Safety and control in underground construction: The importance of instrumentation and monitoring

Richard Marshall

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Why use instrumentation?

- Unnecessary expense?
- No-one ever looks at the data
- The equipment never works properly
- It gets in the way
- It gives too many false alarms
- It’s never in the right place
- It doesn’t give me confidence

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Why use instrumentation?

- Can you afford not to have it?
- What if the data is well presented?
- What if the monitoring programme is well planned, efficiently installed and controlled by reliable people who gave you confidence?

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Can you afford not to monitor?

- Underground construction in congested cities pushing the boundaries of technology
- Construction work is expected to be carried out safely
- Responsible people now being prosecuted for criminal negligence
- 3rd party asset owners will not accept damage to their properties
- Safety of members of the public and safe operation of adjacent transport systems is of paramount importance

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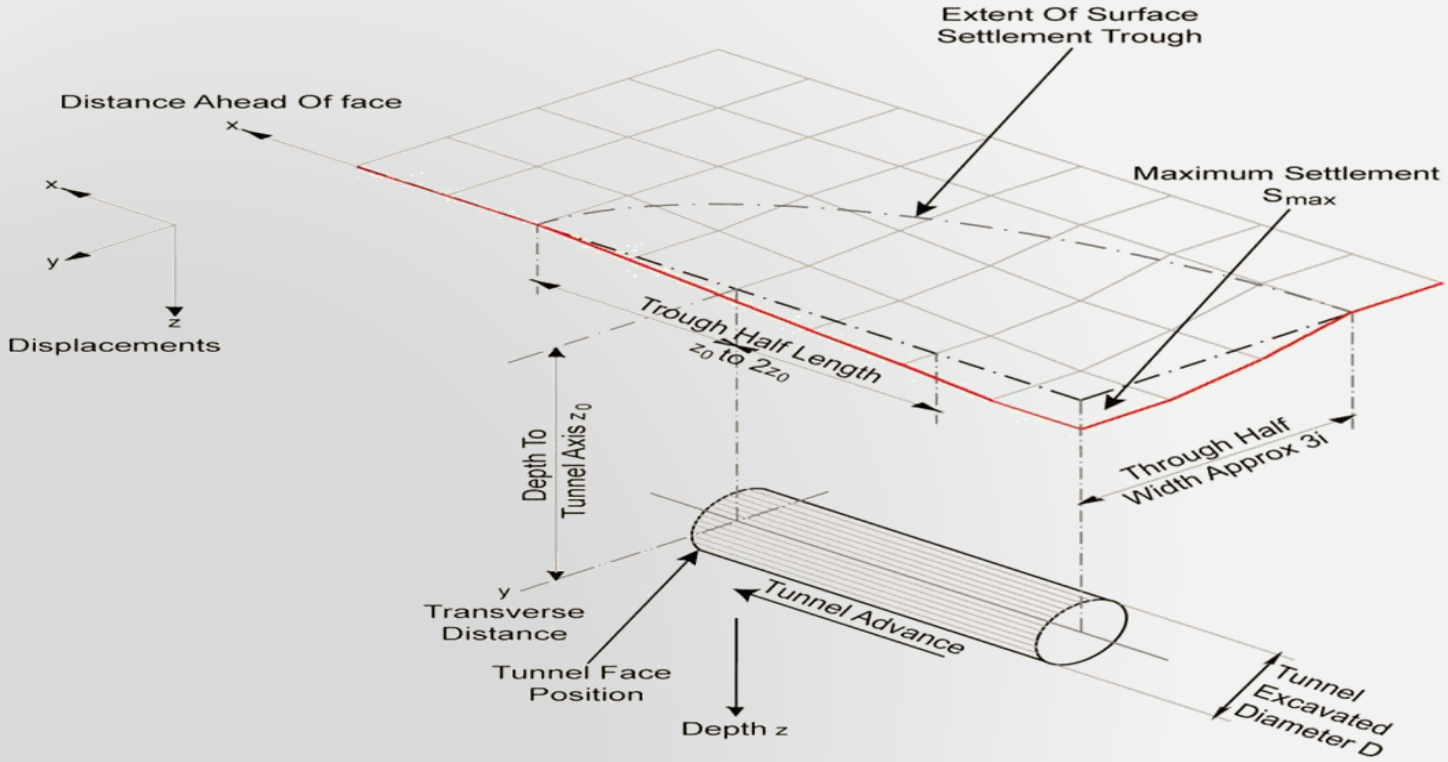
Settlement Predictions due to Tunnelling



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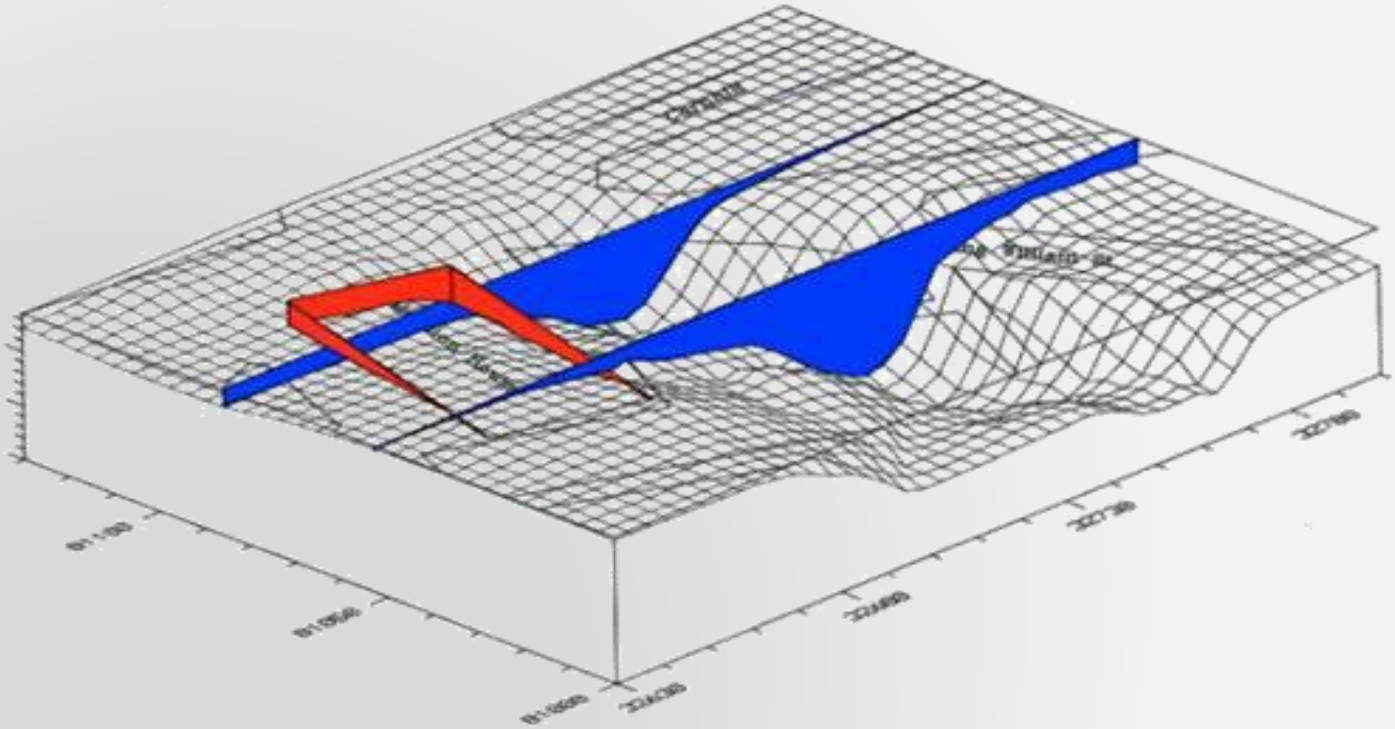
Effects of Settlement due to Tunnelling



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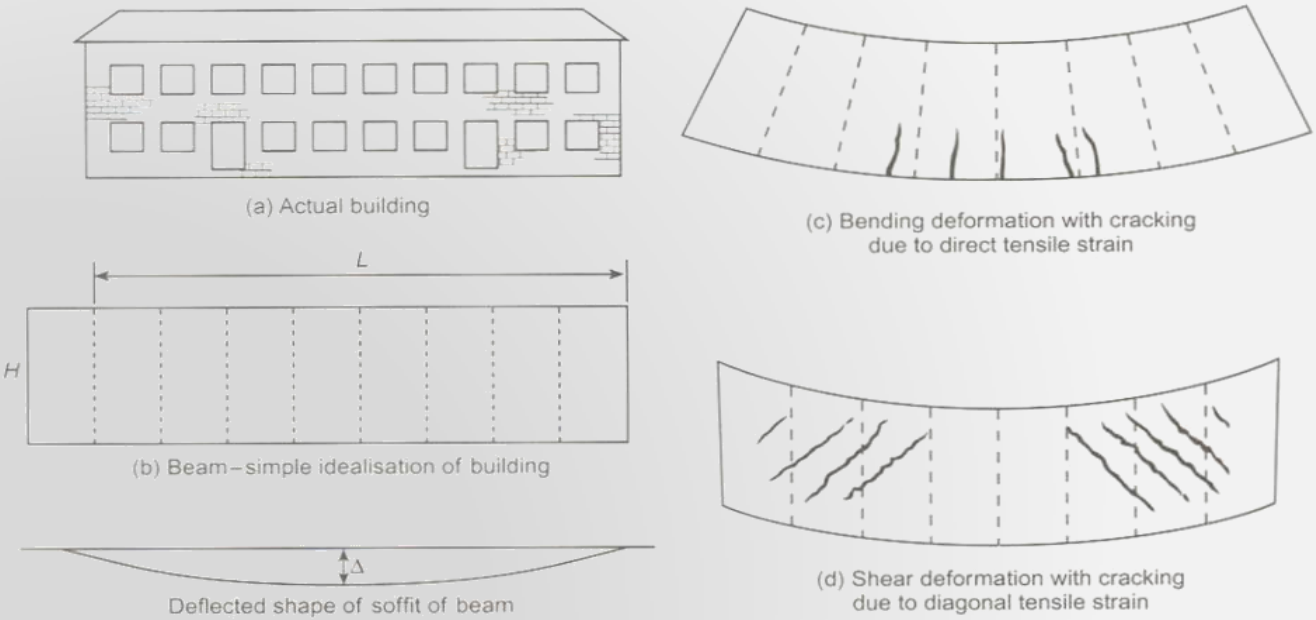
Effects of Settlement due to Tunnelling



Cracking of a simple beam in bending and in shear

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Effects of Settlement due to Tunnelling!

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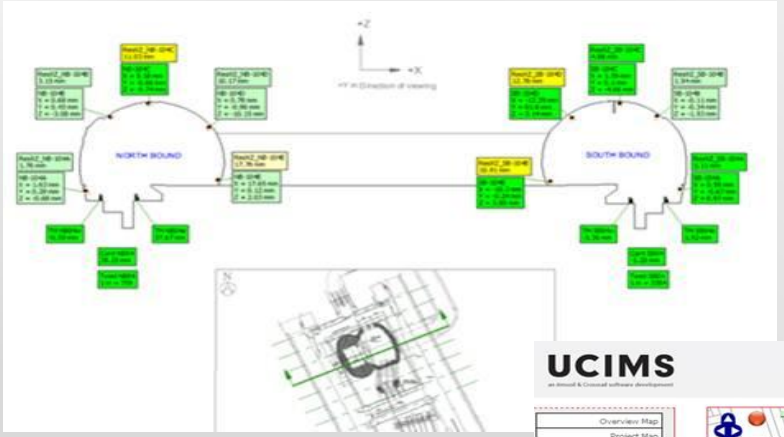
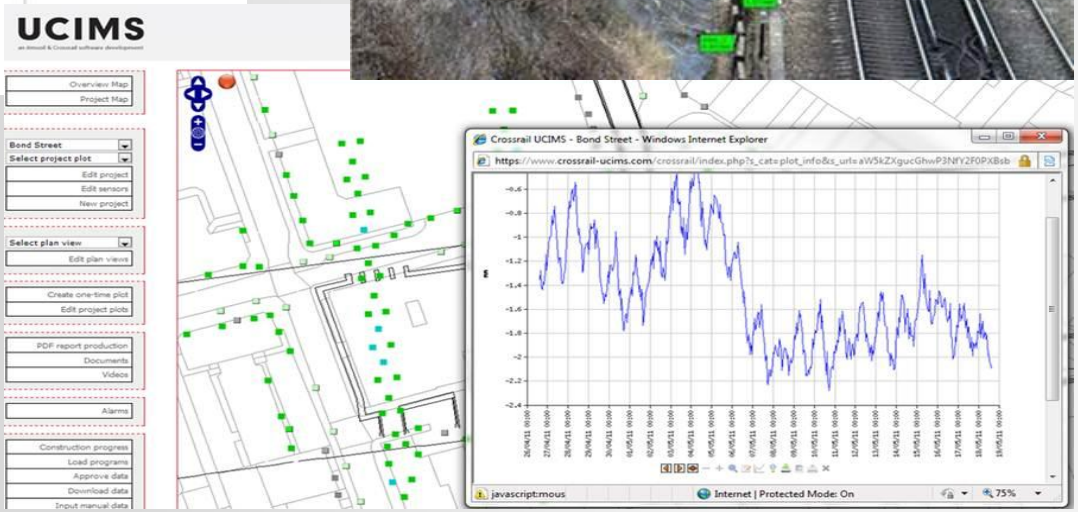
What if the data is well presented?





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What if the monitoring programme is well planned, efficiently installed and controlled by reliable people who gave you confidence?

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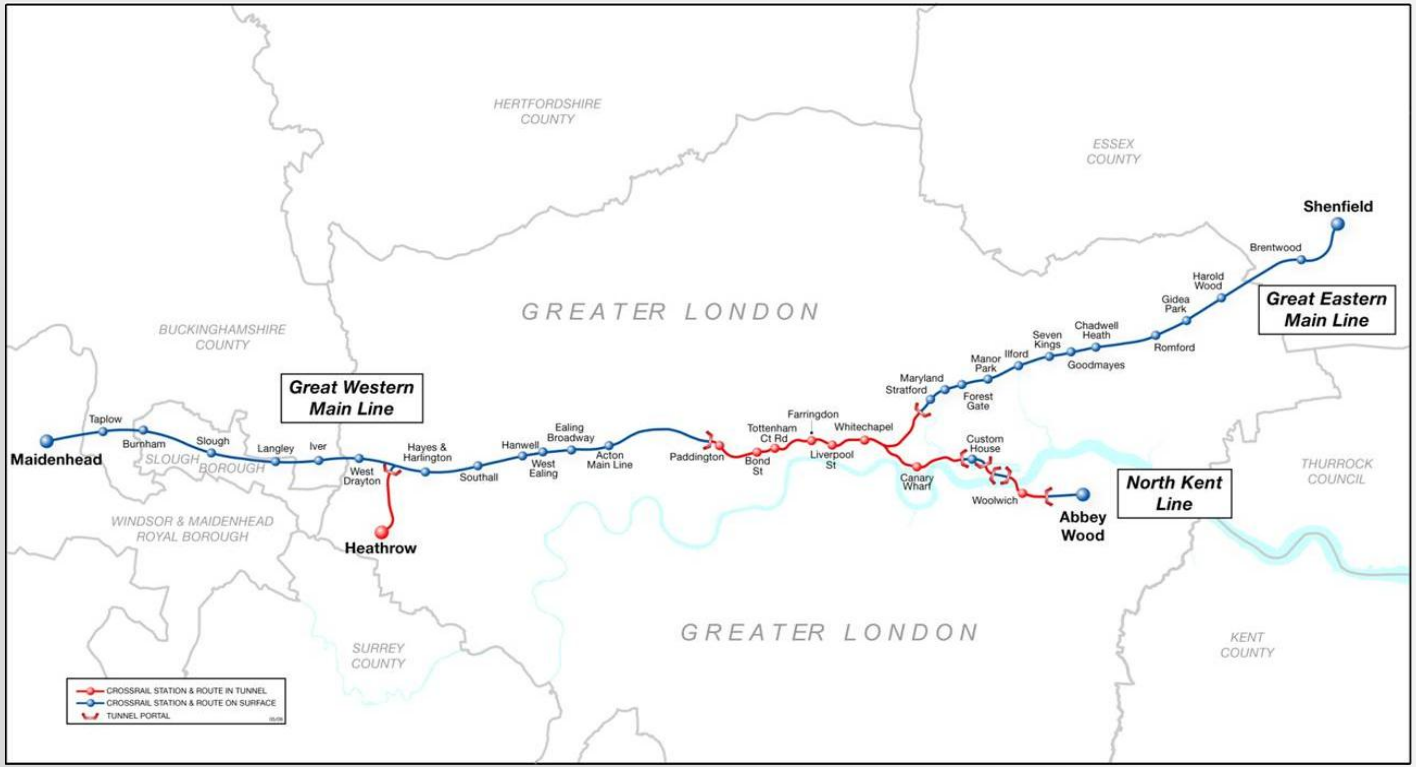
Project Route



Project Overview

- **118km** railway line through London
- **38** new stations
- **200M** passenger journeys a year
- **Cost: £16bn** Europe's largest civil engineering project

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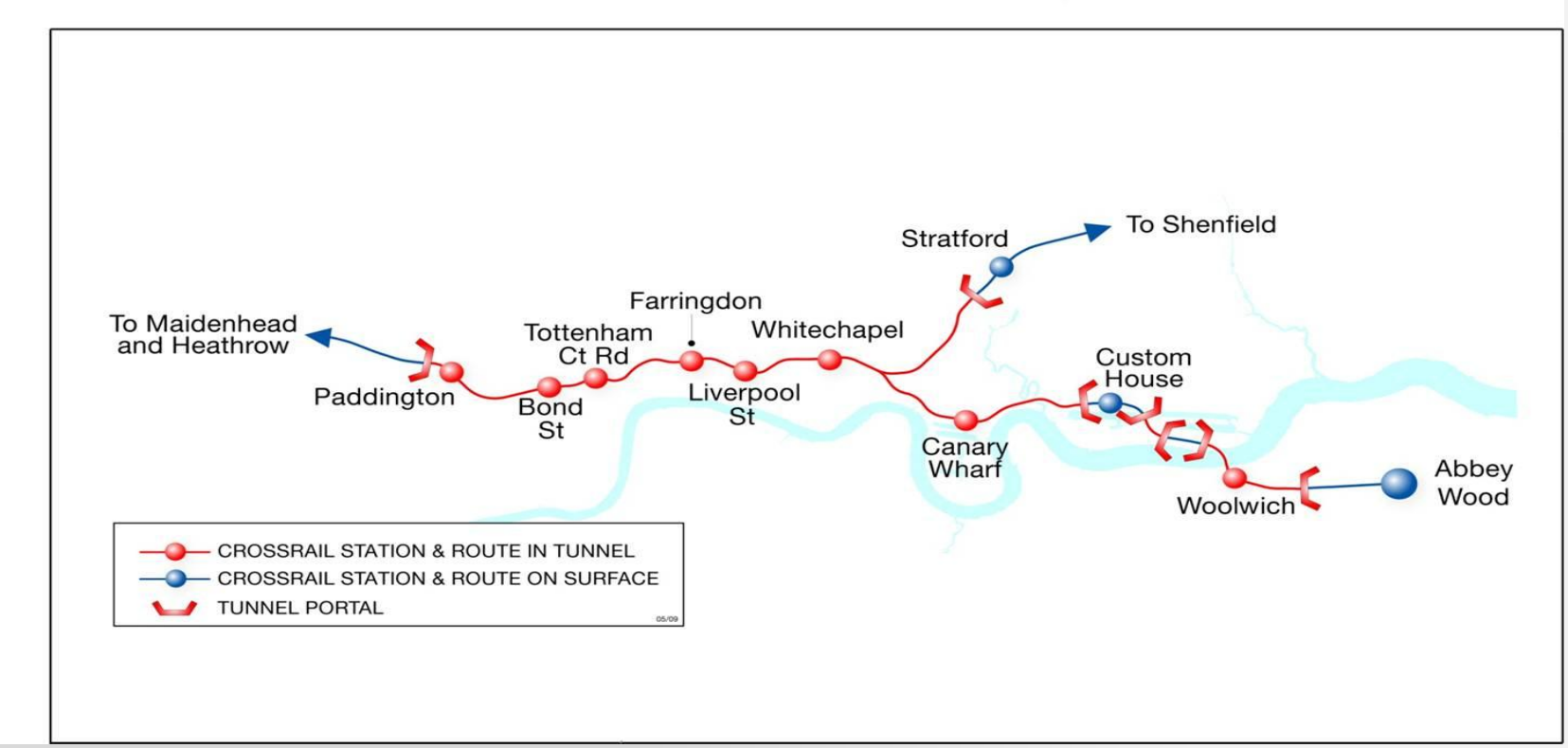
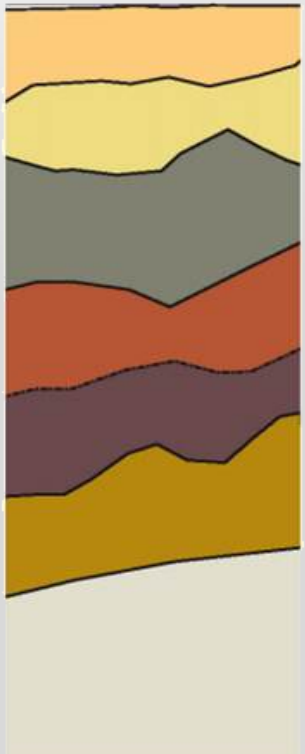
Project Route (Central)



London Geology



Superficial Geology

Made Ground - Typically 2m or 3m in thickness, it is formed by human activity.
Alluvium - Typically 2-4m thick, locally up to 11 m. These are flood plain clays.

River Terrace Deposits - Typically between 2m and 4m in thickness. Layers of sand and gravel were formed during the previous ice ages by snow melting across a wide plain.

Solid Geology Sequence

London Clay - This 55-million-year-old stiff blue grey variably sandy clay is up to 80m thick that contains pyrites (Fools Gold) and charcoal fragments.

Lambeth Group - Typically 15m thick. These beds of sand and clay were deposited in a tropical environment with mangrove swamps covering west London changing to an estuary in east London.

Thanet Sand Formation - The thickness varies from 5m in west London to 15m in east London and Kent. This was formed in a shallow marine delta sand which is fine, soft and light grey.

Chalk Group - the oldest layers that are exposed in the London area. It is formed from the skeletons of millions of tiny sea creatures that built up over time and is about 70 million years old at the top.

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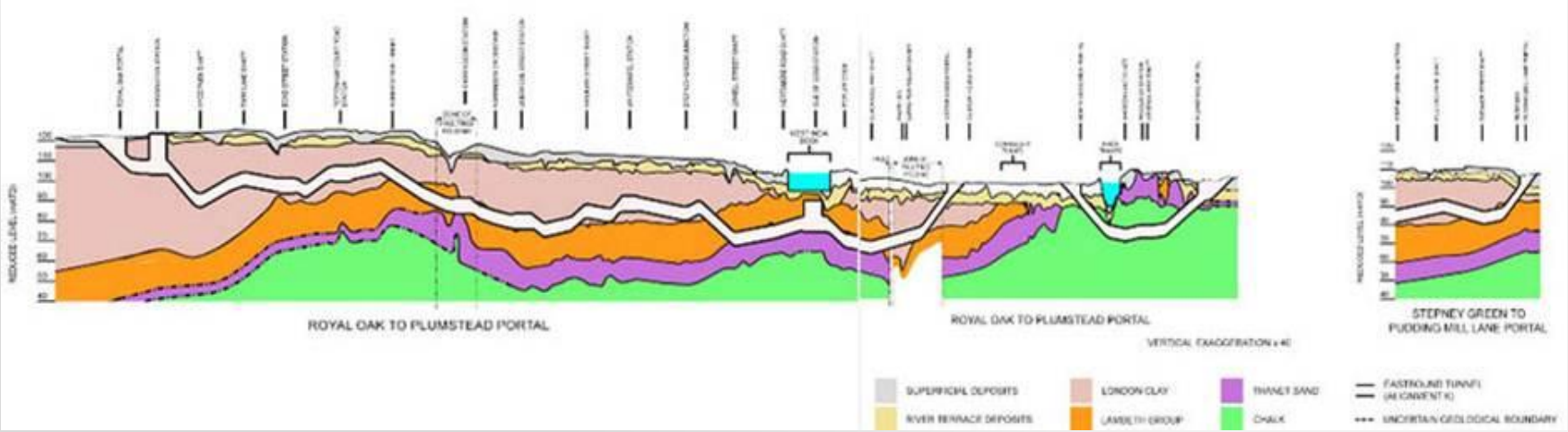
London Geology



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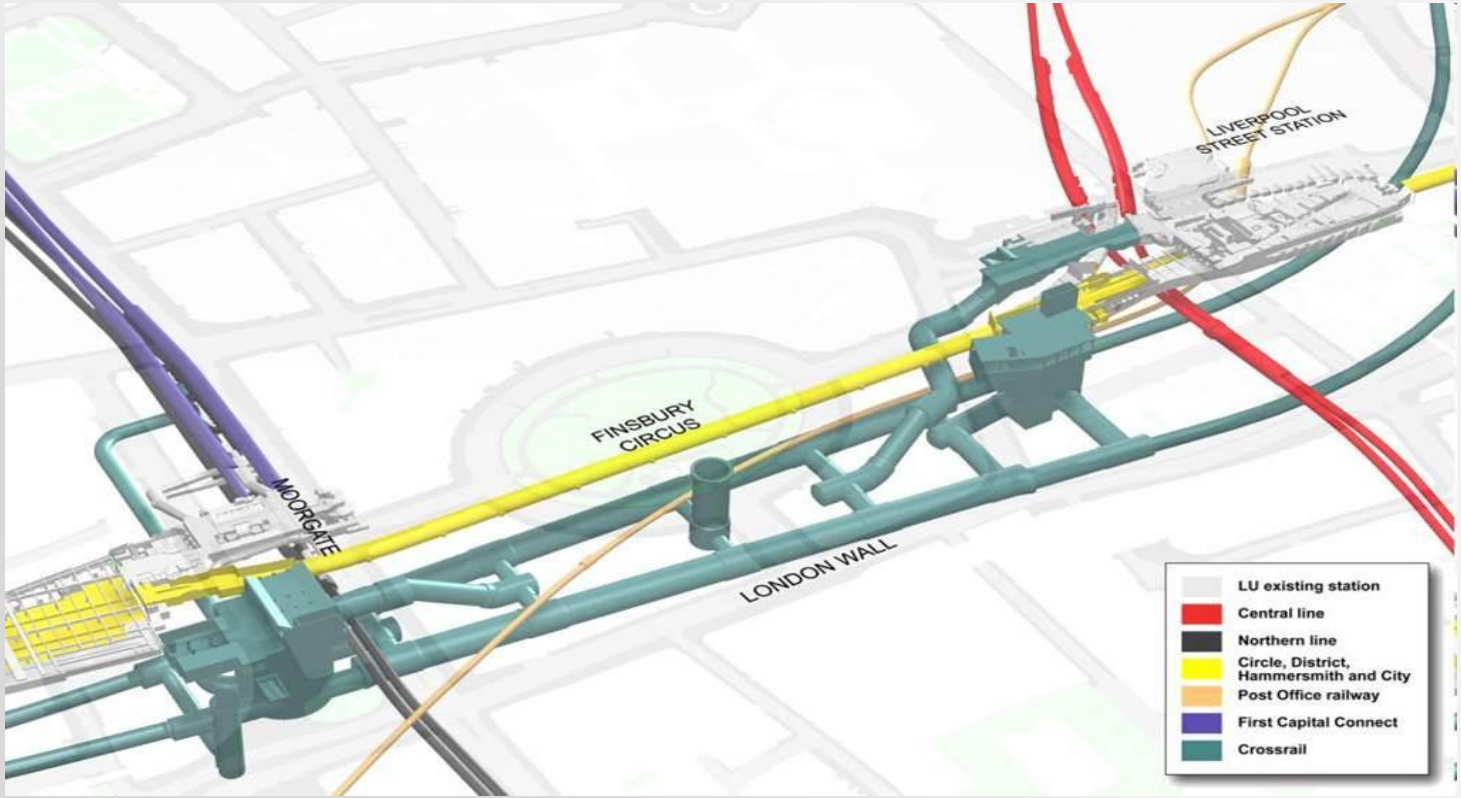
Typical Station Layout



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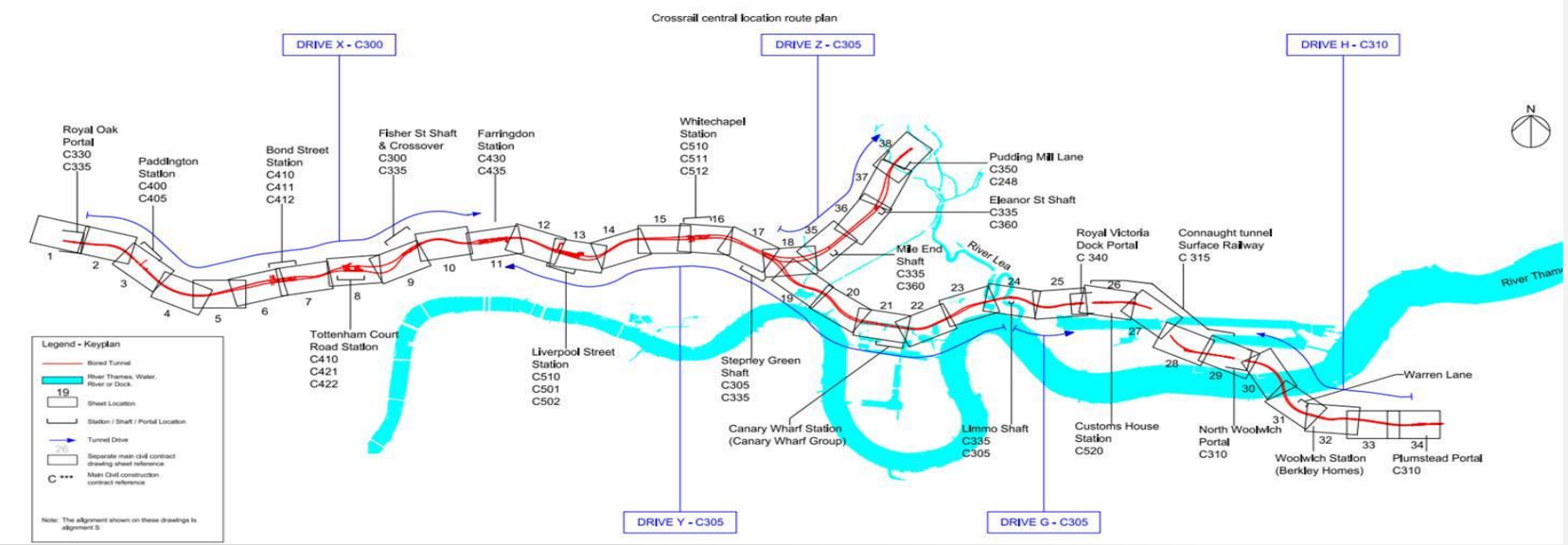
Contracts



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Monitoring Database Requirements
Argus 6

- One holistic project system
- Near real time monitoring capability
- Storage and retrieval of all sensor readings over lifetime of project
- Web-based system for ease of access
- GIS user interface
- Alarm and notification capabilities
- Data import/export and reporting capabilities

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Monitoring Database Scope
Argus 6

- Up to 20 sites across London
- Estimated final number of users = 500
- Number of sensors = 100,000 +

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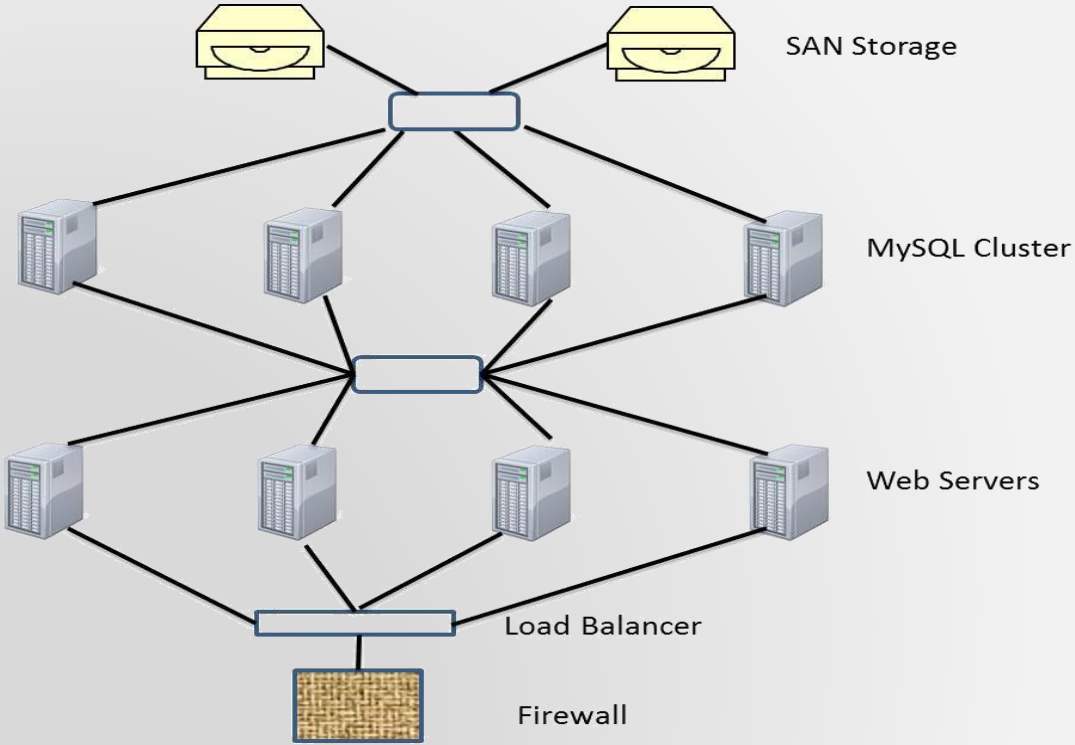
Argus 6 Architecture



Solution scalable as demands of project change

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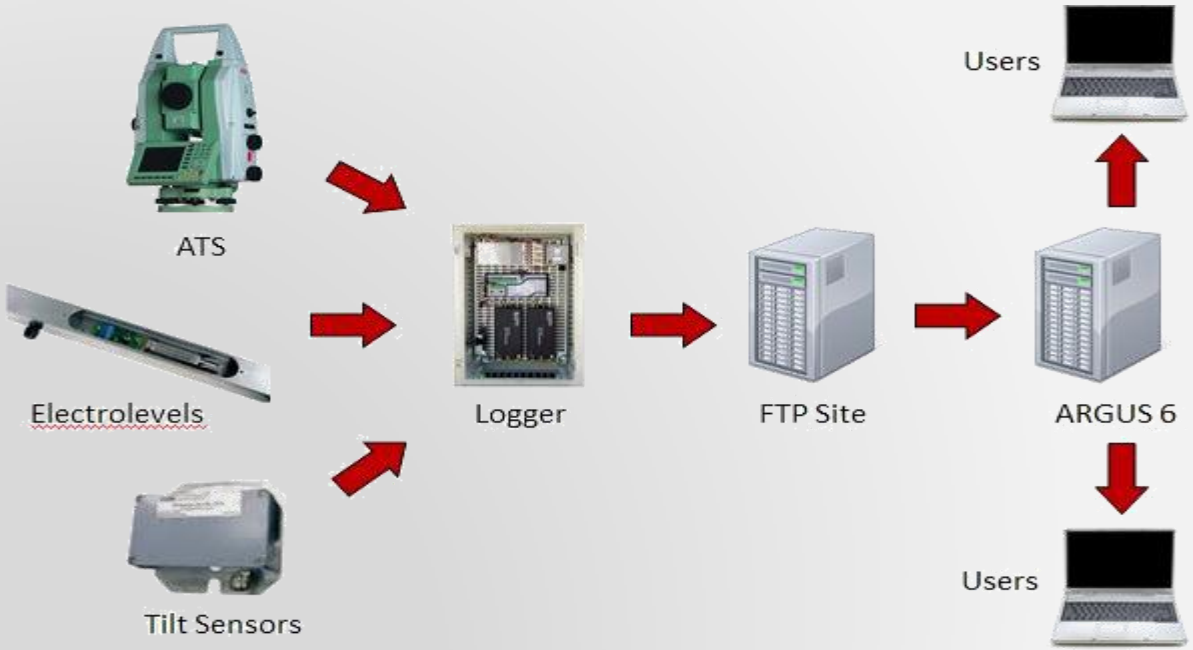
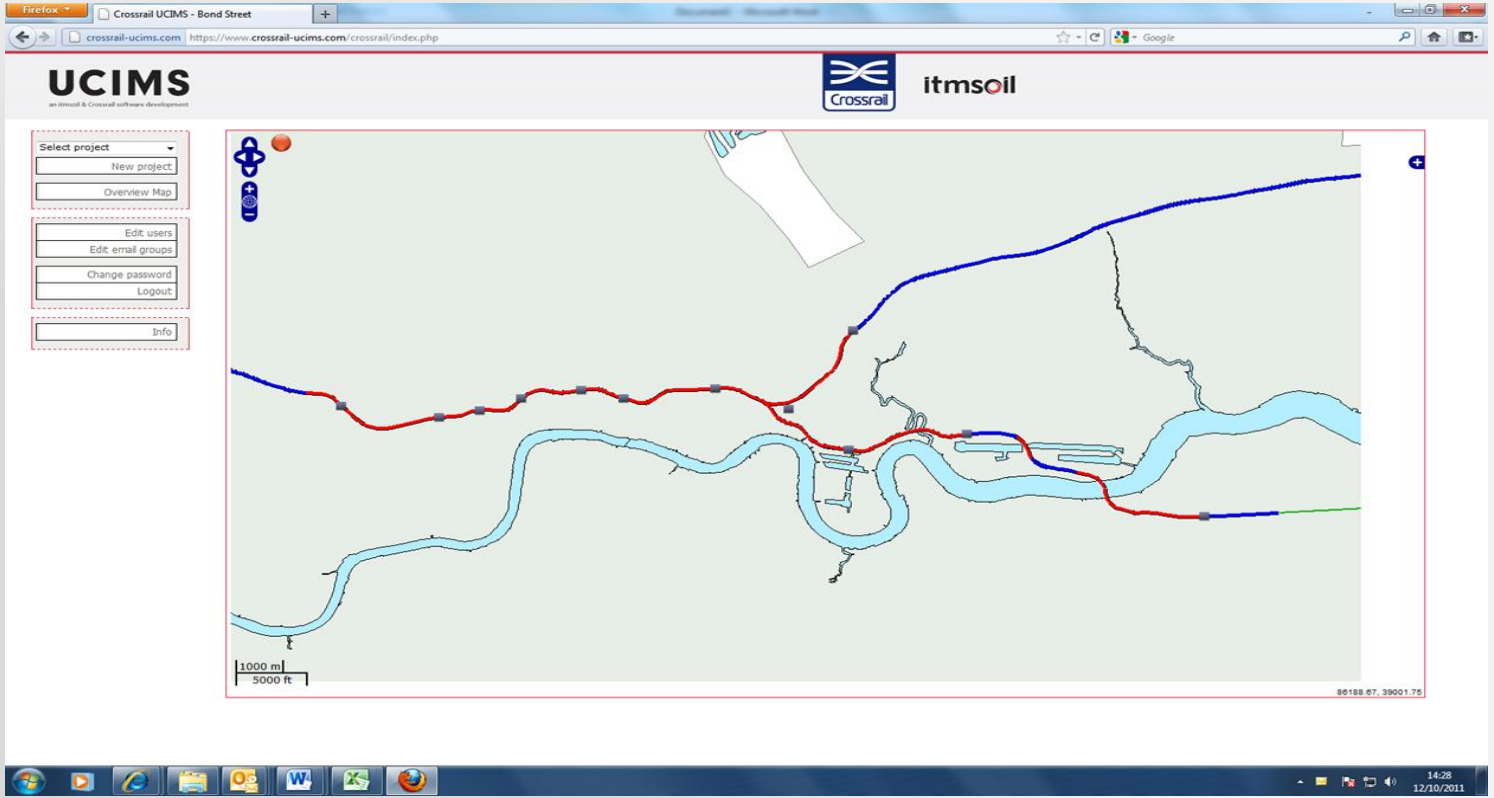
Argus 6 Data Flow Schematic

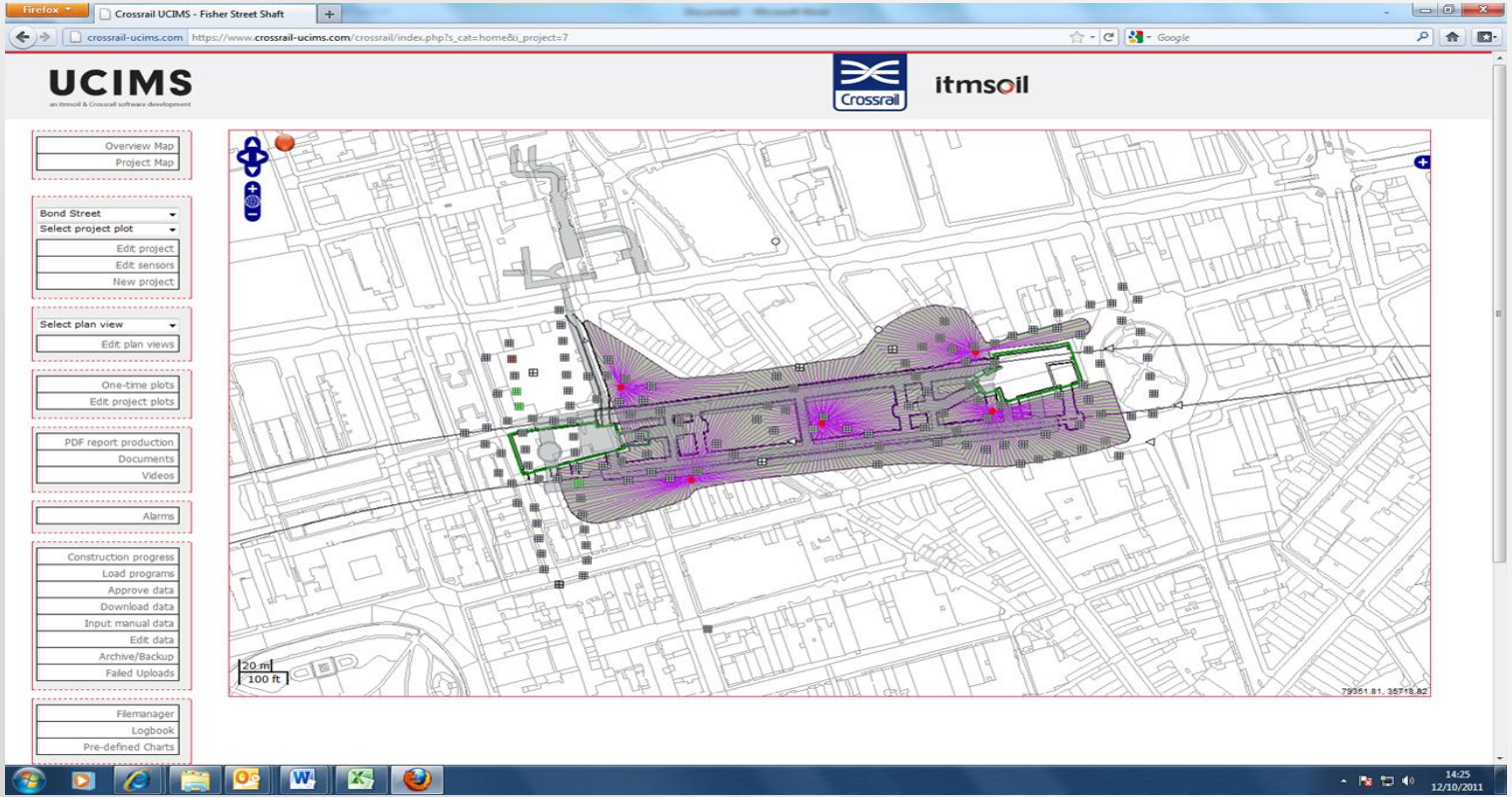


Argus 6 Screen Shots



Opening Index Map

Argus 6 Screen Shots



Map view of a project

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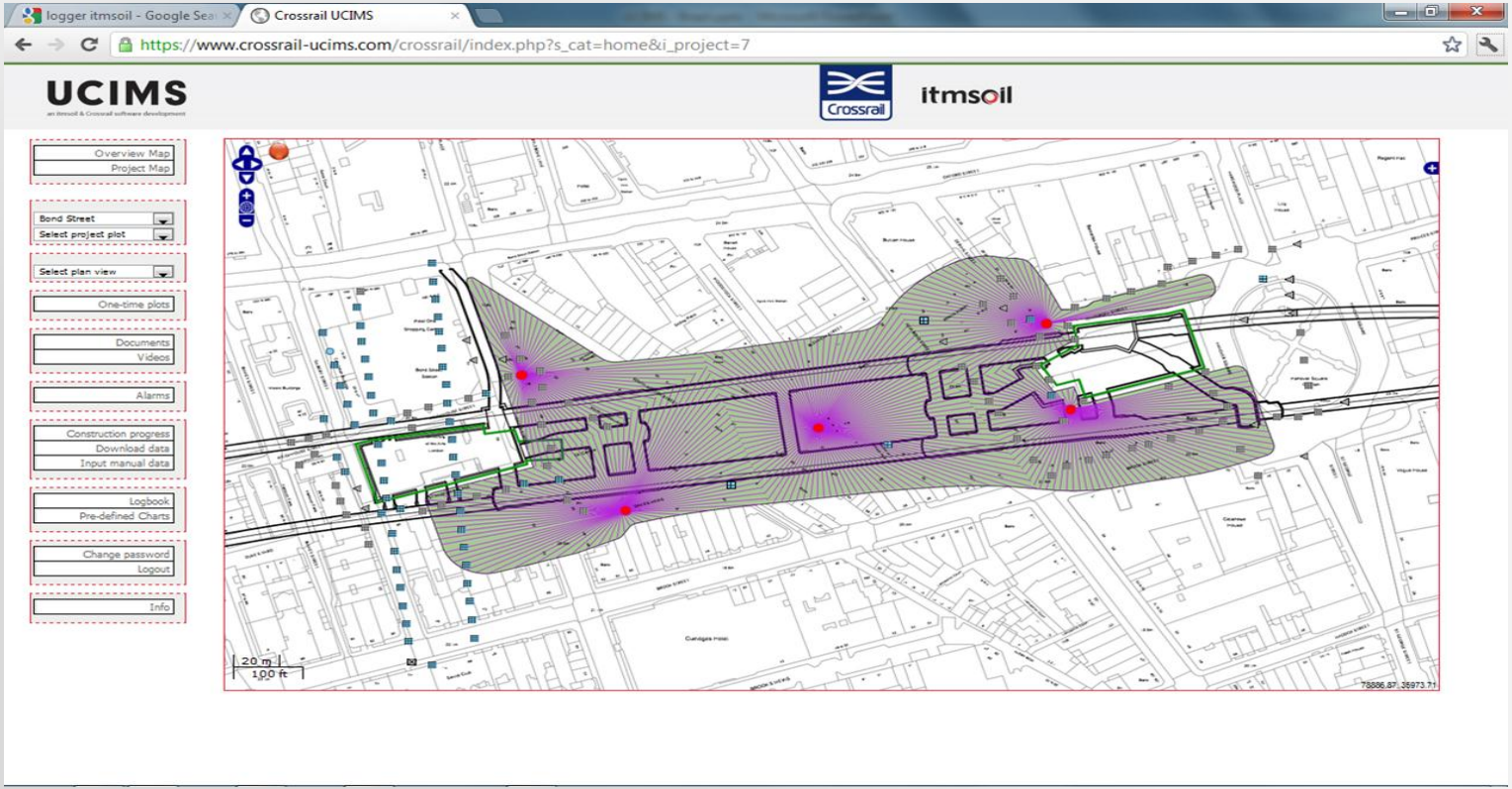
Argus 6 Screen Shots



Map view of a project – zooming in

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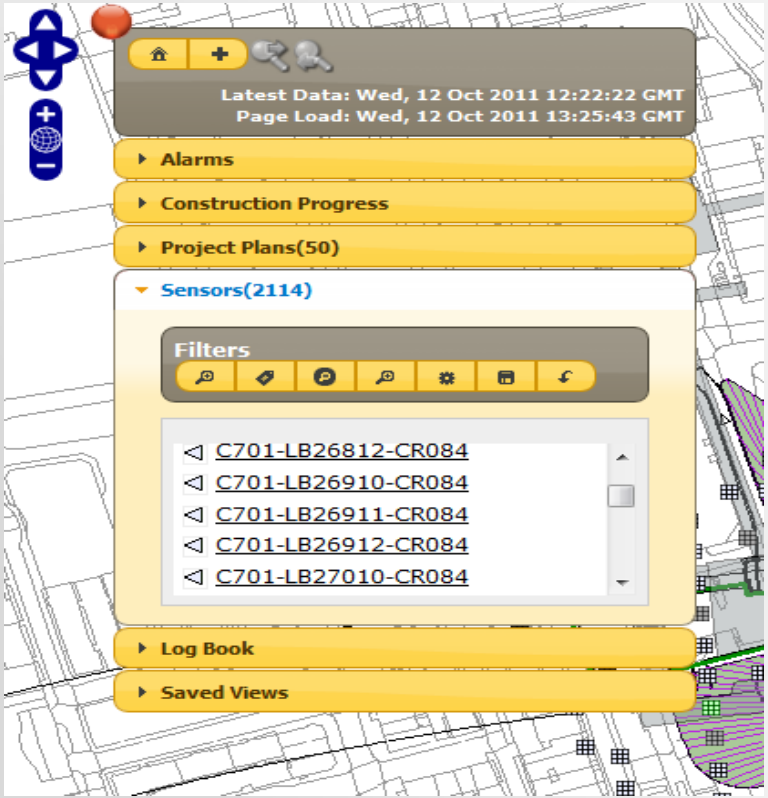
Argus 6 Screen Shots



Enhanced user searching facilities

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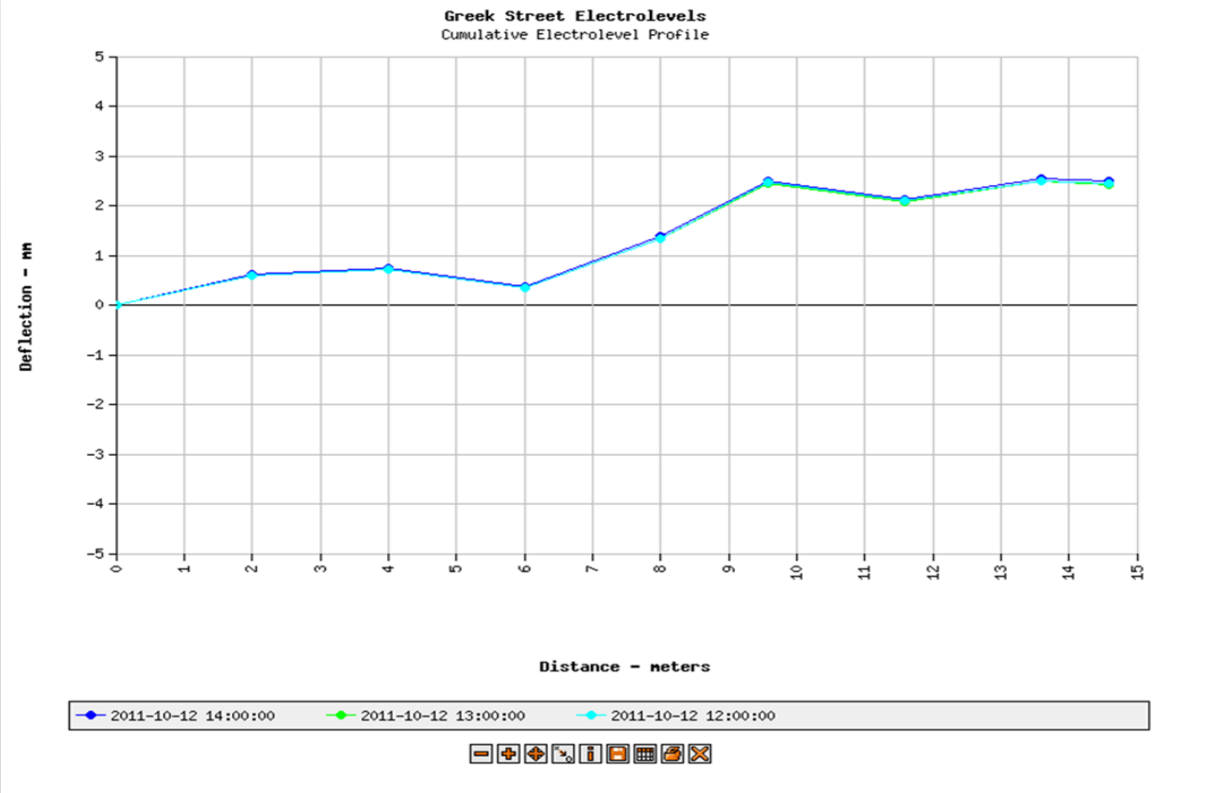
Argus 6 Screen Shots



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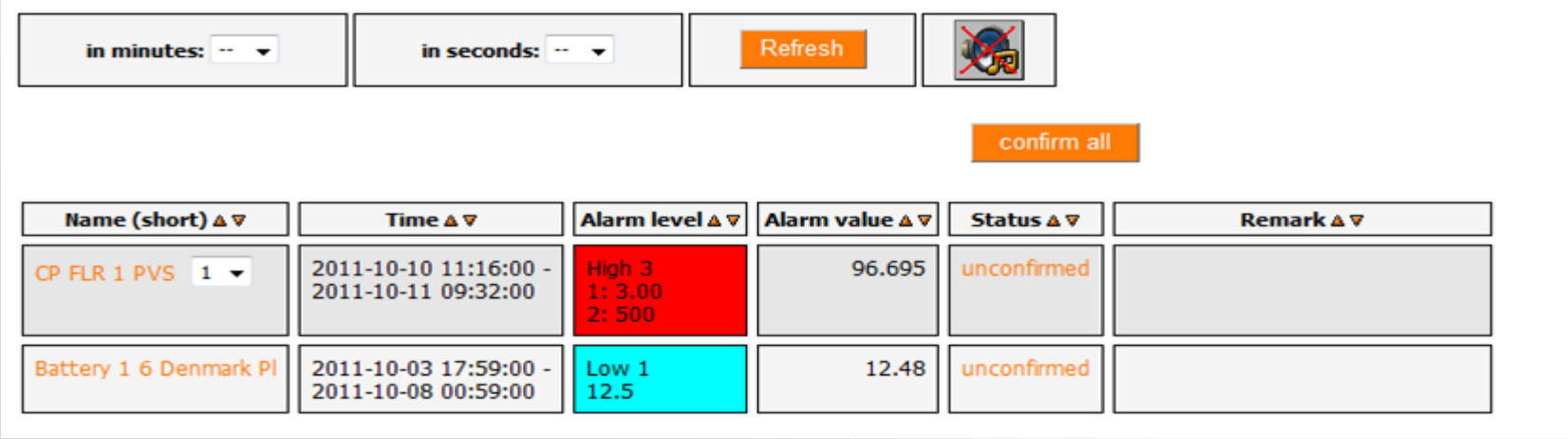
Argus 6 Screen Shots



Alarms triggered when a sensor passes a threshold

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Project Instrumentation Statistics

- **Automatic Total Stations (ATS)** **>300**
- **Prisms** **>20 000**
- **Electrolevels** **>3 800m**
- **Precise Levelling Points** **>3 700**
- **BRE Building Settlement Points** **>2 000**
- **Bassett Convergence Arrays** **>64**
- **Construction Information Management System**

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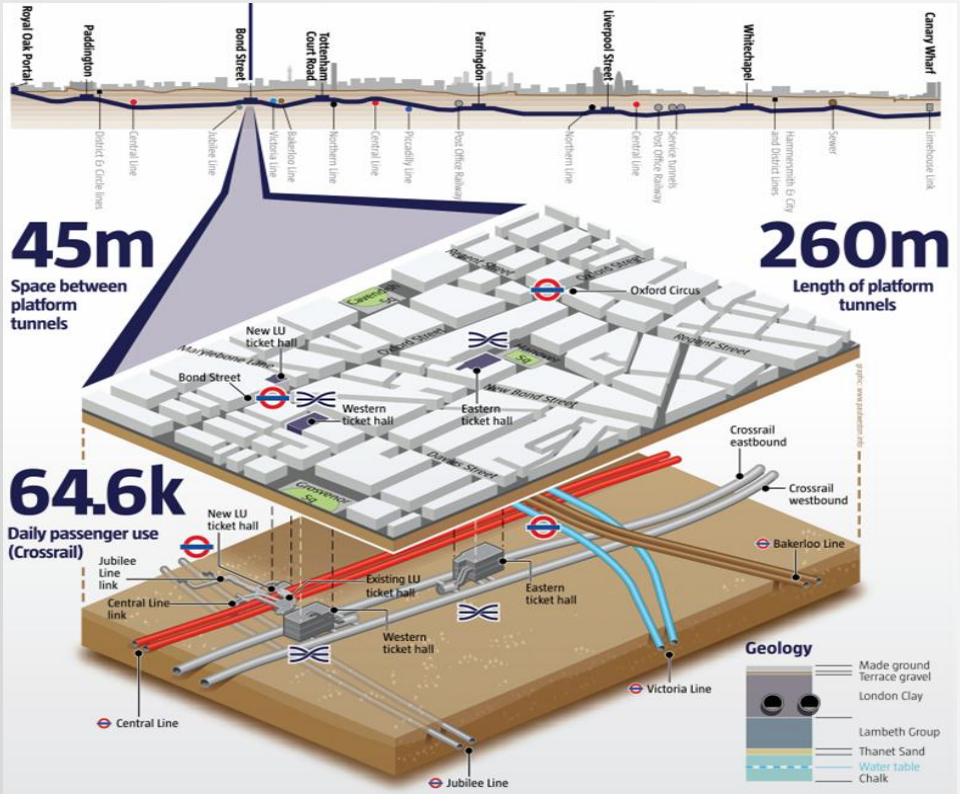
Bond Street Overview



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Bond Street
Automated Total Station (ATS)

A total station is an electronic/optical instrument used in modern surveying.

The instrument is controlled via software running either on a data logger or a computer.

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Bond Street Above Ground

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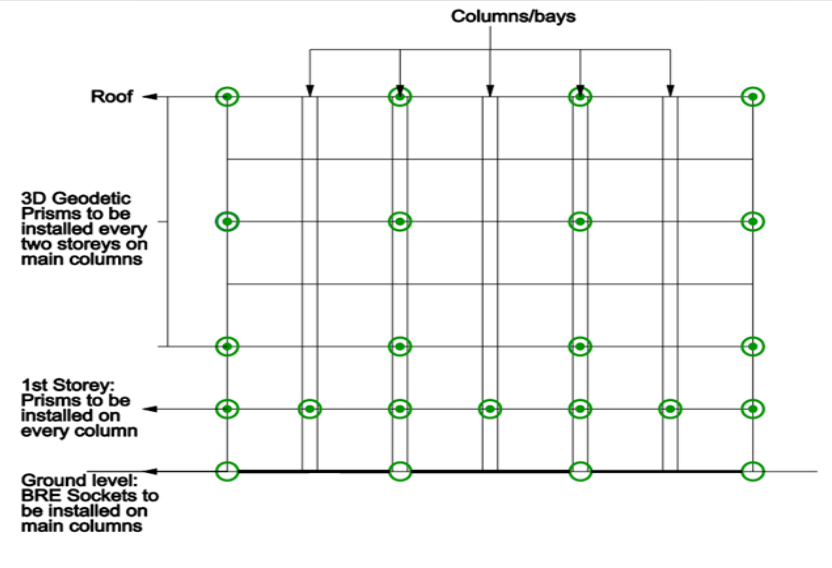
Bond Street – Above Ground
General Design



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Bond Street – Aboveground Automated Total Station (ATS)

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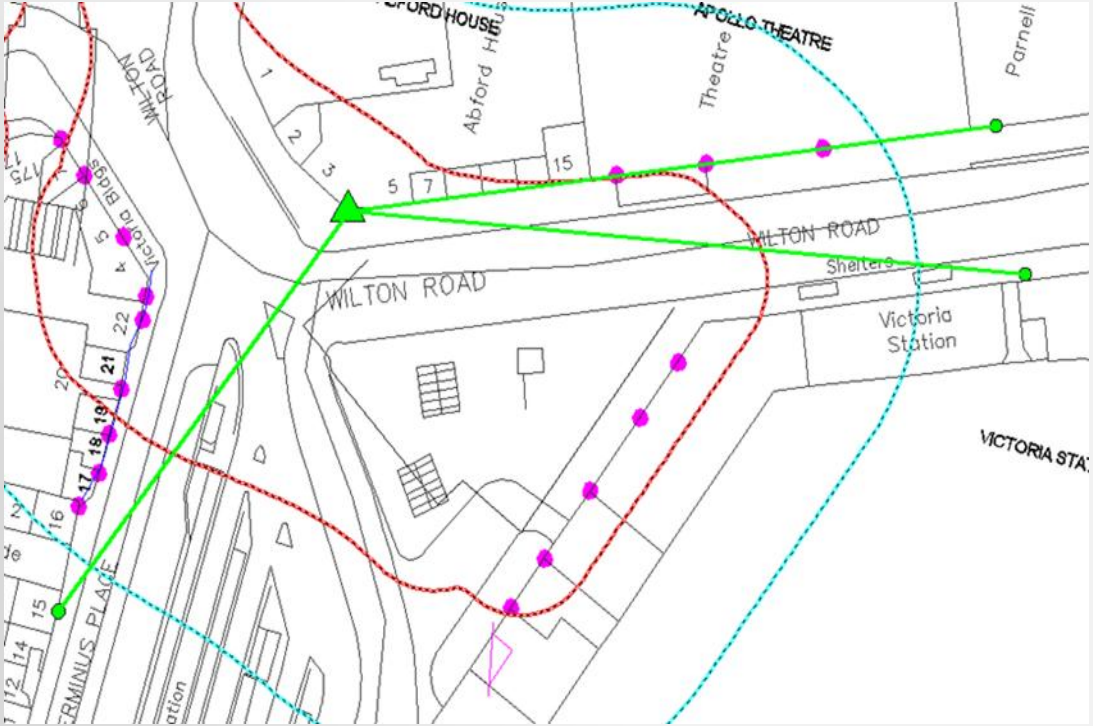
Bond Street – Underground Automated Total Station (ATS)

Ideally the RTS is located outside of the zone of influence of any movements. This can usually be achieved on small projects, but often the instrument has to be sited in an area which it is known will move.

In this instance the position of the RTS must be determined before each cycle of measurements.

The simplest correction is to use 3 (or more) reference points outside the zone, this is called resection.



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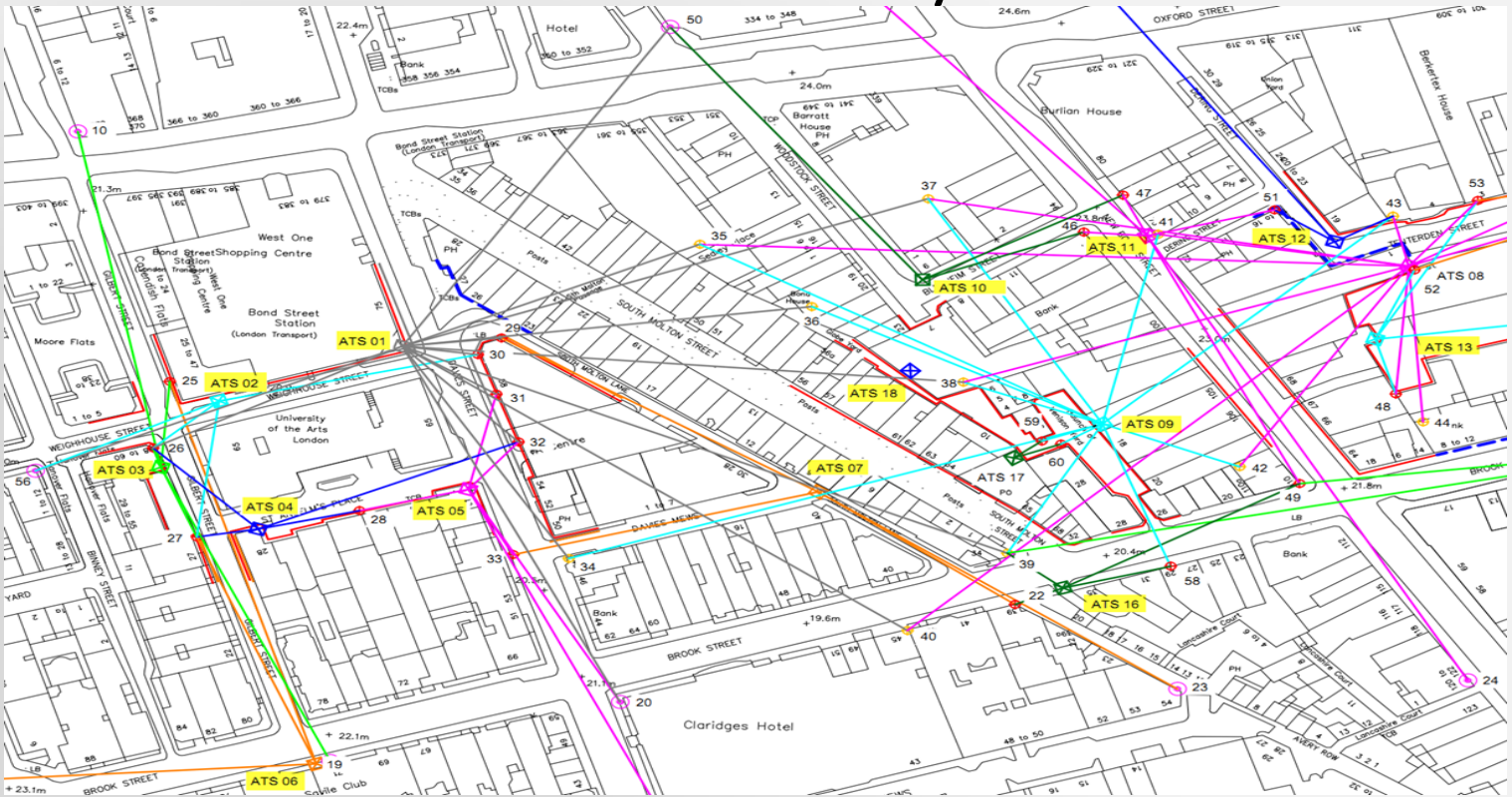
Bond Street – Aboveground
ATS network layout



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Bond Street – Aboveground Manual Survey

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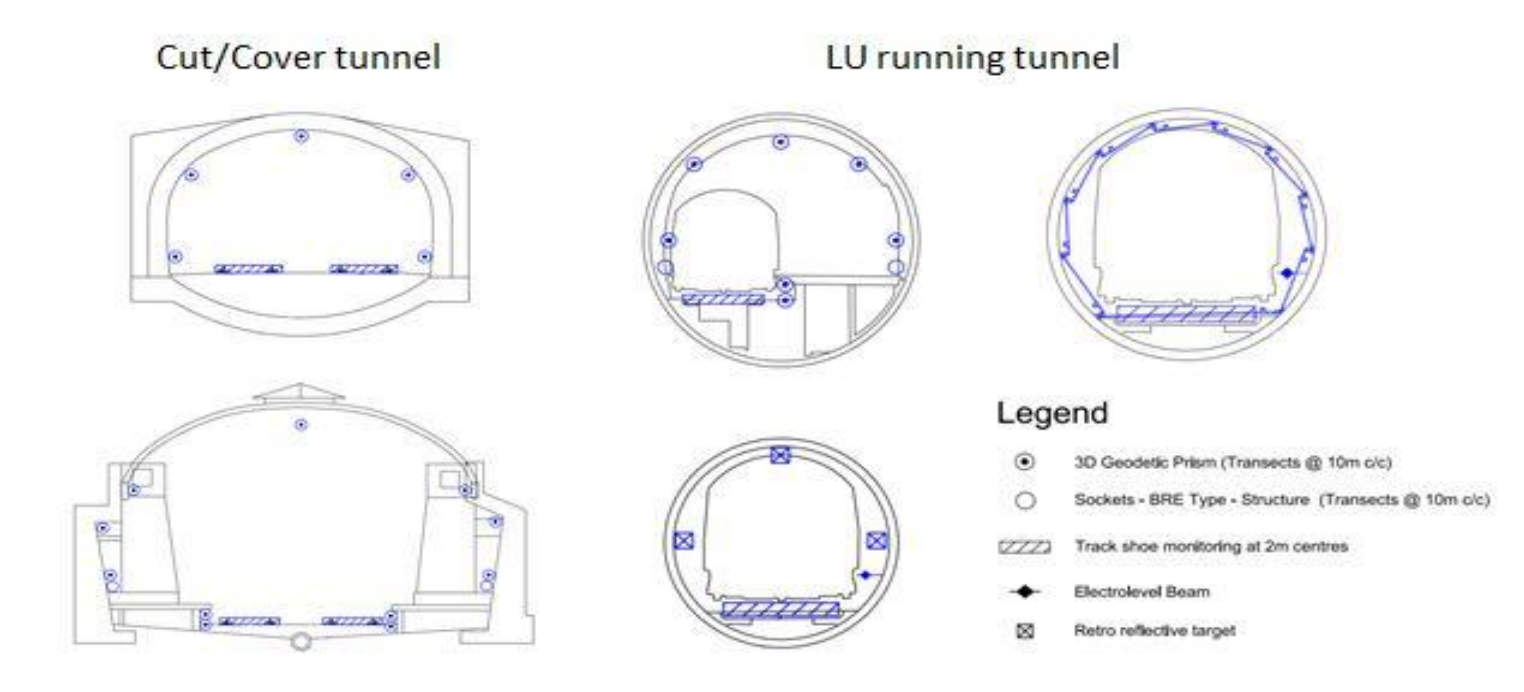
Underground
General Design



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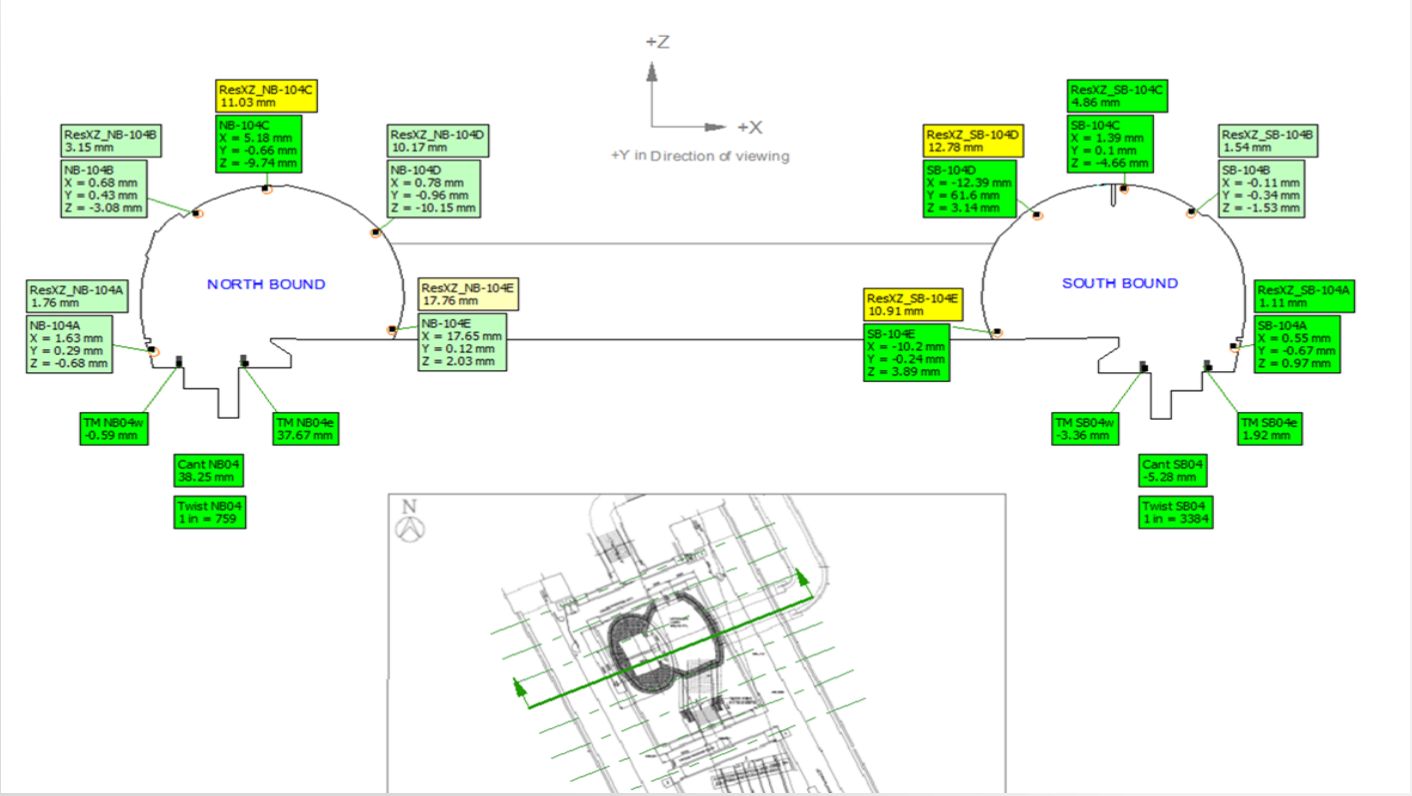
Underground
Automated Total Station (ATS)



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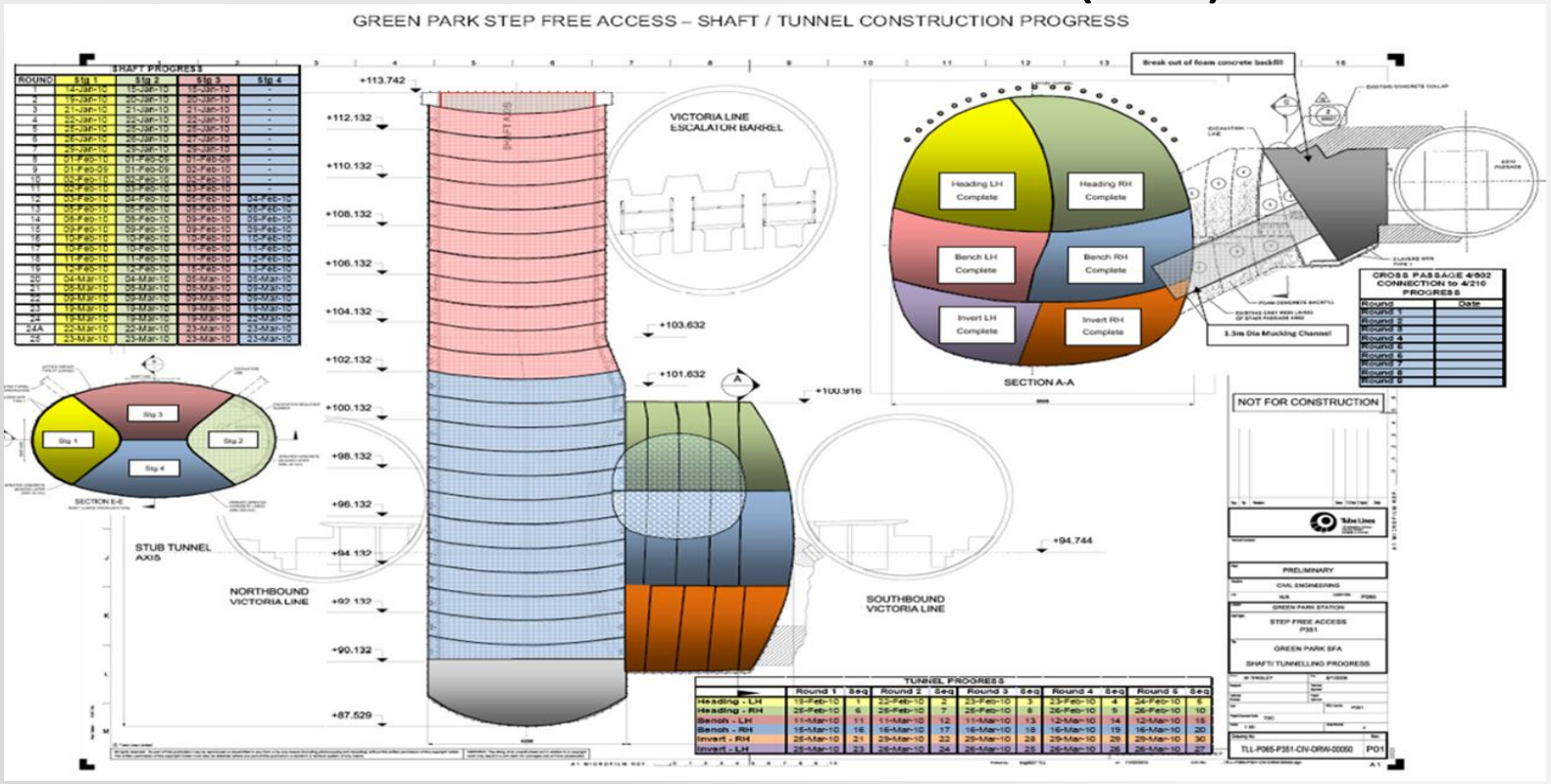
Underground
Automated Total Station (ATS)



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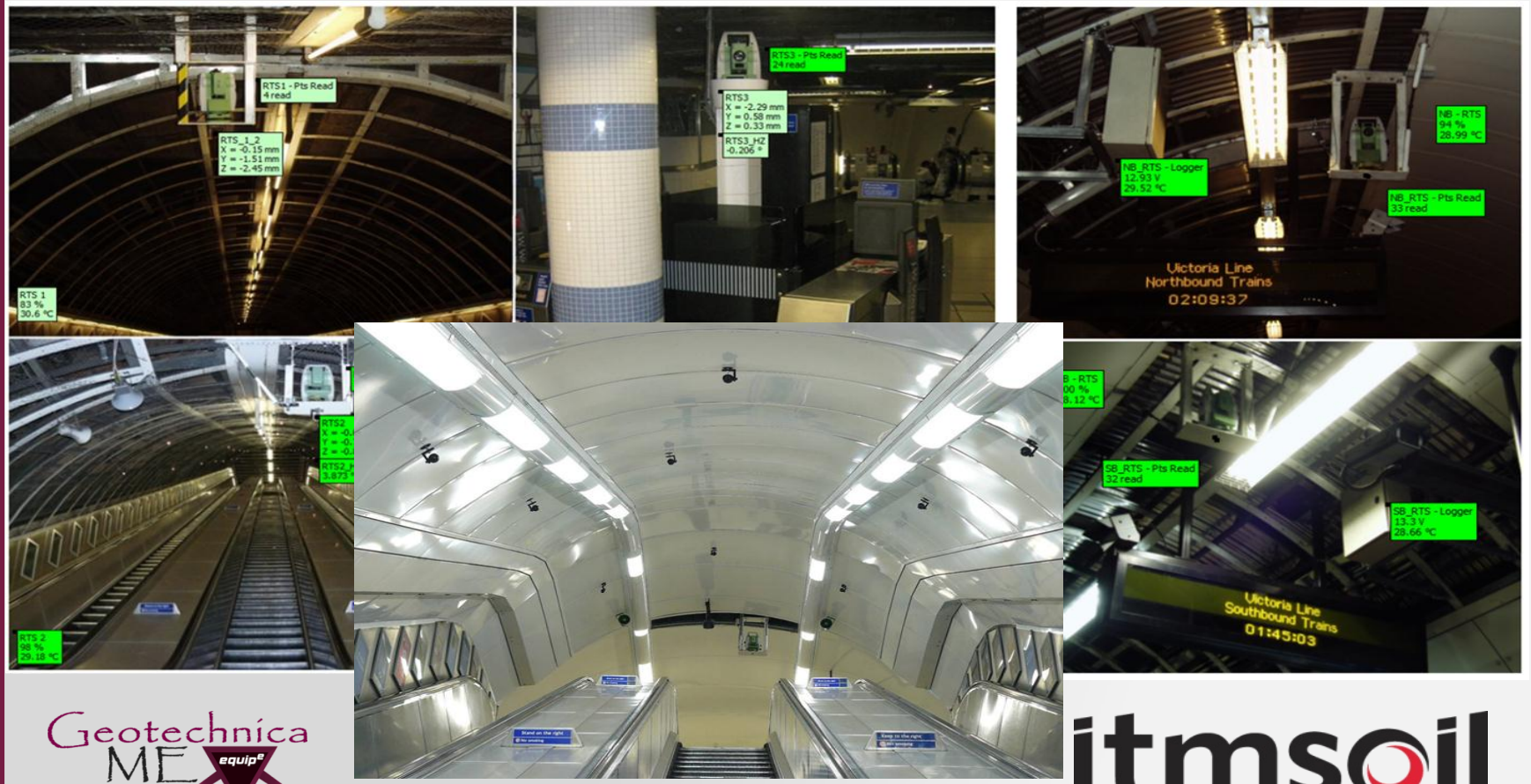
Underground
Automated Total Station (ATS)



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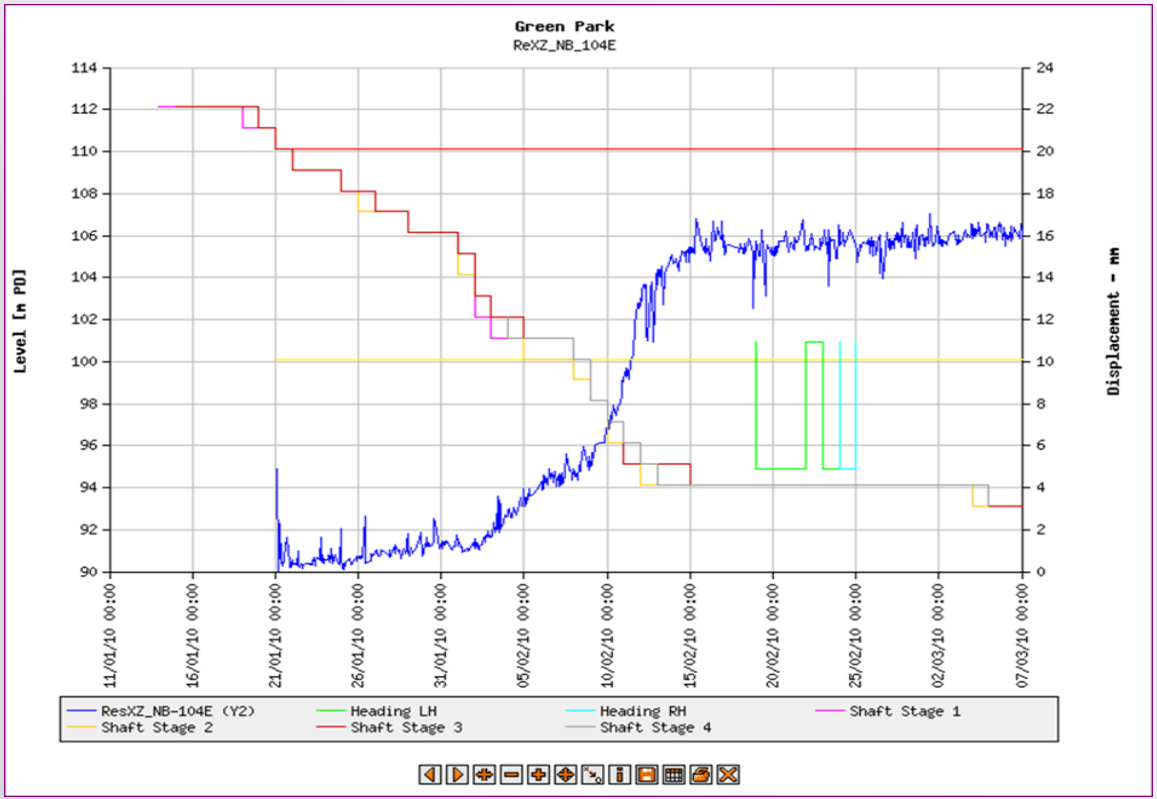
Underground
Automated Total Station (ATS)



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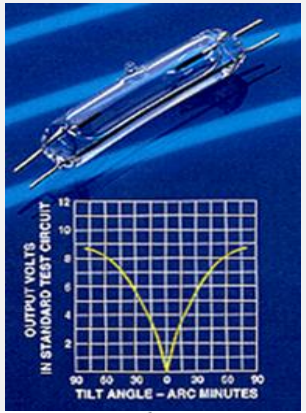
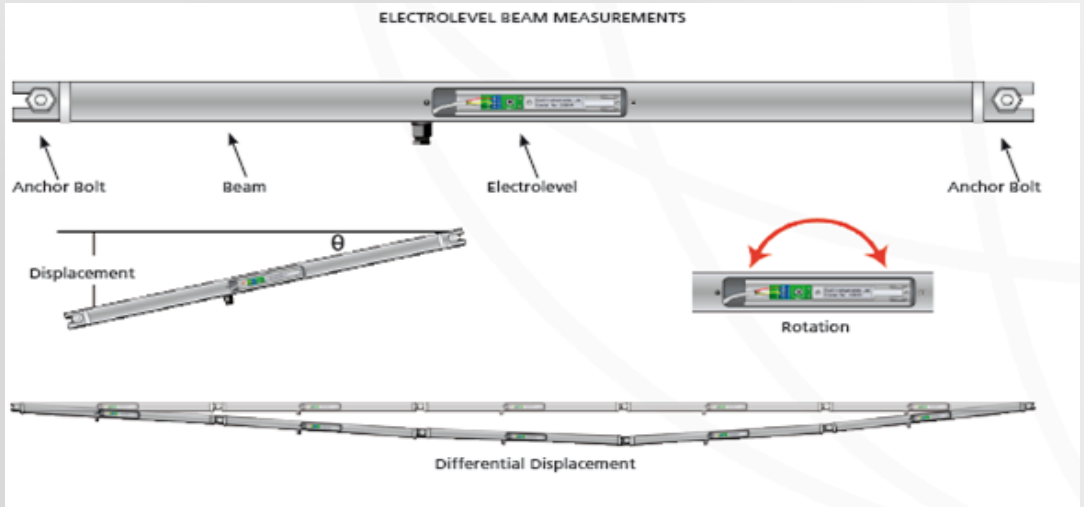
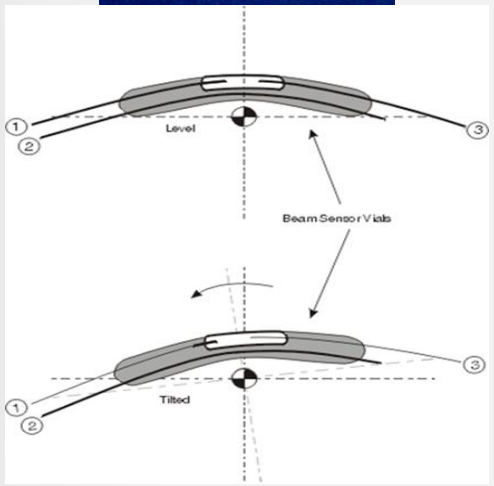
Underground Electrolevel Beams







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Underground
Electrolevel Beams

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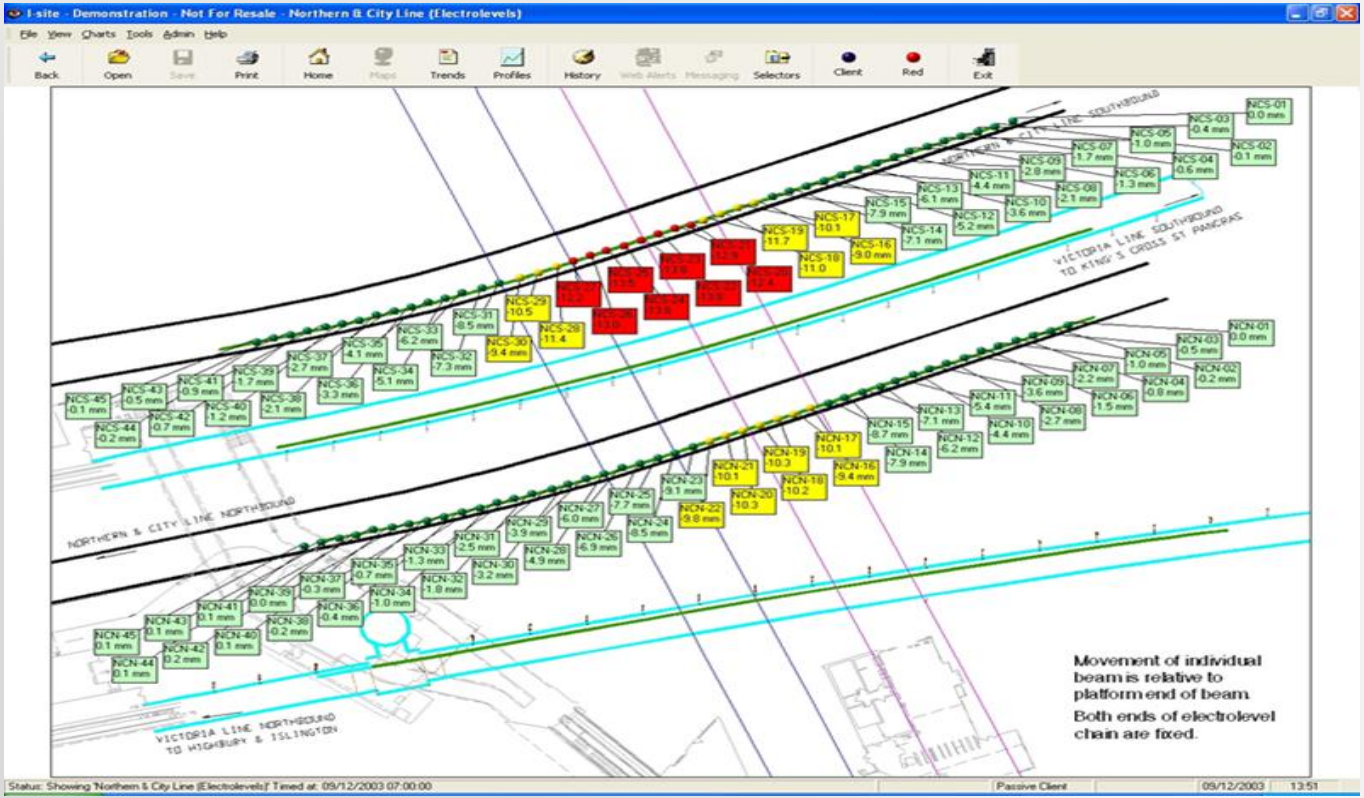
Underground
Electrolevel Beams



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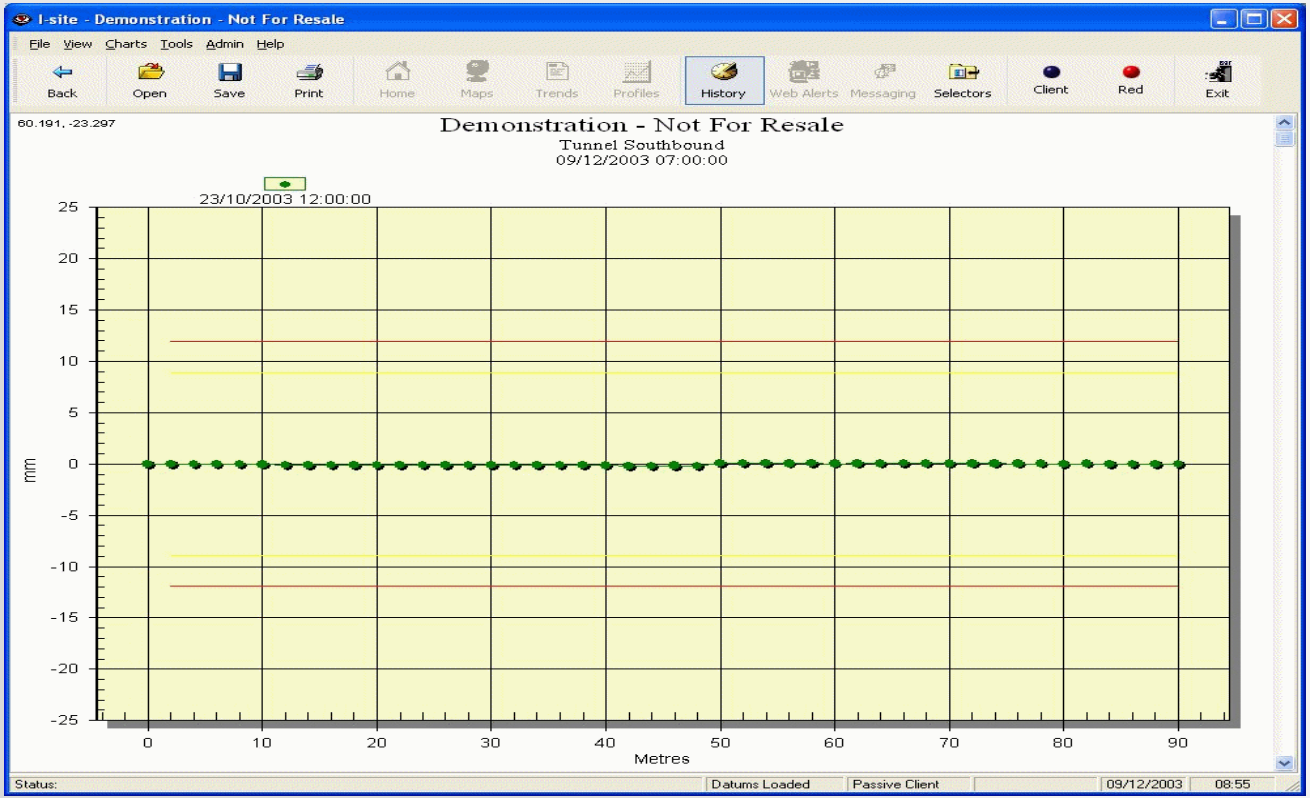
Underground Electrolevel Beams



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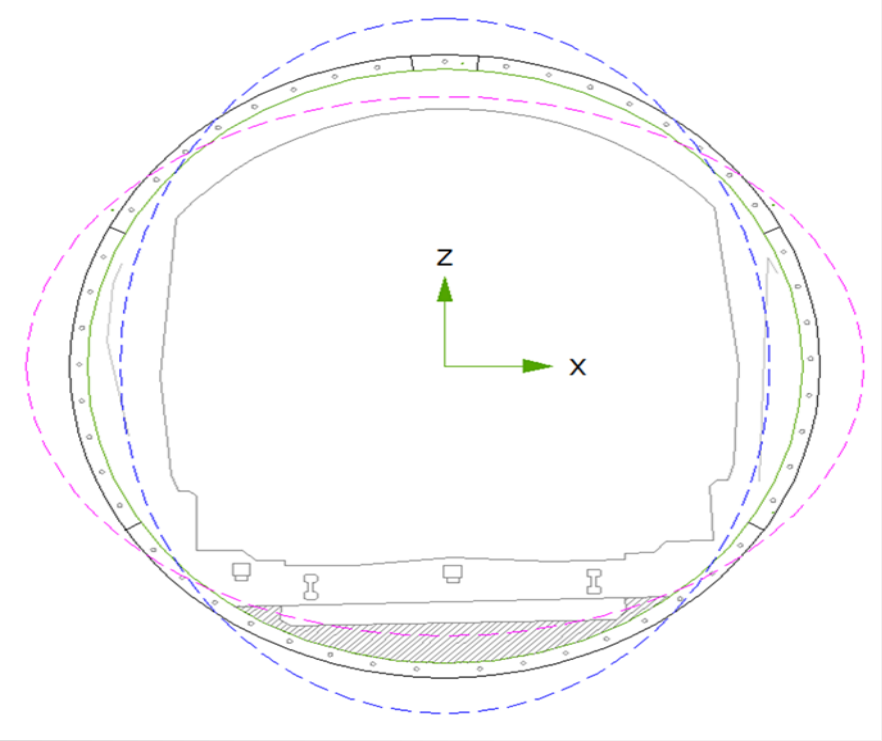
Underground
Bassett Convergence System

The Bassett Convergence System (BCS) is designed to monitor δx and δz displacements of structures and tunnels in near real-time.

From these displacements we can calculate squat and convergence of the tunnel.



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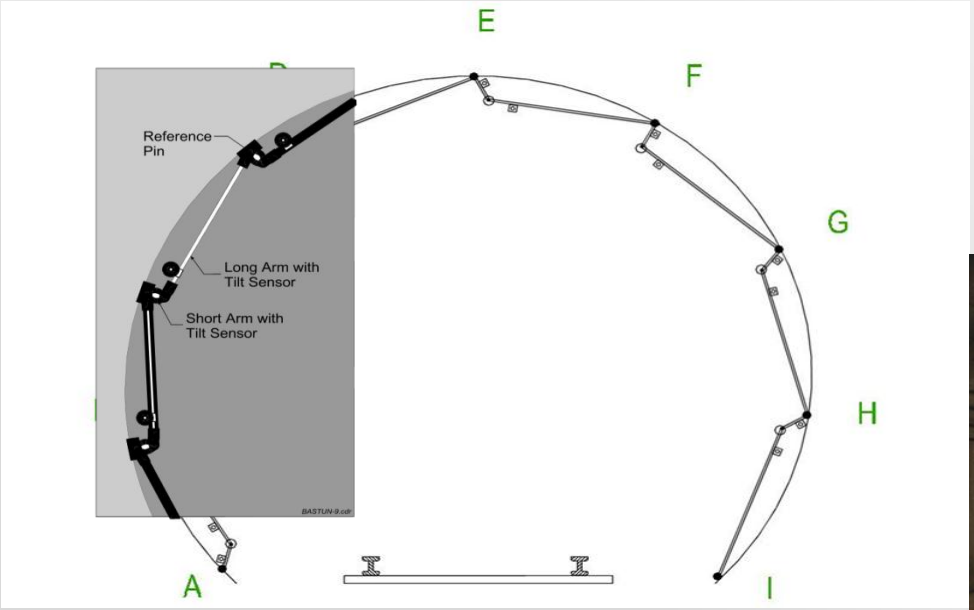
Underground
Bassett Convergence System



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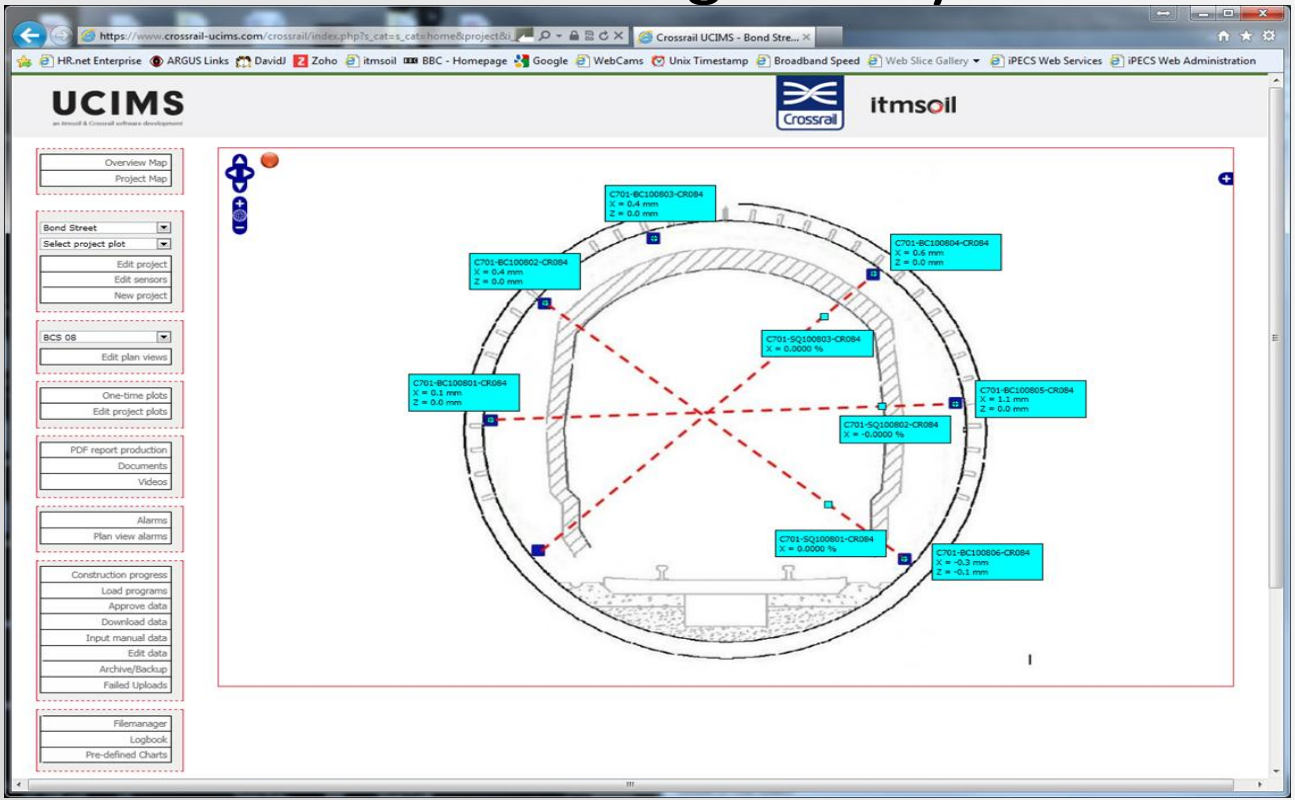
Underground
Basset Convergence System



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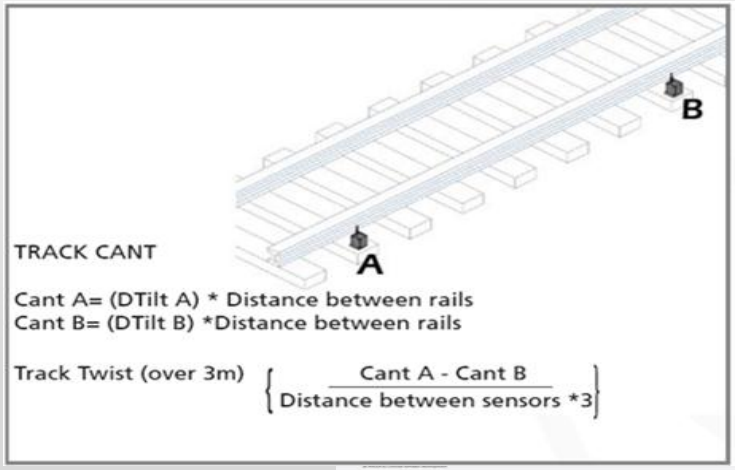
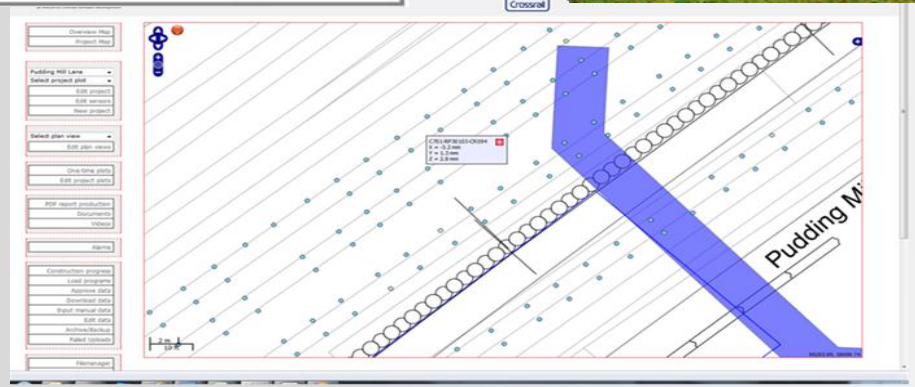
Track Monitoring





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Track Monitoring

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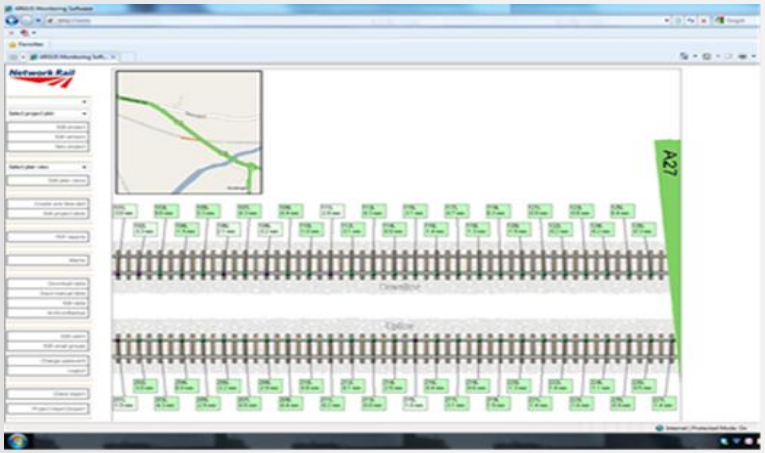
Crossrail
Track Monitoring

Wireless Track Tiltmeter



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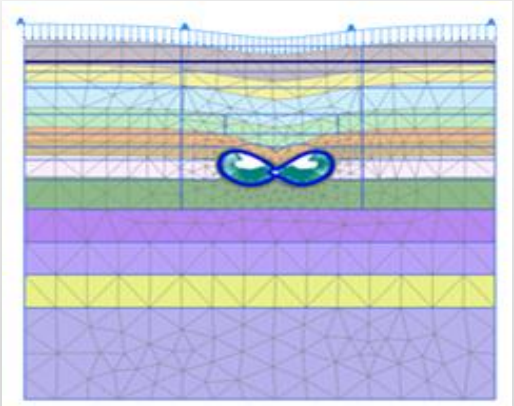
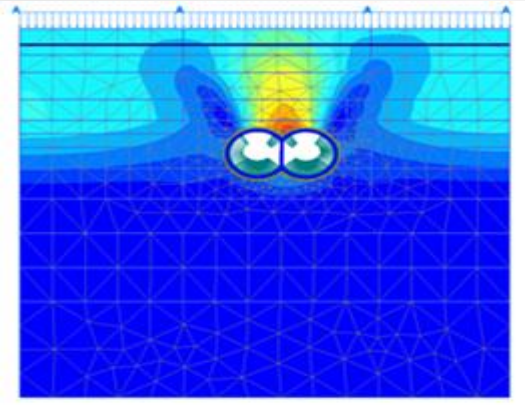
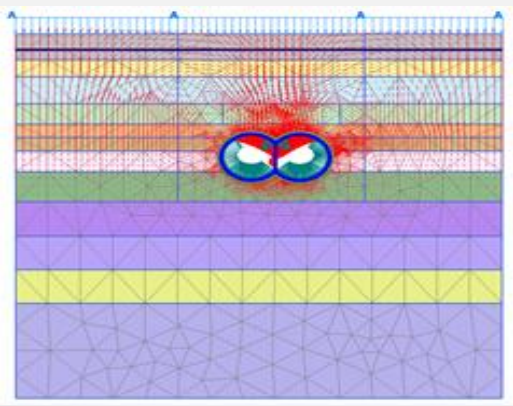
Ground Instrumentation







Key Areas for Instrumentation

I Prediction must identify two features:

a) Where are the critical zones?

b) What are the magnitudes of deformation and stress changes?

II Are the changes in the critical zones:

a) Acceptable – monitored for record & learning purposes

b) Some concern – monitored adopting the “Observational Method”

c) Unacceptable and requires planned intervention – monitored to ensure the intervention is working

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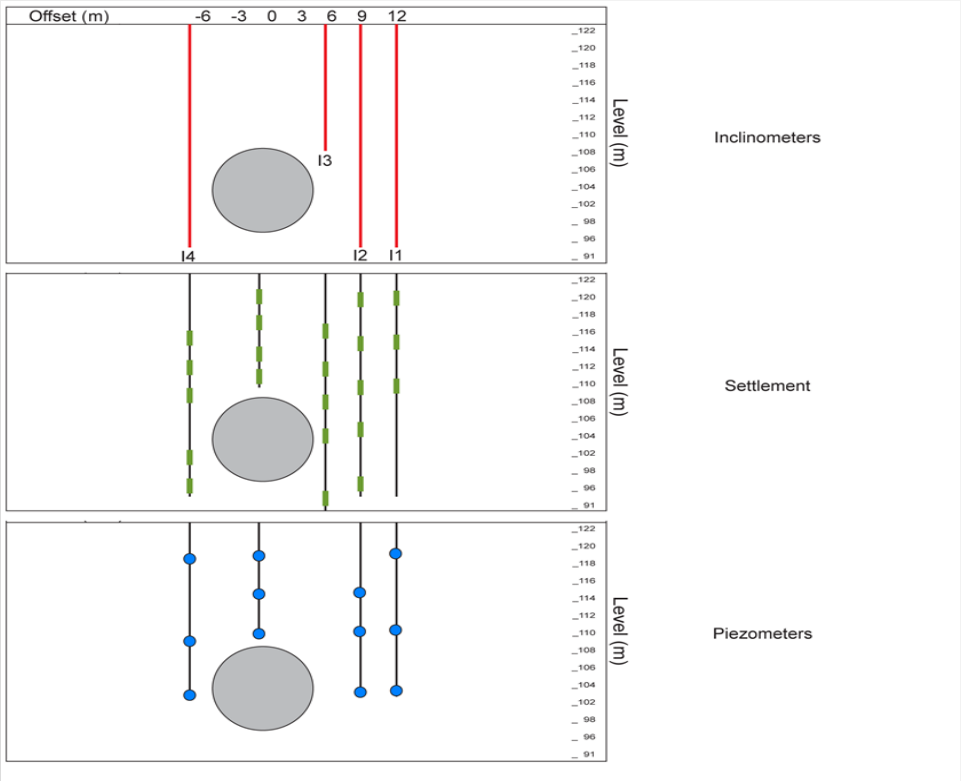
Ground Instrumentation

Location of Instrumentation

- Inclinometers
- Extensometers
- Piezometers



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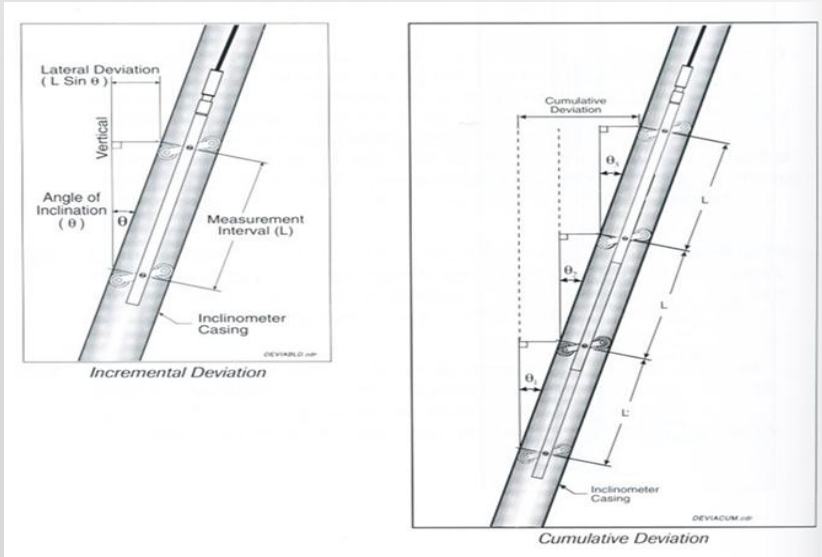
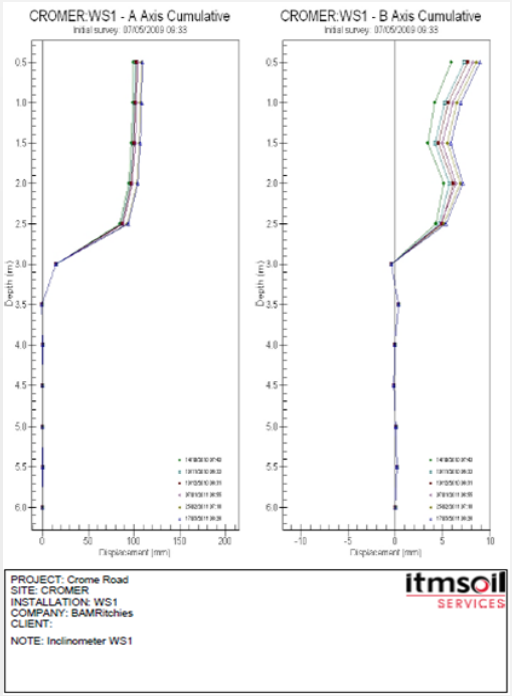
Ground Instrumentation - Inclinometers





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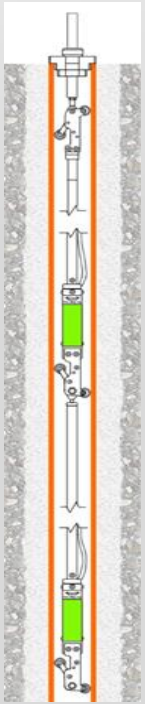
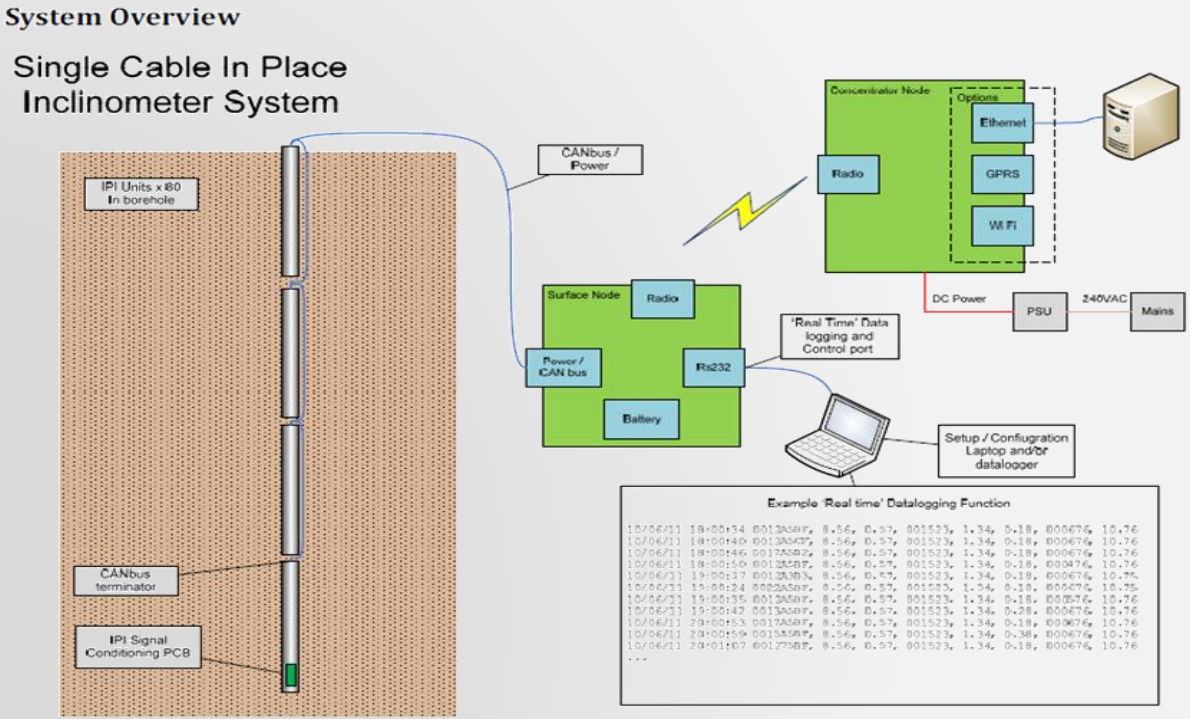
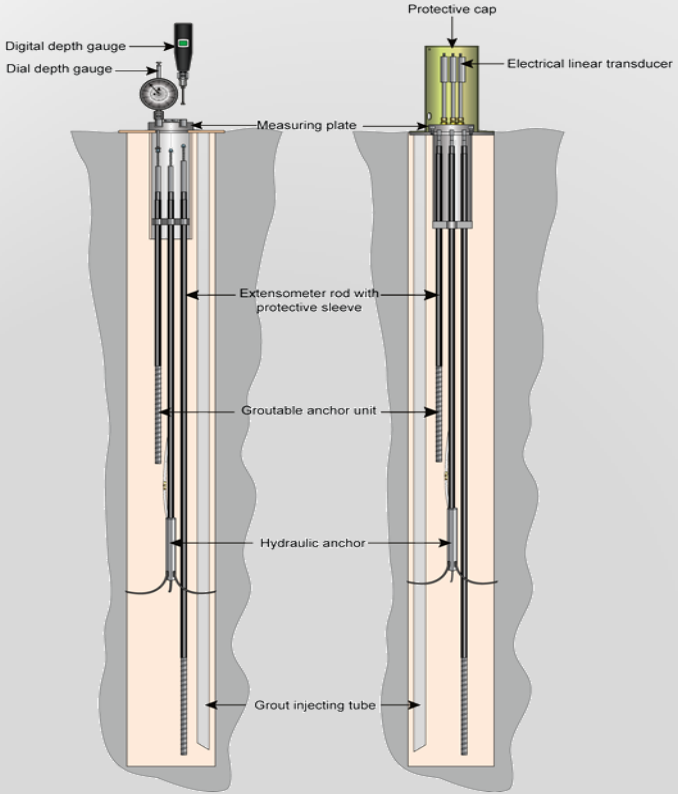
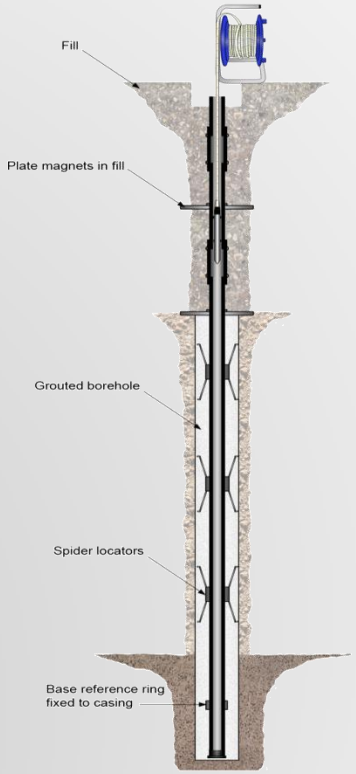
Ground Instrumentation – In-place Inclinometers

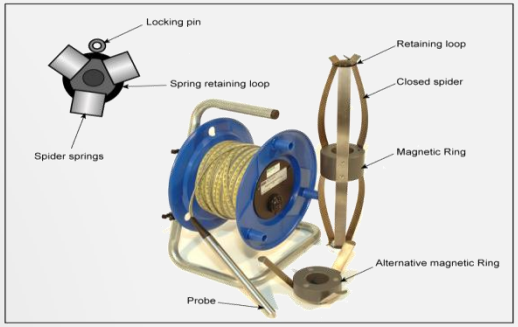




Ground Instrumentation – Extensometers







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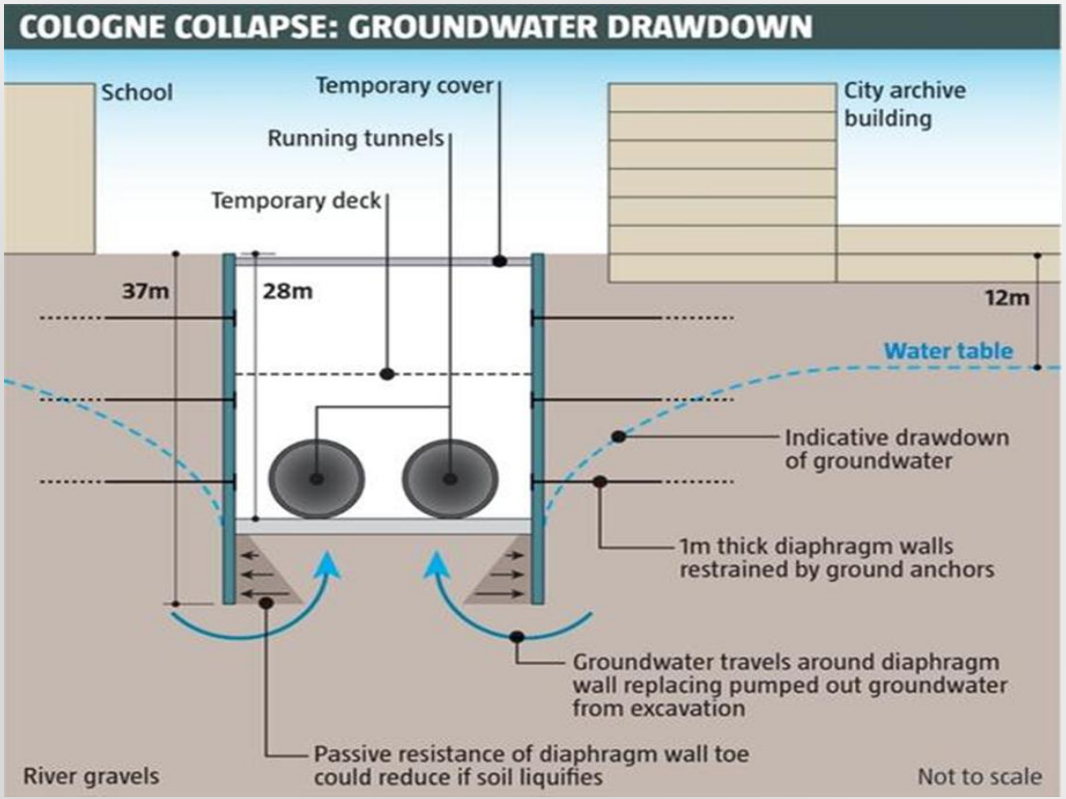
Ground Instrumentation – Piezometers



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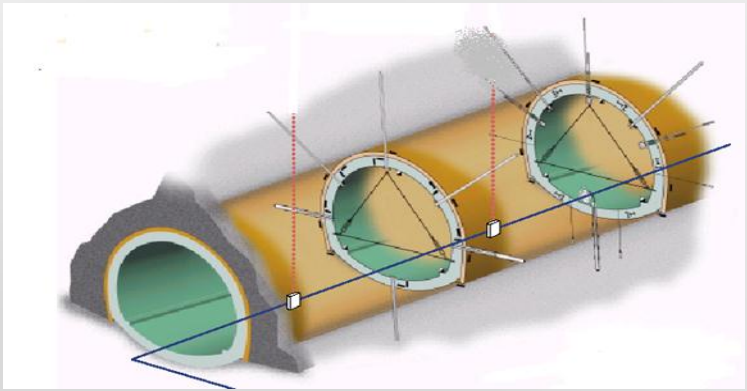
Ground Instrumentation – Tunnel Monitoring



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Conclusion

1) Is instrumentation an unnecessary expense?
2) Does it get in the way of the programme and cause delays?
3) Does it gives too many false alarms?
4) Is it always in the wrong place?
5) Does no-one ever look at the data?

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Questions?

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