:	Advance 2 - Zone A

FACE PHOTOGRAPHS / SKETCHES

CROWN

LEFT SIDE

FACE



RIGHT SIDEWALL

Ground Conditions Description (Intact rock and discontinuities):
Weak reddish-brown MUDSTONE

Observations and recommendations:
Probe 3 is weeping groundwater but the excavation is otherwise dry.

Groundwater inflow or seepage:
Probe 3 is weeping groundwater but the excavation is otherwise dry.

Overbreak:
n/a

Probe holes / investigation holes:
Probe 3 is weeping groundwater but the excavation is otherwise dry.

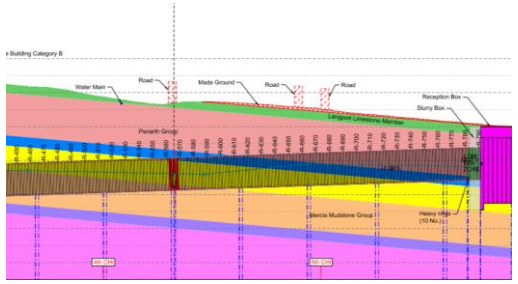
Obstructions or man-made features:
None

Ground Inspections Cross Passage during SCL Excavation

CP3 location Chainage : 127+878

Cover: 16m

Geology:
MMG Blue Anchor / Branscombe



Balfour Beatty VINCI Working on behalf of HS2

1MC08-BBV-DS-PRO-N001-000002

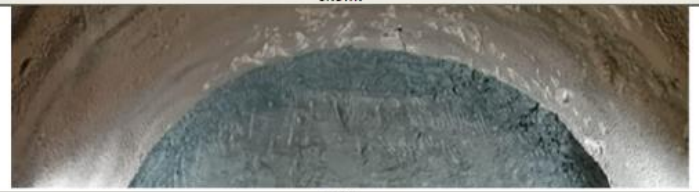
PAGE: 1 OF 3 Rev: 0

GEOTECHNICAL LOGGING SHEET - SCL EXCAVATION

PROJECT TITLE:			HS2 - Area North									
RESS:		Structure:	Long Itchington Wood Tunnel - Cross Passage 3	Date:	16/05/2024	Time:	04:00	Advance length:	1m	Chainage:	127,525	Advance ID:	Advance 9

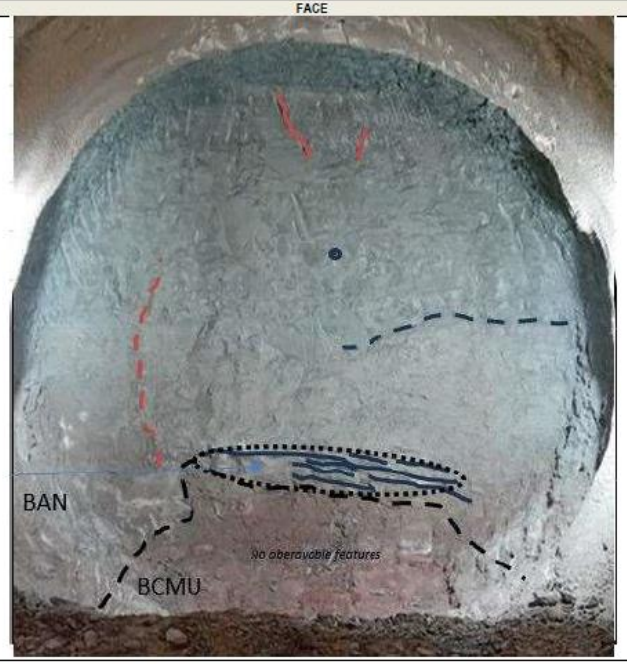
FACE PHOTOGRAPHS / SKETCHES

CROWN



LEFT SIDE

FACE



RIGHT SIDEWALL

Ground Conditions Description (Intact rock and discontinuities):
Weak apparently medium bedded locally thinly bedded grey slightly silty MUDSTONE (BLUE ANCHOR FORMATION)

Observations and recommendations:
Face appears to be stable

Groundwater inflow or seepage:
Dry

Overbreak:
Not observed

Probe holes / investigation holes:
Not observed

Obstructions or man-made features:
None

Monitored Summary and Volume Loss

Array	TBM Passing Date	Settlement Data Date Range	Volume Loss (%)	Maximum Settlement (mm)
Cross Passage 1	08.01.2023	15 – 19.01.2023	0.2 – 0.3	3.4
Cross Passage 2	02.02.2023	02 – 09.02.2023	0.15	1.7
Trail Zone	11.02.2023	11 – 12.02.2023	0.20	4.0
Cross Passage 3	25.02.2023	24 – 26.02.2023	0.10	2.5

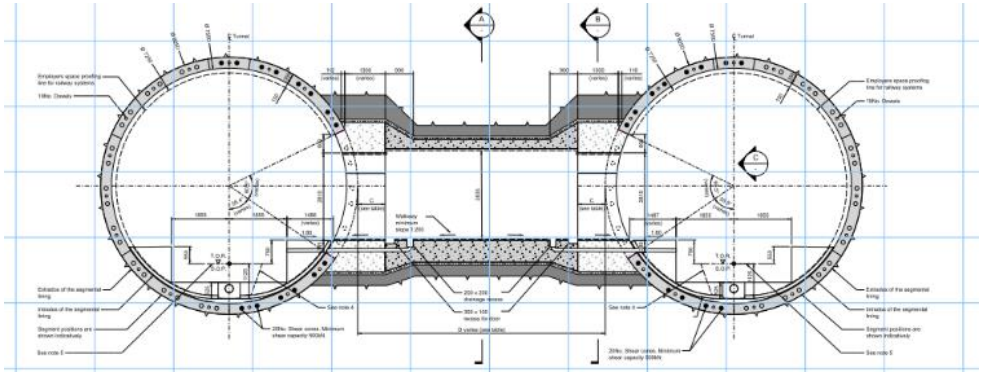
Conclusion

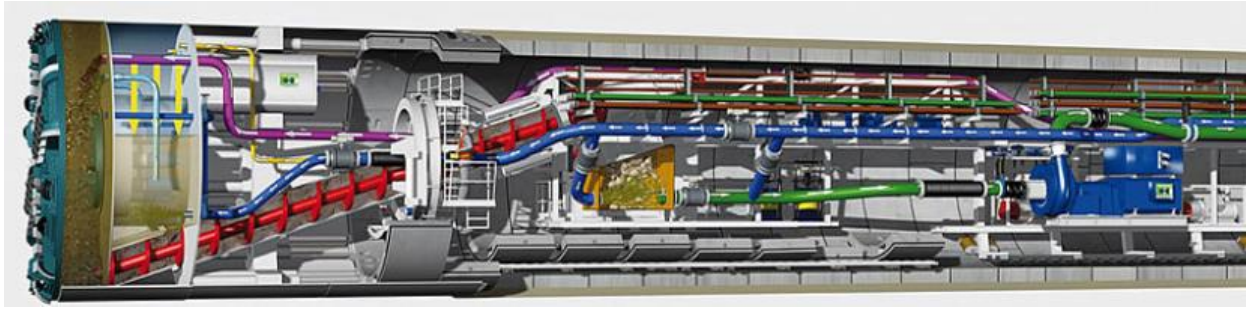
- LIW tunnel, the **first** twin bored tunnel to be **completed on the HS2 project in March 2023.**
- The case history from LIW tunnel has successfully demonstrated that Design approach and Tunnelling excavation process were suitable for **controlling ground movements** the effectiveness of this strategy.
- **BBV gained significant experience** and confirmed the construction **strategy** for the second tunnel, **Bromford**, which traverses urbanized areas, beneath **critical assets** such as the **M6 viaduct,** the **River Tame**, a **Network Rail embankment** and running close and parallel to the **National Grid** power lines alignment.

Bromford Bored Tunnels

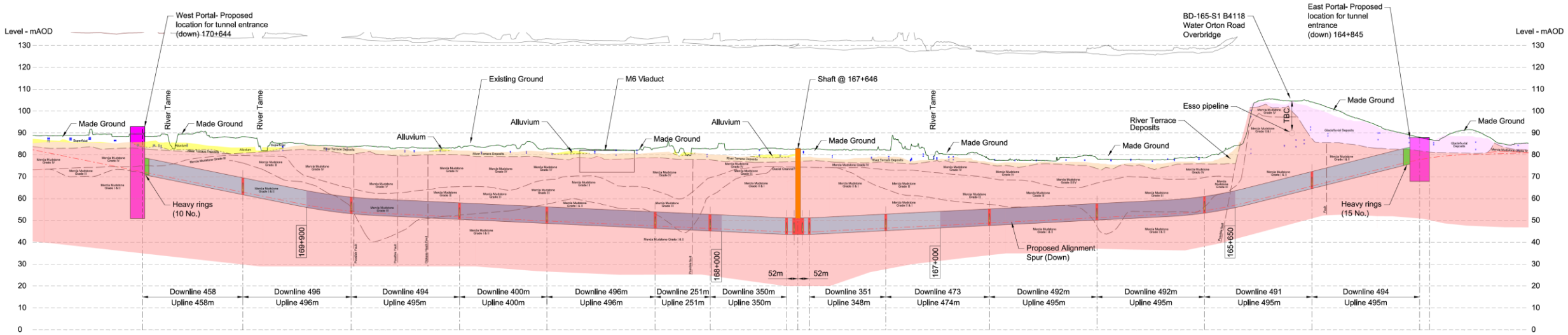
Tunnel Overview

- 2no. 5.8km (total 11.6km)
- Downline 78% completed
- Upline 49% completed
- 2 no. TBM (Variable Density®)
- 13 no. cross passages
- Excavation diameter (TBM) 8.60m
- Internal diameter 7.55m
- Intermediate Shaft (20m diameter)





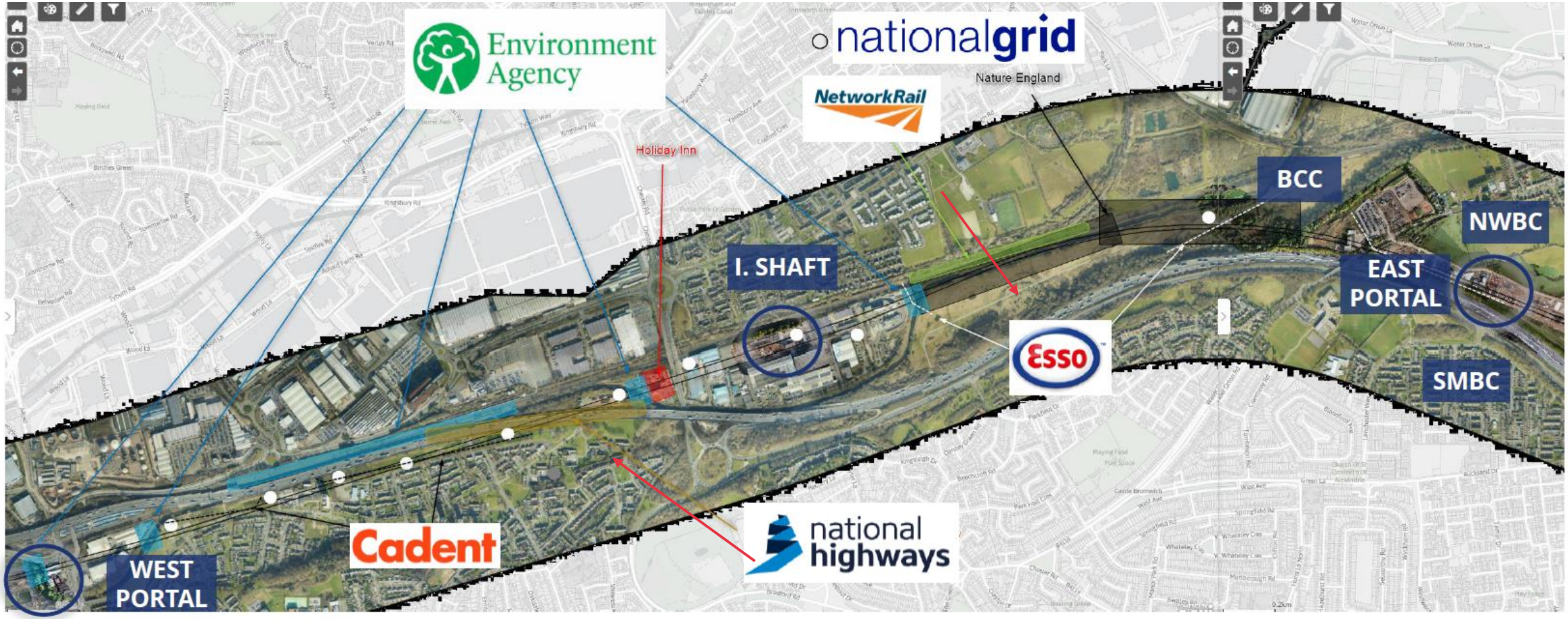
Bromford Tunnel– Ground Conditions



Ground composed of Mercia mudstone Group (MMG – Sidmouth Formation)

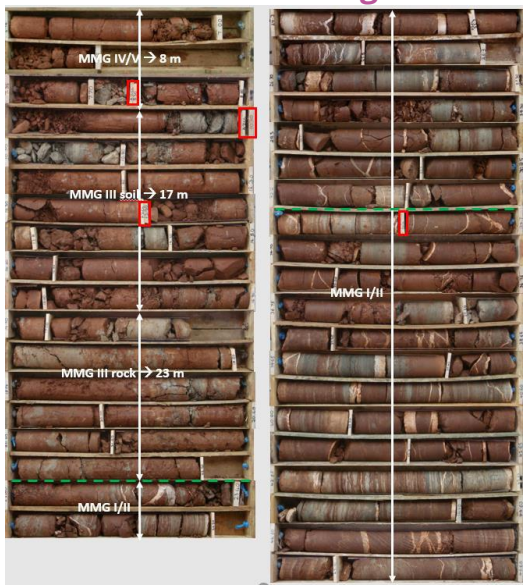
- **Grade I/II** : Extremely weak to weak, laminated to thinly bedded, reddish brown MUDSTONE
- **Grade III** : Stiff, fissured, reddish brown, sandy gravelly CLAY
- **Grade IV**: Firm, fissured, reddish brown, mottled greenish grey, slightly, gravelly CLAY
- **Groundwater conditions**: Water table is close to ground level and tunnel along the full drive is considered fully submersible. Material permeability is low.

Bromford tunnel – Key Asset Owners with Tunnel Influence Zone (ZOI)



Bromford Tunnel– Design Approach followed similar to LIW

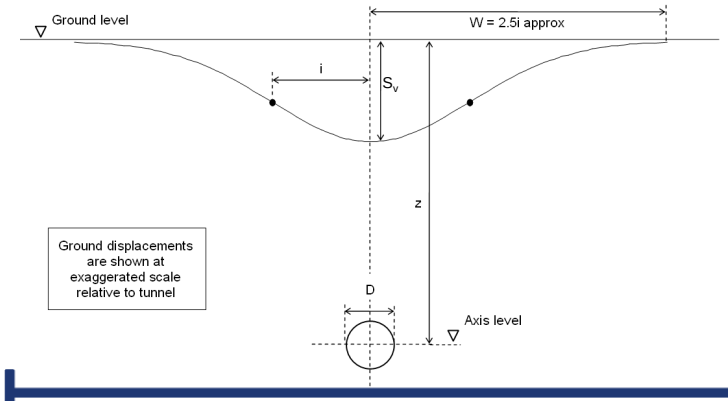
Geotechnical Investigation



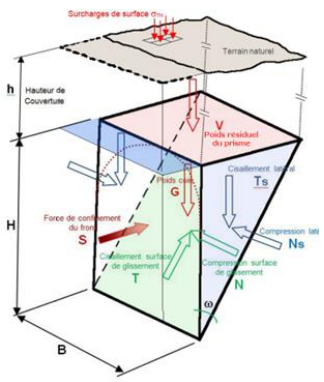
Characteristic Design Parameters

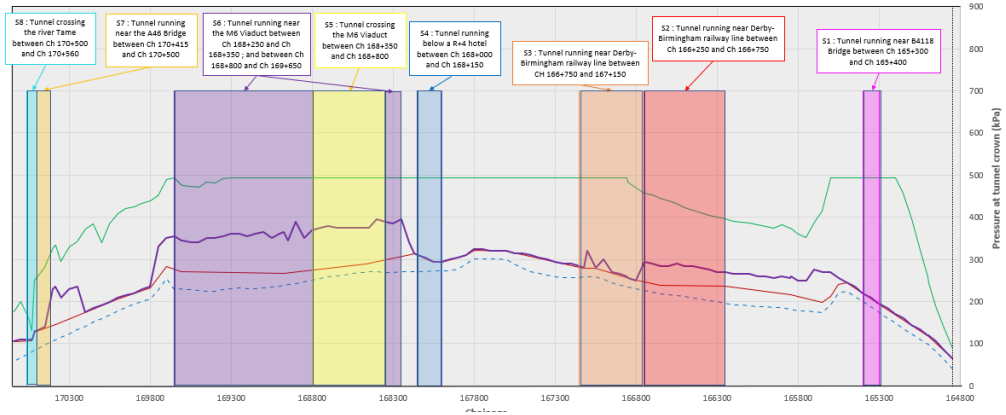
Strata Parameters		Made ground (granular)		Alluvium (cohesive)		River Terrace Deposits		Sidmouth Formation (MMG) Grade IV		Sidmouth Formation (MMG) Grade II&I	
		Inferior	Superior	Inferior	Superior	Inferior	Superior	Inferior	Superior	Inferior	Superior
Unit weight	γ (kN/m³)	19	NR	20.5	NR	21	NR	21	NR	23.5	NR
Undrained shear strength	c_u (kPa)	-	-	50	75	-	-	75+35(z-2) Capped at 200	90+35(z-2) Capped at 215	-	-
Peak angle of shearing resistance	φ'_{pk} (°)	33	37	24	27	32	37	29	31	-	-
Constant volume angle of shearing resistance	φ'_{cv} (°)	33	35	22	25	30	35	27	29	-	-
Cohesion	c' (kPa)	0	0	0	0	0	0	3	7	-	-
In-situ horizontal stress	σ_h (kPa)	-	-	-	-	-	-	42.5z to 15m bgl, below 15m bgl = 637.5+27(z-15)		42.5z to 15m bgl, below 15m bgl = 637.5+27(z-15)	
Coefficient of earth pressure at rest – see note 5 and 11	K_0 (-)	0.5	0.5	0.5	0.5	0.5	0.5	Ko=2.5 to 15m bgl, below 15m bgl Ko= 1.3+18/z		Ko=2.5 to 15m bgl, below 15m bgl Ko= 1.3+18/z	
Drained Young's Modulus (0.01-0.1% Strain)	E' (MPa)	6	10	11	17	25	40	39+18(z-2) Capped at 100 Check against Section 4.3	47+18(z-2) Capped at 110 Check against Section 4.3	500 Check against Section 4.3	500 Check against Section 4.3
Undrained Young's Modulus (0.01-0.1% Strain)	E_u (MPa)	-	-	12.5	19	-	-	45+21(z-2) Capped at 120	54+21(z-2) Capped at 130	-	-
Poisson's ratio	v' (-)	0.35		0.35		0.25		0.3		0.2	
Unconfined Compressive Strength	UCS (MPa)	-	-	-	-	-	-	-	-	2	10
Geological Strength Index	GSI (-)	-	-	-	-	-	-	-	-	45	55
Intact Rock Constant	Mi (-)	-	-	-	-	-	-	-	-	4	7
Disturbance Factor – see note 13	D (-)	-	-	-	-	-	-	-	-	0	0
Permeability	m/s	See Permeability Section 6-11									
Swelling Index and Consolidation parameters		See Swelling and Heave Properties Section 6.10									

Ground Movement Assessment for all critical structures and Utilities within Tunnel Influence Zone



Confinement Pressure Design with Upper and Lower bound Support Pressure





Tailored Design of I&M Systems

For each structure, a **comprehensive, innovative I&M system has been specifically designed and agreed upon with Asset Owners** to:

- **Monitor** the **sensitive elements** of different structures.
- **Serve the needs and specifications** of each asset owner.
- **Safeguard** the various types **of structures** by alerting in case of a breach.
- **Maintain serviceability** throughout the tunnelling and post-construction period.
- **Ensuring** that any **impact** of tunnelling operation is within **design parameters.**

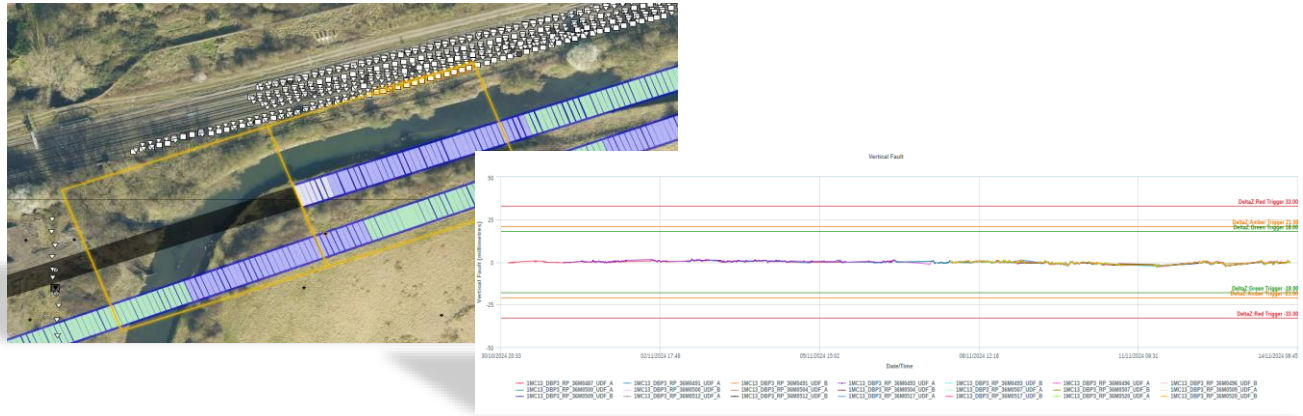
The designed I&M systems include an **automated recording** mechanism, for **timely alerting** of involved parties in case of a breach, followed by a t**raditional manual mechanism** for validation purposes.

Monitoring data presented daily to 3rd Party Asset Owners during crossings

CONTRACT TECHNICAL COMMITTEE (CTC)				
Reference No				
Job	Bromford Tunnel Down			
Site	Sublot 1			
Instrument(s) Triggered AAA Level	Period	20/01/2025 00:00 to 27/01/2025 00:00	Review Status	None
Report Created	27/01/2025 10:01			

SIGNATORIES	
NAME	ORGANISATION

INTERPRETATIVE MONITORING REPORT-SUMMARY	
1. Attendees (by)	
2. Work Progress since last meeting (by)	Jitendra Kumar 16/10/2023 11:48 Refer to CTC Minutes
3. Brief description of monitoring readings (by)	Jitendra Kumar 16/10/2023 11:57 Rod extensometer XR00000: Stable, maximum heave value recorded 3mm. PV00000: Stable pore water pressure in all transducers. Levelling points on electrical slab, LP-ES0061-62-63-64-65: Stable readings, maximum value of heave recorded, ~5mm. First levelling point array: Stable, maximum heave recorded ~5mm. Second levelling point array: Stable, maximum settlement recorded ~3mm.



- Monitoring data are uploaded daily or in real time to the **monitoring database (MissionOS).**
- **TBM** is tracked **live** through monitoring database.
- **Automated email notifications** are sent to concern parties in case of any **trigger breaching.**
- **Daily, SRG** (Shift Review Group) is reviewing all monitoring data associated with TBM
- **Weekly, CTC** (Contract Technical Committee) is reviewing all data and agree on any actions if required.
- In case of **Amber/Red/Black** trigger breaching, Specific **SRG or MAT** (Management Action Team) meeting is called in accordance with **response action plan** to discuss and agree on actions.

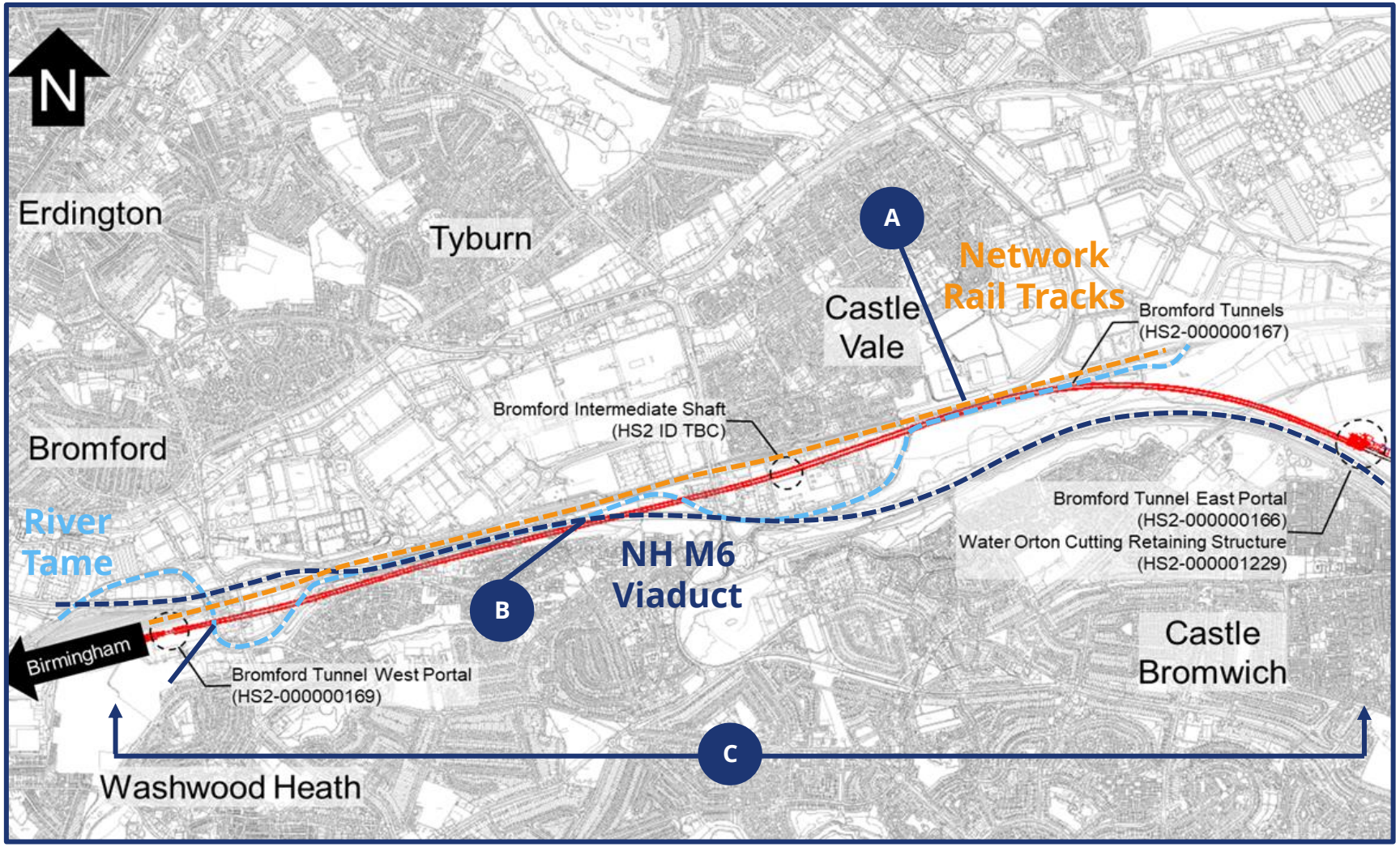
Bromford Tunnel Route - Critical Third-Party Assets

Bromford Tunnel among other utility and environmental assets, is crossing **3 critical structures** owned by major UK's asset owners:

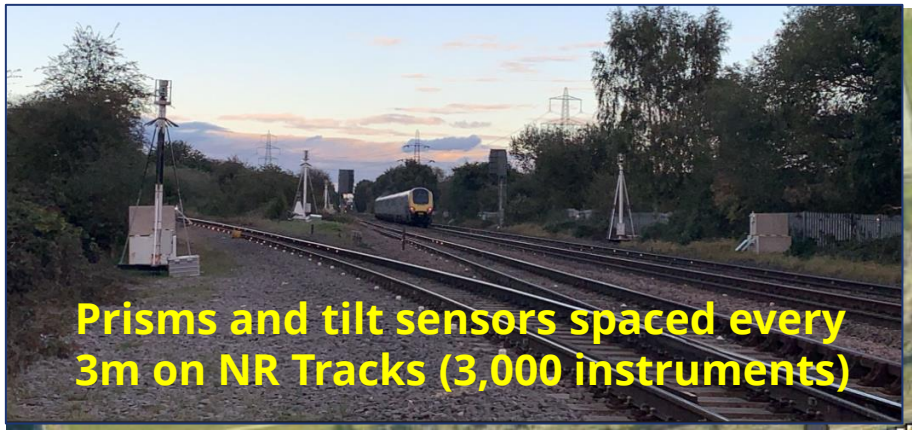
A: Network Rail: A historic Midlands Rail track embankment and a masonry underbridge built in 19th century.

B: National Highways: M6 Bromford Viaduct, the longest UK operational motorway Viaduct, built in 70s.

C: National Grid: Ten (10) lattice steel towers supporting high-voltage cables built in 70's.

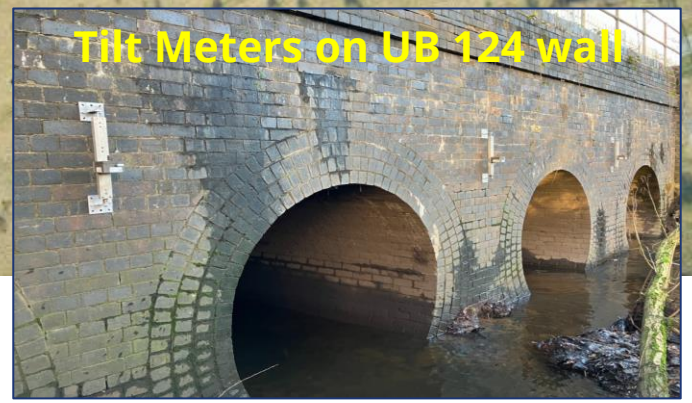


Network Rail Instrumentation & Monitoring

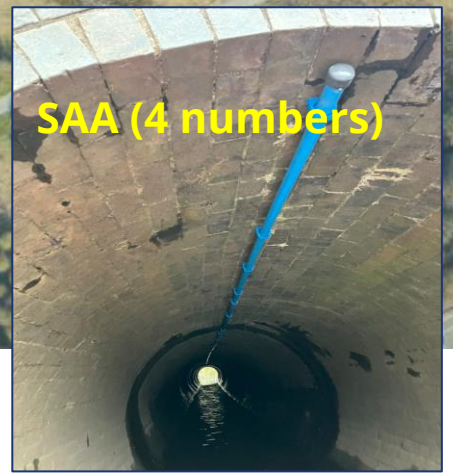


Prisms and tilt sensors spaced every 3m on NR Tracks (3,000 instruments)

Gateway



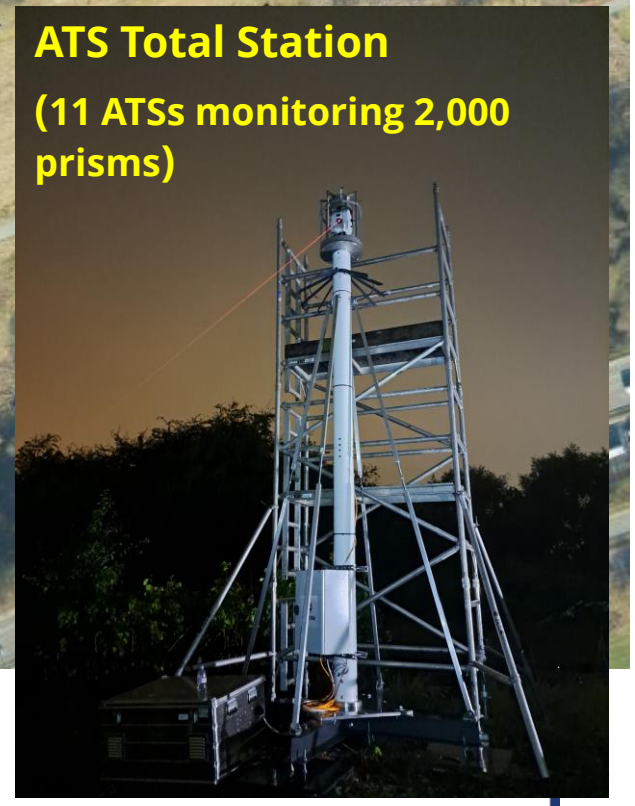
Tilt Meters on UB 124 wall



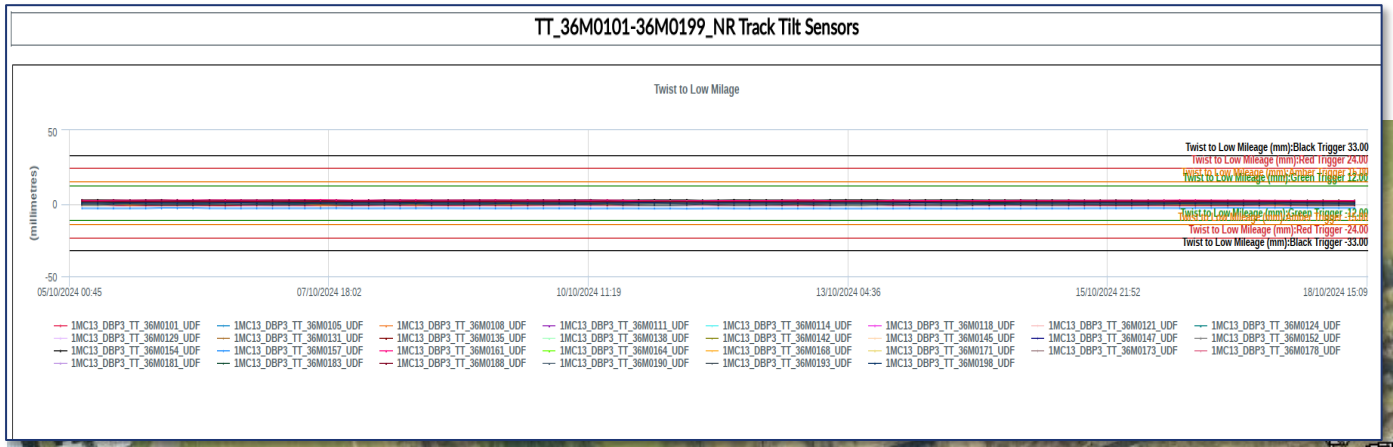
SAA (4 numbers)

ATS Total Station

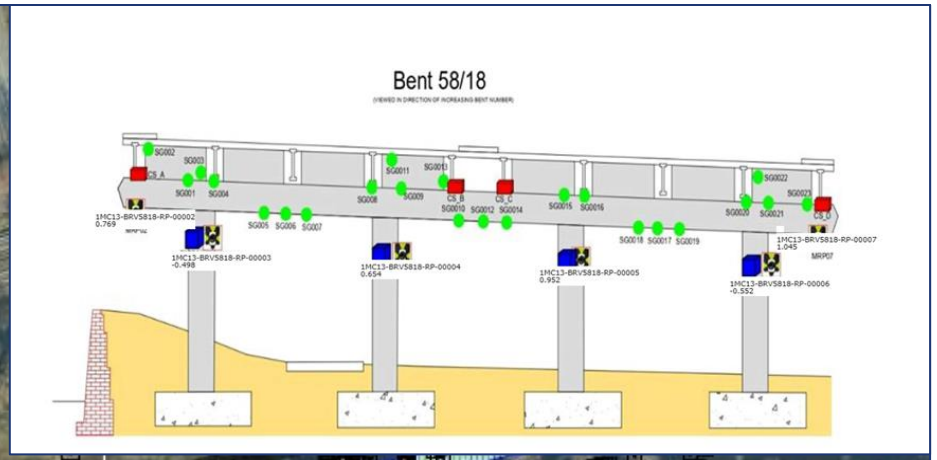
(11 ATSs monitoring 2,000 prisms)



Network Rail Instrumentation & Monitoring



M6 Viaduct: Structural Monitoring Instrumentation



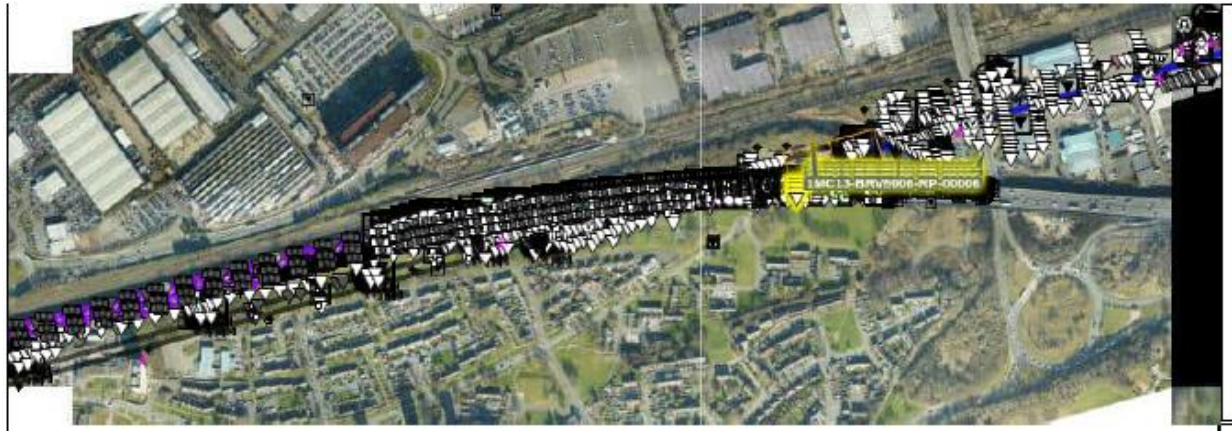
Automatic Total Station (ATS)

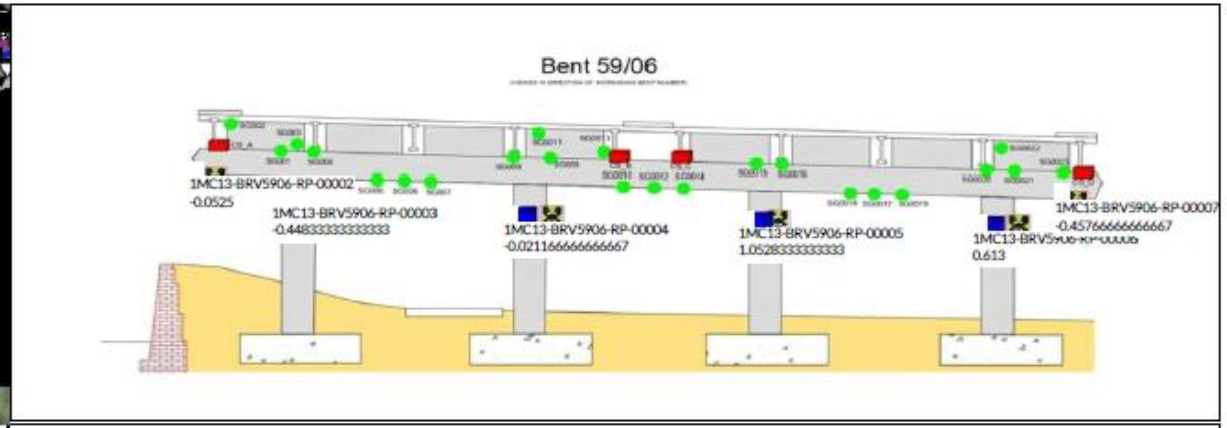
Column Prism

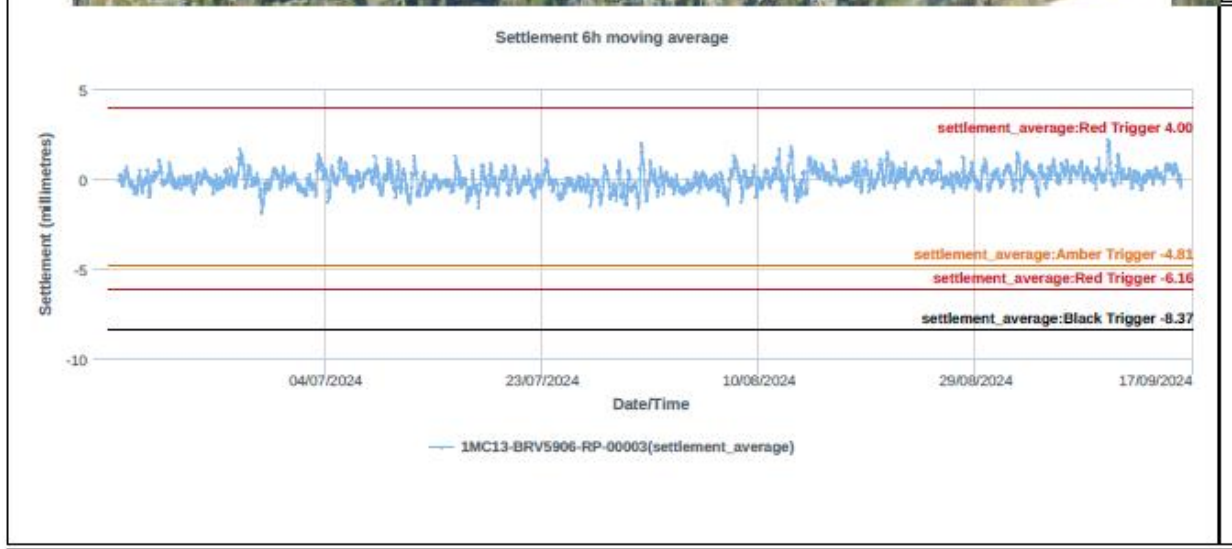
GPS Fixed Point

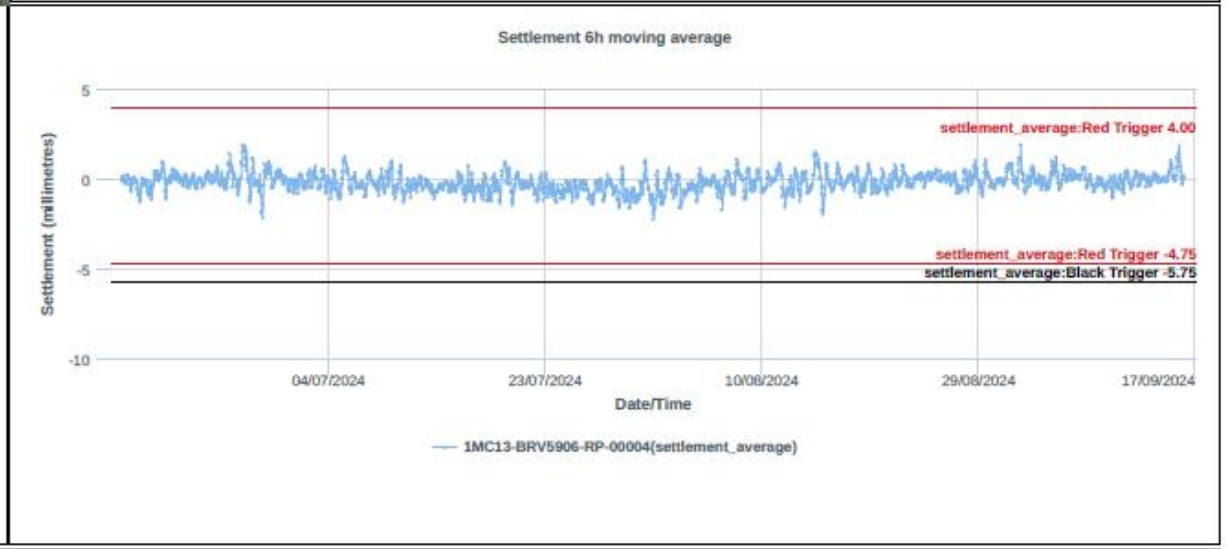
Bar-Coded Strip

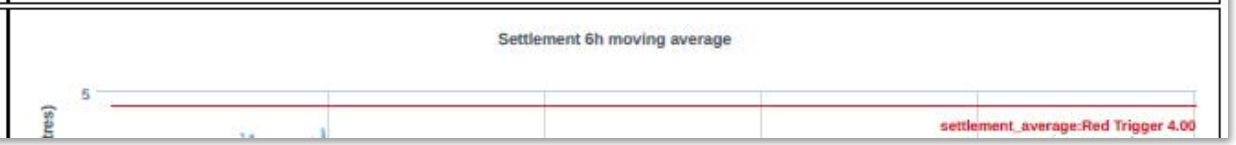
National Highways M6 Viaduct Instrumentation & Monitoring





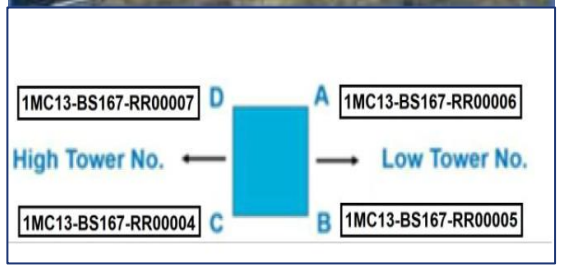




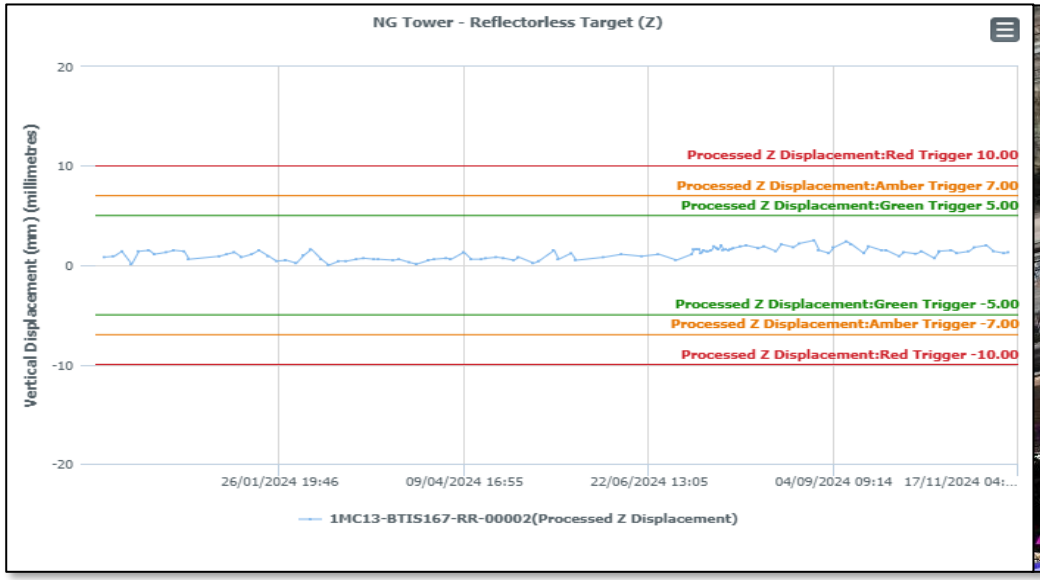


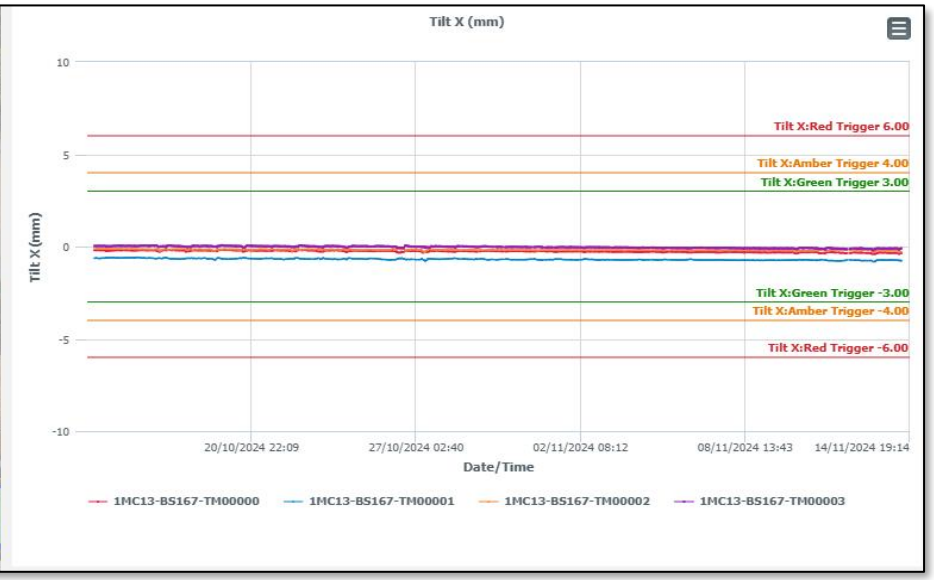
National Grid Pylons Instrumentation

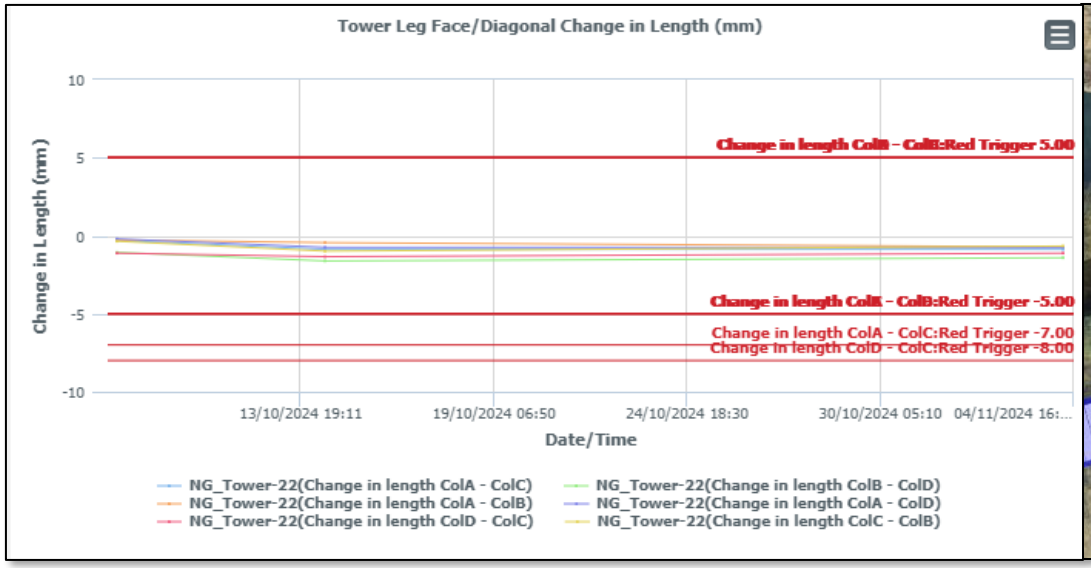
- Precise Manual levelling with Retro Reflective Targets or Levelling studs installed on each leg.
- Automatic Monitoring with Triaxial Tilt Meters on each leg.

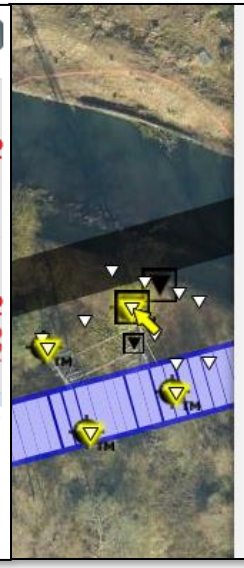


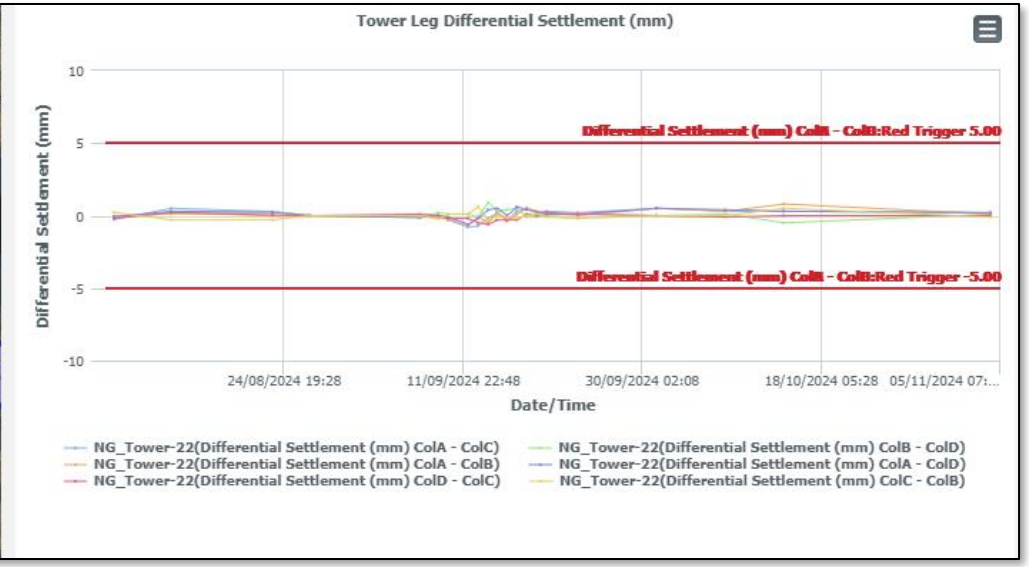
National Grid Pylons Instrumentation



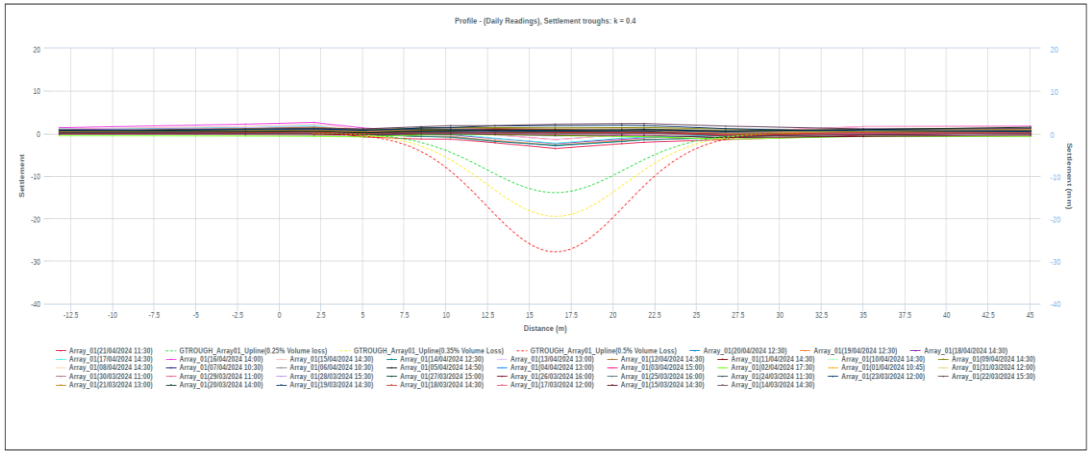


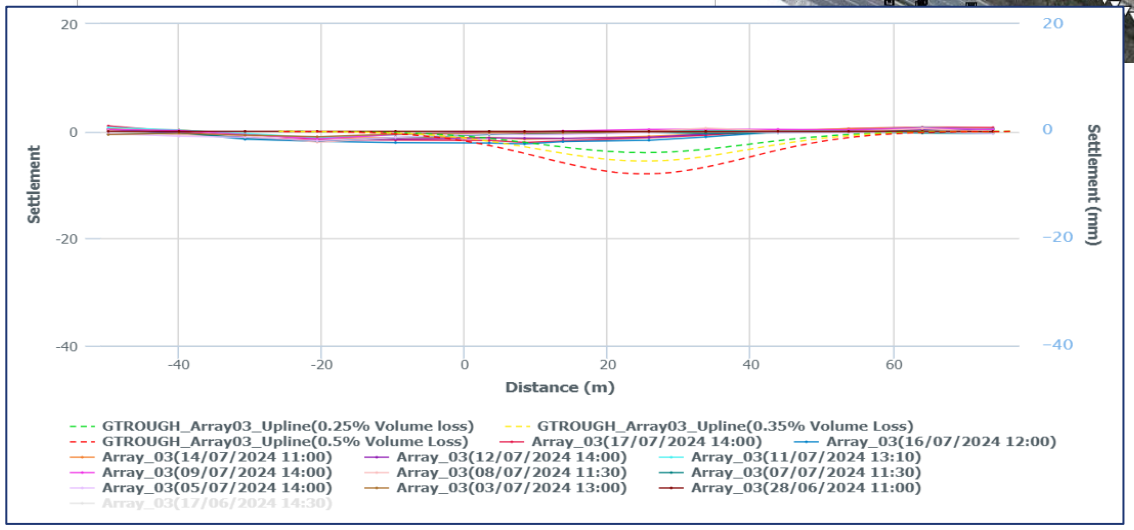


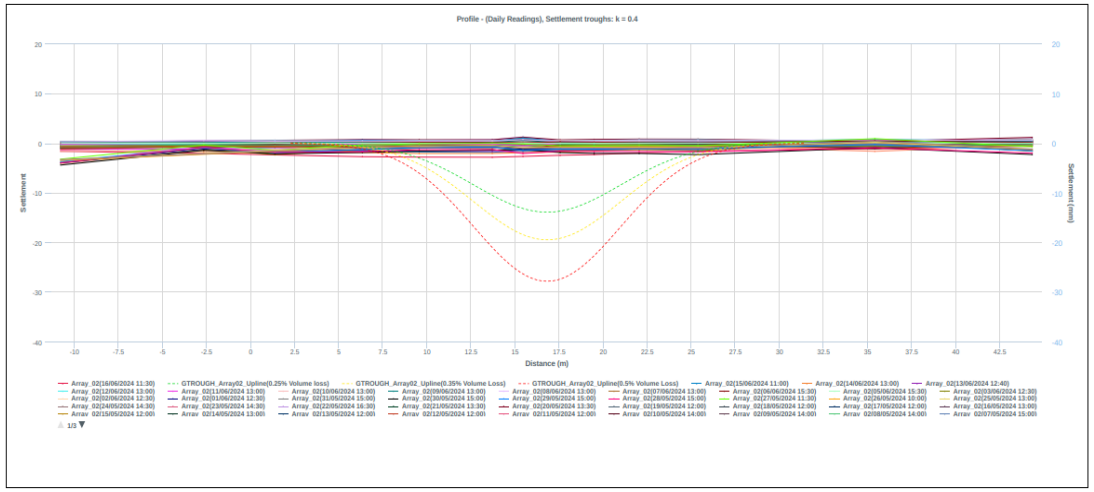




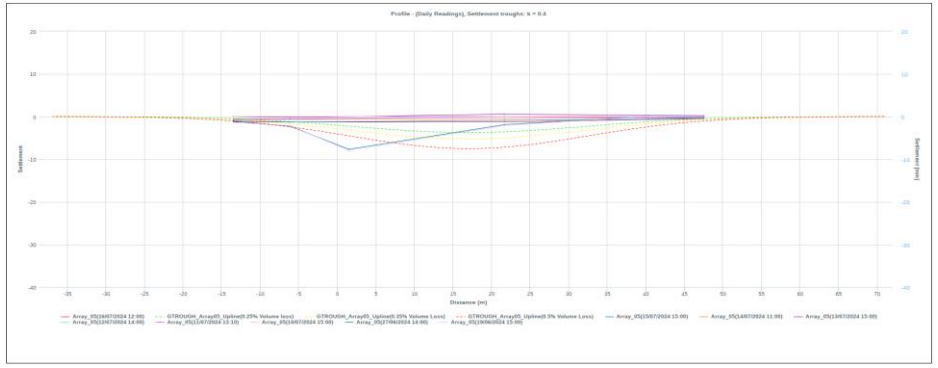
Greenfield levelling readings at TBM launching area - VL~0.10%

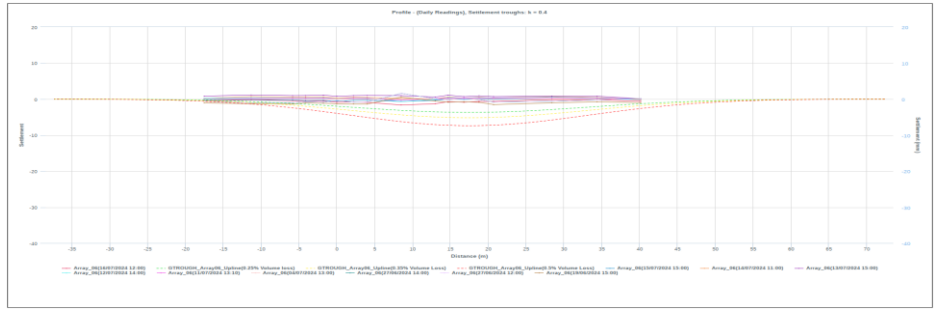


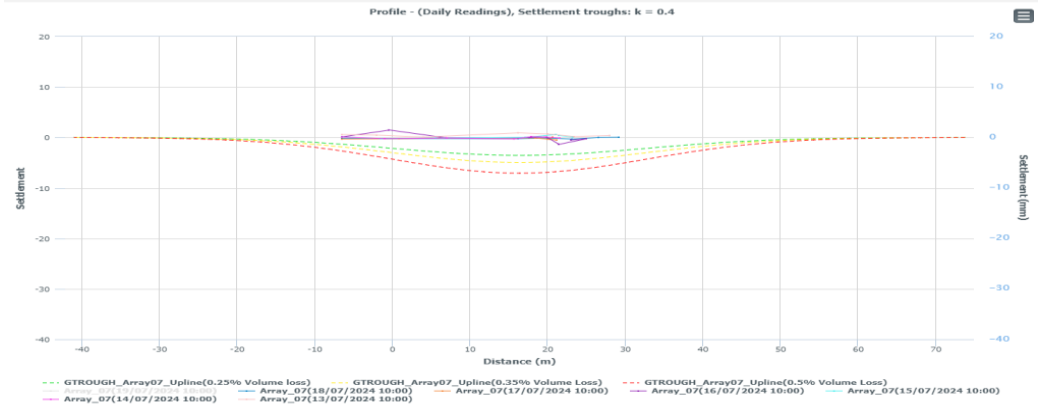


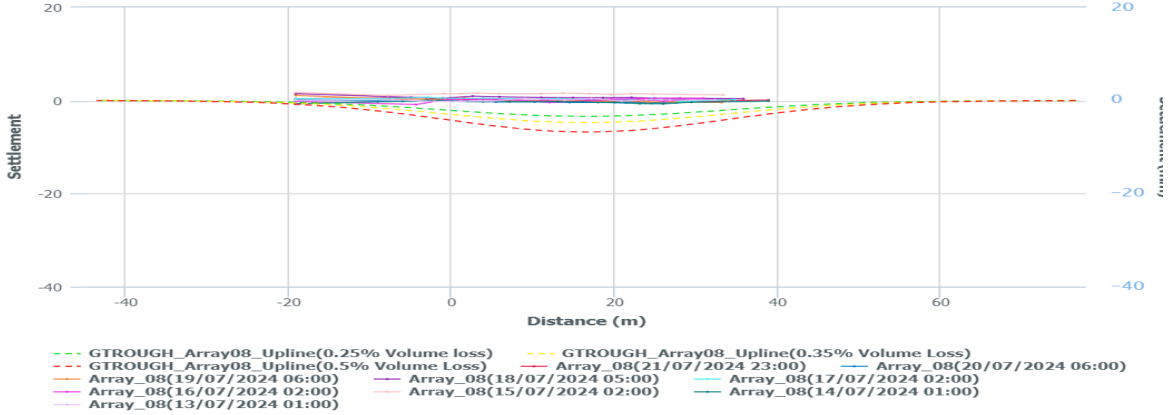


Greenfield levelling readings at TBM Verification Zone - VL~0.10%

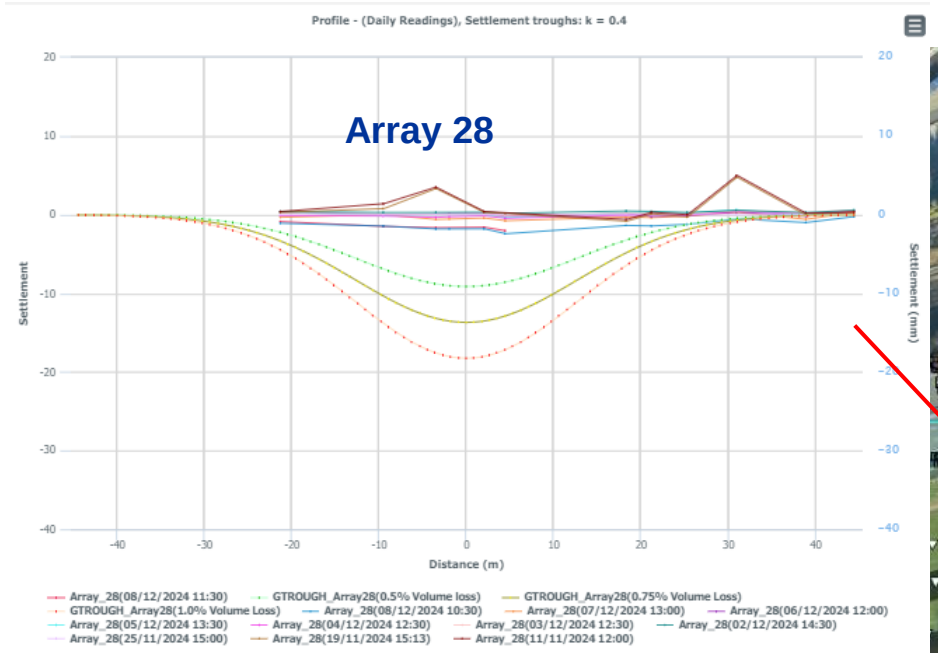


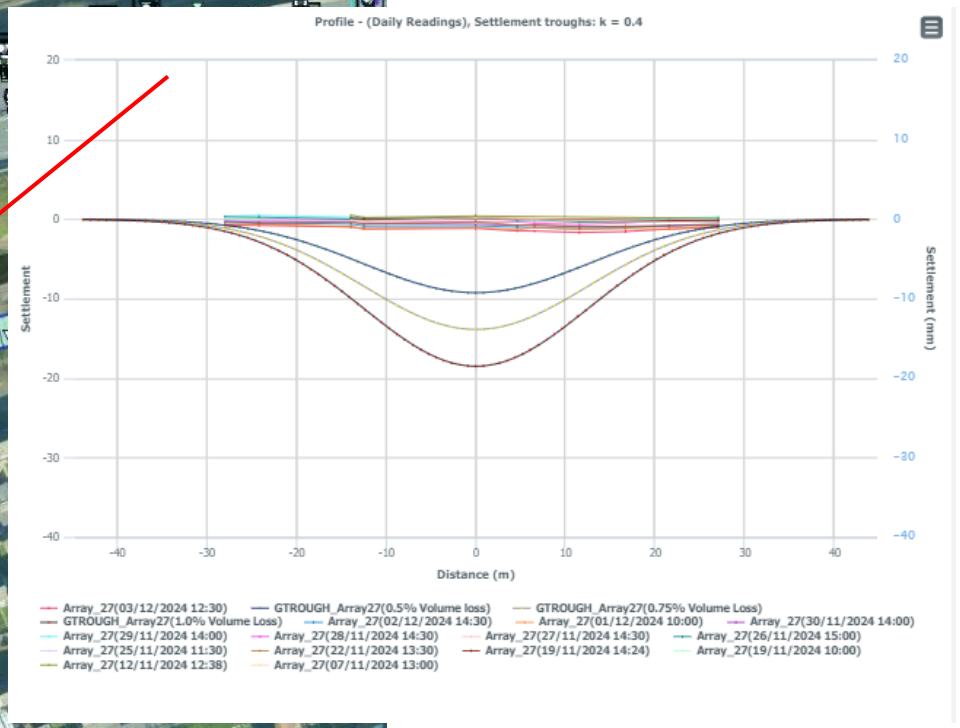






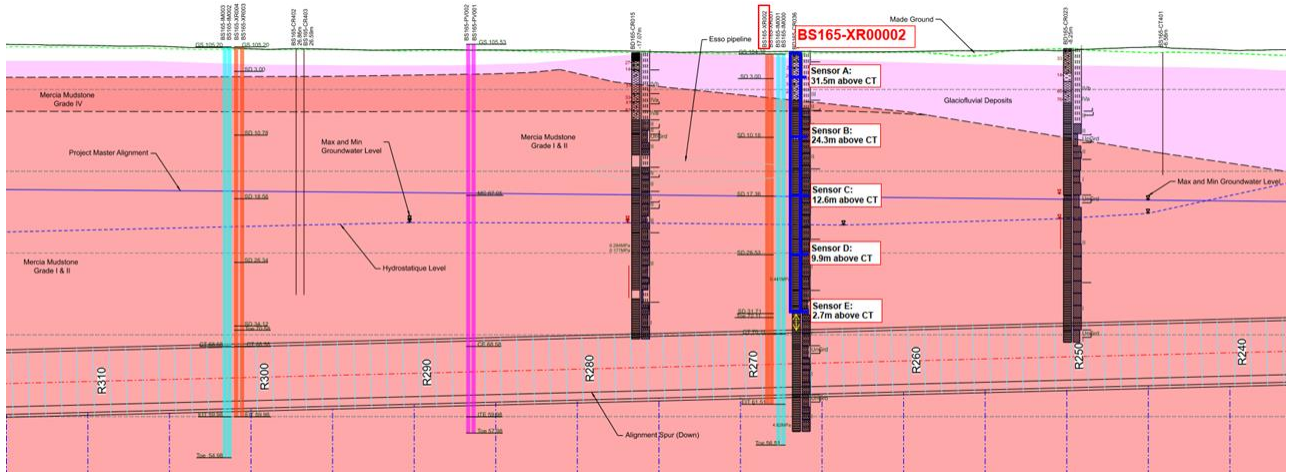
Greenfield levelling readings at TBM after M6 Viaduct area - VL~0.10%



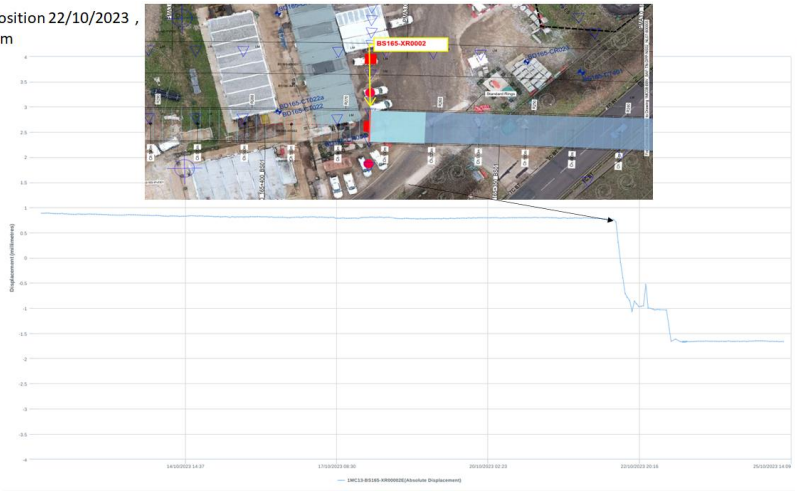


Extensometers Recorded Impact during Tunnelling

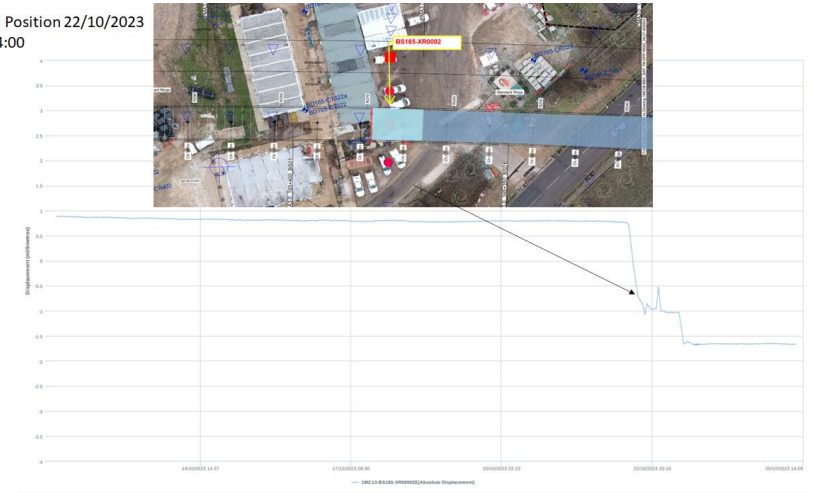
BS165-XR002: Vertical Ground Displacement from TBM



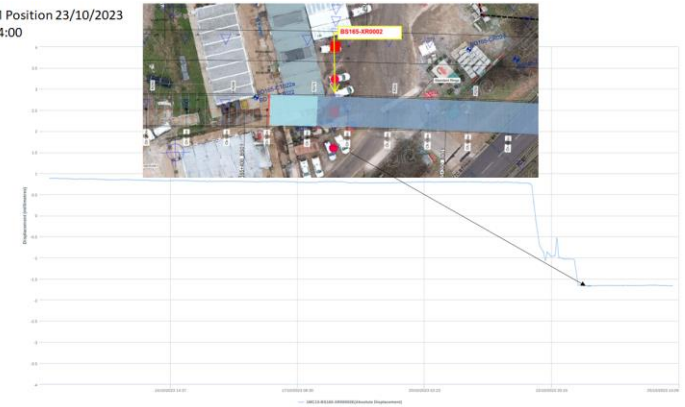
TBM Position 22/10/2023 , 10:15am



TBM Position 22/10/2023 at 14:00

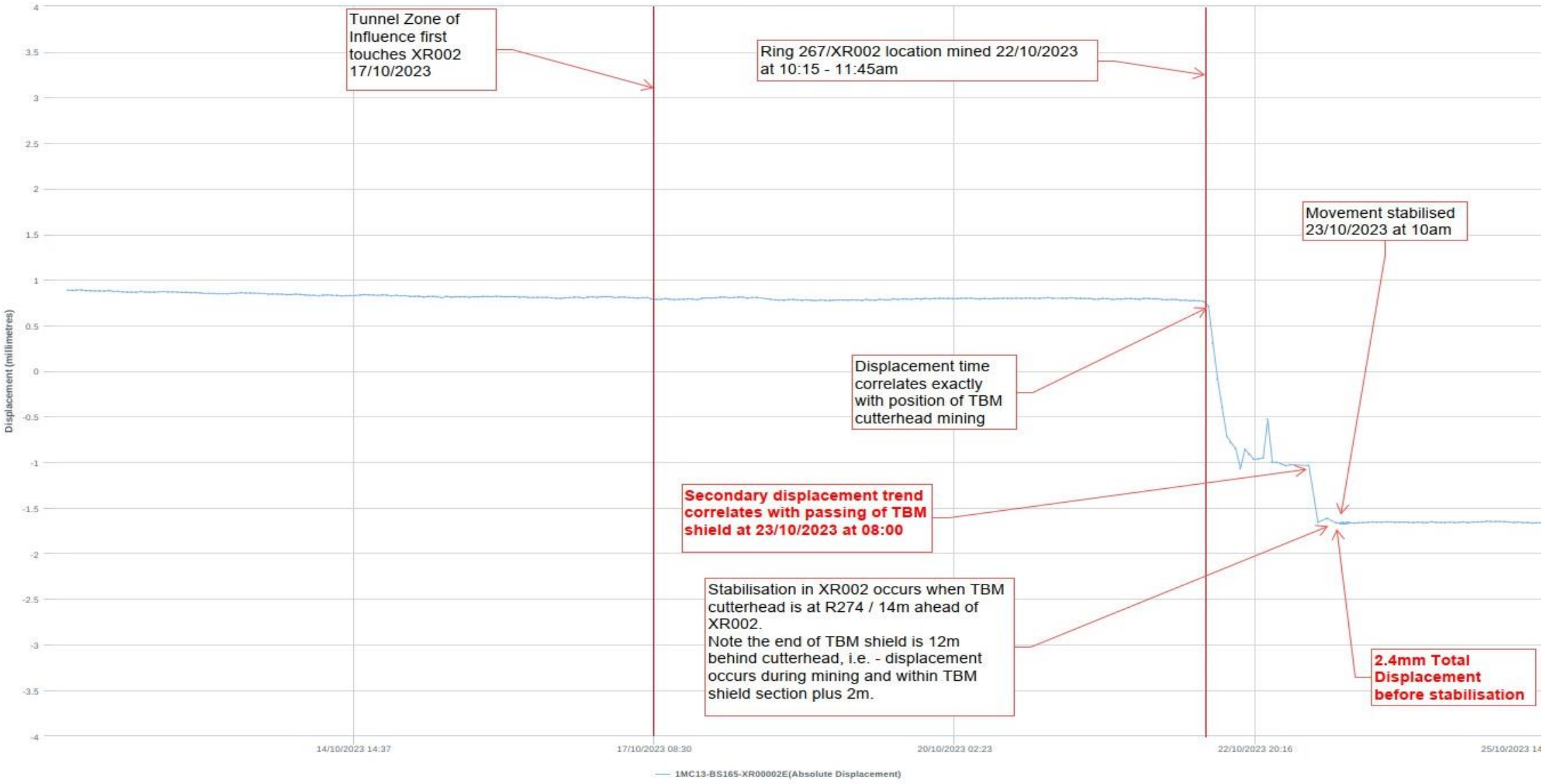


TBM Position 23/10/2023 at 14:00



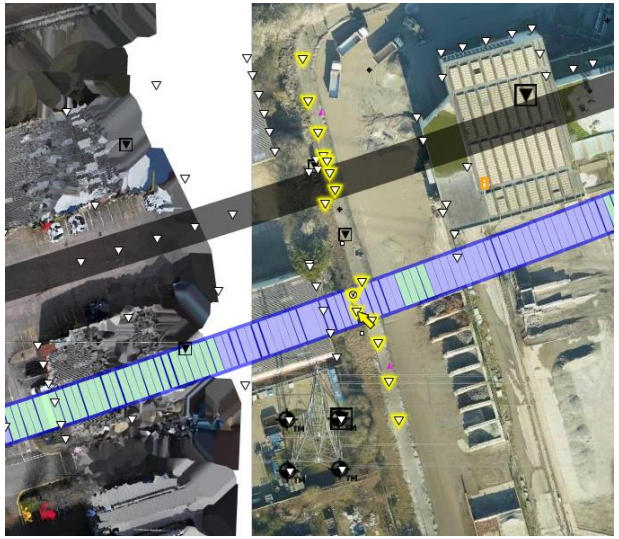
Extensometers Recorded Impact during Tunnelling

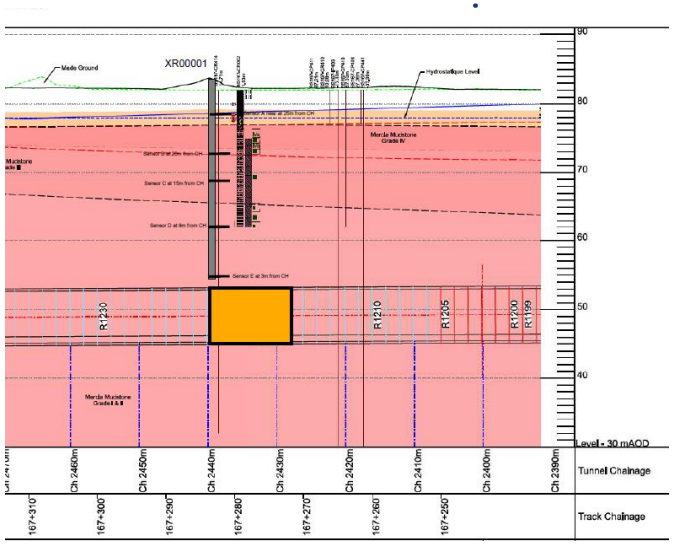
BS165-XR0002: Vertical Ground Displacement during TBM crossing

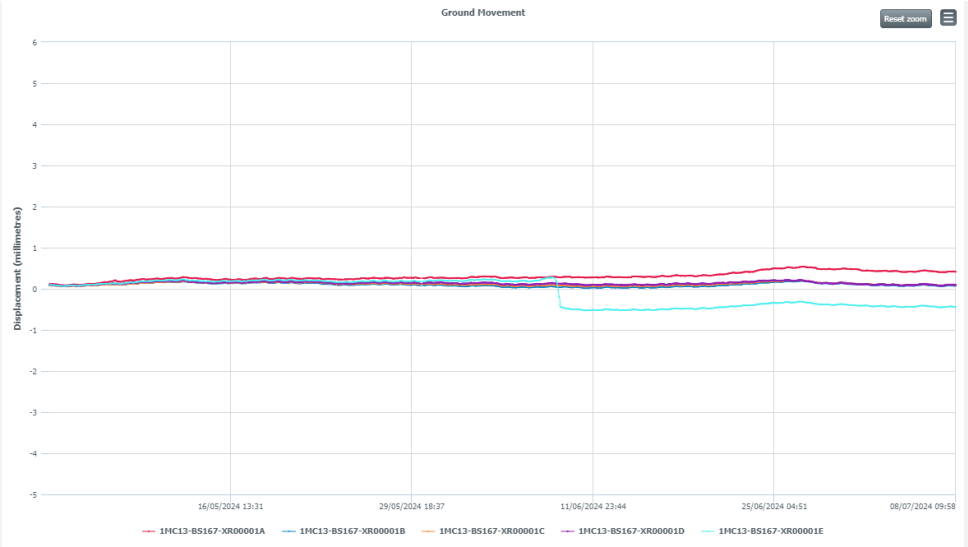


Extensometers Recorded Impact during Tunnelling

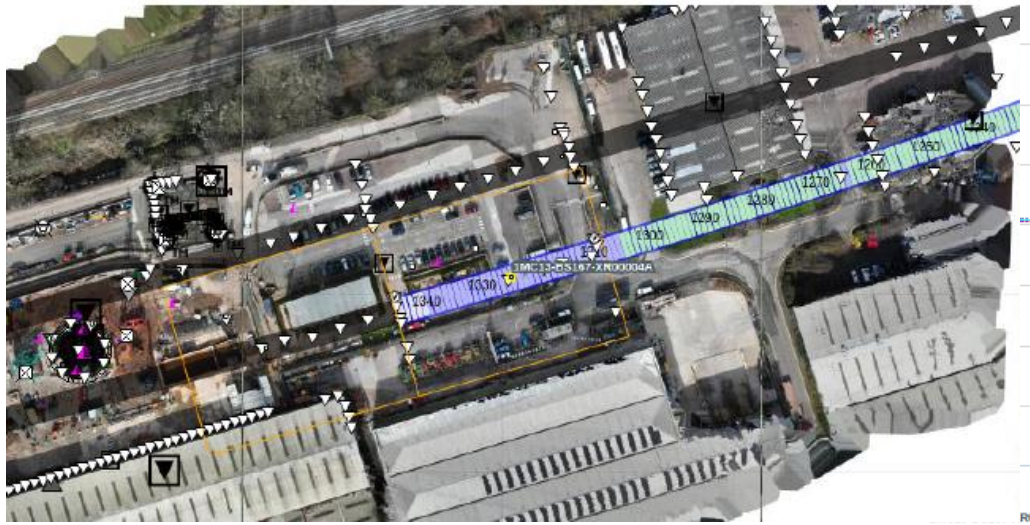
BS167-XR00012: Vertical Ground Displacement during TBM

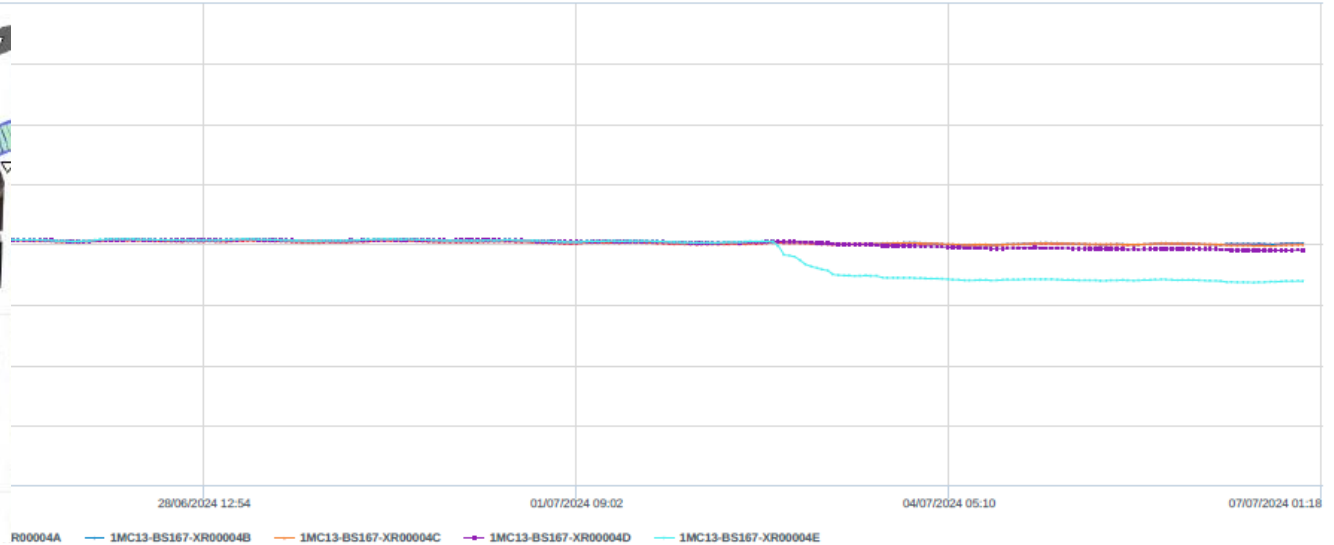






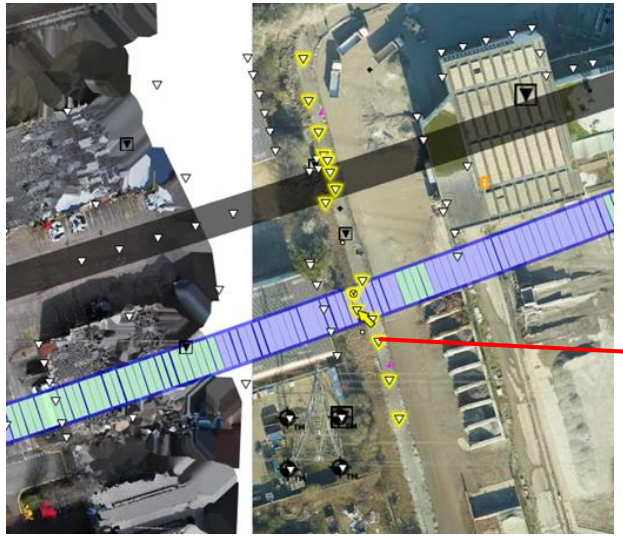
BS167-XR0004: Vertical Ground Displacement from TBM

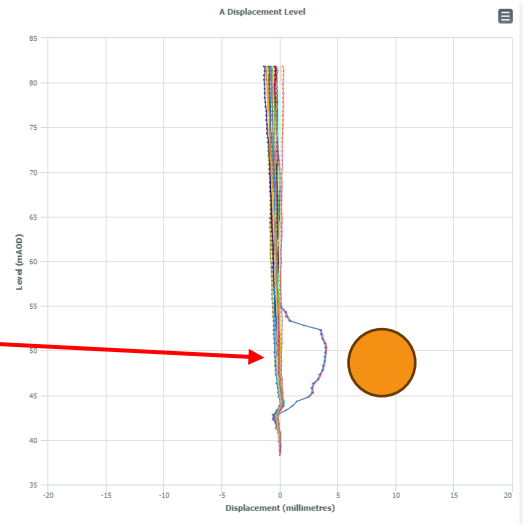




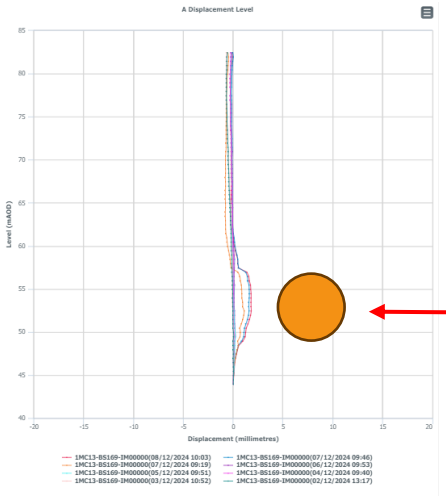
Inclinometers Recorded Impact during Tunnelling

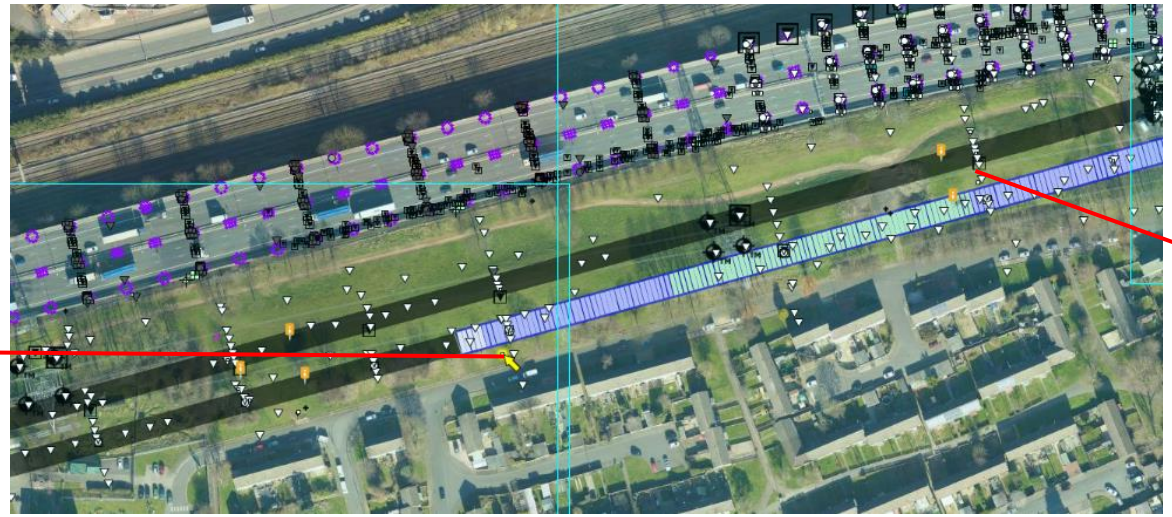
Lateral Ground Displacement during TBM crossing

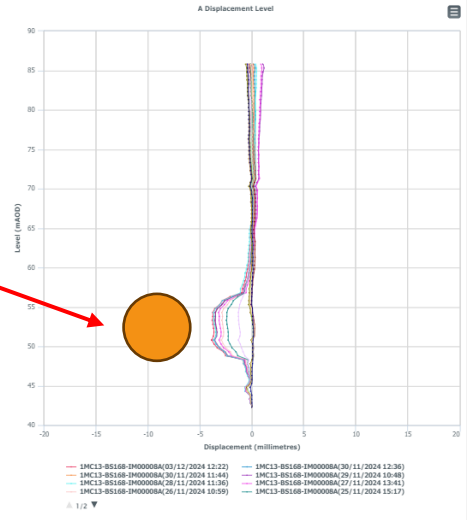




Indicative TBM Level







Conclusions

- The **case history from LIW tunnel** has successfully demonstrated that Design approach and Tunnelling excavation process were **suitable for controlling ground movements**.
- Experience from LIW tunnel **shared** by Tunnel teams to improve even more the performance along the longer and **more critical Bromford tunnel**.
- A **robust Monitoring Instrumentation arrangement** has been installed along **Bromford** tunnel to confirm ground movement performance.
- So far monitoring readings verifying **no structural impact and Volume Loss (VL%),** less than assumed on GMA design reports and HS2 standards for 3rd party assets.
- **Bromford TBM**, crosses already **successfully** and with minimum impact the major critical assets of **M6 viaduct**, **National Grid Towers**, **River Tame Crossings** and **Network Rail embankment**.
- TBM Cutterhead Interventions and SCL Cross Passage **Excavation inspection records** provide a very valuable geological, hydrogeological and geotechnical information of the Mercia Mudstone Group of strata.
- A **back analysis** of the ground movement **monitoring data**, collected during tunnelling activity, can be used to **optimized tunnelling assumptions and mining operation parameters**.
- As there is a **limited tunnelling experience in the Midlands area**, the available ground monitoring data through the **HS2 project**, would be a useful information for a future reference, on **upcoming construction projects**, planned to be built in the **Mercia Mudstone formation**.


Thank you...
Any Questions ?