AN ADVANCED WEB-BASED MANAGEMENT SYSTEM FOR INSTRUMENTATION AND MONITORING DATA

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ABSTRACT

EIC GeoView is an advanced web-based management system for instrumentation and monitoring data that has been developed by EIC Activities, a member of CIMIC Group, for sole use on the Group's construction projects providing valuable competitive advantage. The System automates the processing of raw data and delivers graphical outputs of the information via an online portal. This system has the capacity to collate information from innumerable sources, then process and store the information via a cloud server. This paper presents how EIC GeoView has been used on three major projects in Australia to collate and process monitoring data to assess the performance and management of built structures. On the Torrens Road to River Torrens Project in South Australia, EIC GeoView was used to manage large quantities of movement data collected along a 3km long soil nail wall designed using unsaturated soil mechanics principles. Use of EIC GeoView allowed large volumes of data to be accurately delegated and processed with ease and minimal human effort. On Sydney Metro Northwest TSC, EIC GeoView was used to collate and process real-time rail track movements and ground surface deformation of existing structures relative to the progress of the underground tunnel, presenting the construction team with the ability to assess the impact of tunnel construction with up-to-the-minute accuracy. On the Frederickton to Eungai Pacific Highway Upgrade project, a considerable portion of the alignment involved construction upon soft soils. The grouping functionality in EIC GeoView was used to cluster different instrument readings on a single output, allowing engineers to observe and compare between linked phenomena, such as piezometer records, fill height, horizontal profile gauges and ground settlements from plate readings, all at the same time.

1 INTRODUCTION

Geotechnical engineers deal with non-uniform materials – earth and rock which have properties that can vary unexpectedly and behave in often unpredictable ways. To manage this risk, geotechnical engineers deploy instruments that are capable of providing quantitative measurements of the ground and associated built structures. Monitoring records from these instruments are interpreted by engineers to provide insight into the performance of as-built conditions. Thus, the application of instrumentation and monitoring (I&M) in geotechnical engineering plays a vital role in the management of built assets during construction and the operational phases. According to Transport for NSW (2016), instrumentation and monitoring in the rail environment is used as "a tool for asset integrity assurance, operational risk management of potential geotechnical hazards and construction control".

On large scale projects, vast numbers of instruments are often deployed, resulting in significant volumes of monitoring data. Project teams are faced with the challenge of effectively and efficiently, collecting, processing, presenting, distributing and storing the monitoring data, without mobilising a small army of engineers and surveyors. EIC GeoView is an in-house I&M database manipulation platform developed by EIC Activities, a member of CIMIC Group, to overcome this challenge.

2 EIC GEOVIEW DATABASE MANAGEMENT SYSTEM

2.1 OVERVIEW

EIC GeoView is a centralised database management system (DMS) which automates the processing of raw data and delivers outputs of the information in graphical formats. This web-based system has the capacity to collate information from numerous sources, then process and store the information via an online server.

The basic architecture of EIC GeoView follows a simple three-stage process, as shown in Figure 1. EIC GeoView has several built-in readers that allows data entries to be made from monitoring instruments such as standard data templates, data loggers, real-time instruments and automated total stations, etc. Inside the EIC GeoView core, there are several processors developed to process data in the background, and eventually present the data in the form of visual outputs such as reports, graphs, location maps, or deliver electronic notifications such as SMS or email.

Figure 1: EIC GeoView System Architecture

EIC GeoView's capability extends beyond the management of I&M data with the ability to manage information arising from any asset where data acquisition, processing and reporting is required, such as site inspections, geotechnical data, and geological mapping records, etc. Thus, EIC GeoView can be used as a project management tool by virtue of its ability to provide users with real-time project status reports for large volumes of assets, all within a centralised platform. EIC GeoView also allows users to set predetermined targets and limits whereupon alert notifications can be sent to users, presenting itself as a useful tool for risk management.

Examples of applications where EIC GeoView has been used to manage other forms of construction data are shown below in **Figure 2**.

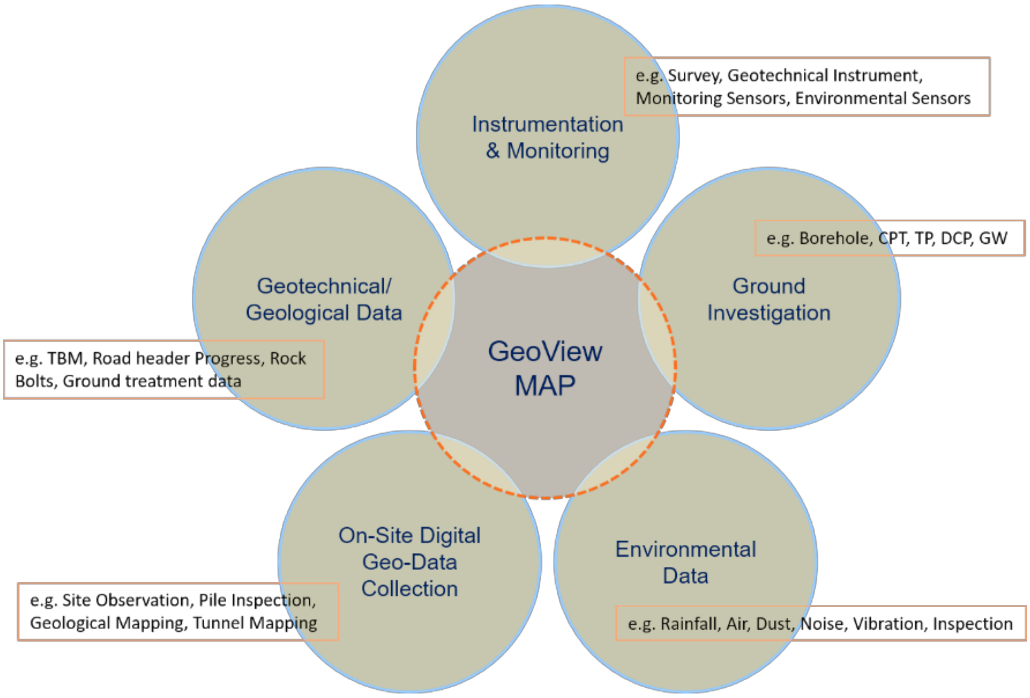


Figure 2: Applications of EIC GeoView as a management tool for other construction data

EIC GeoView has been used extensively on large scale infrastructure construction projects, including, railways, highways, tunnels and buildings. Projects of note include:

- Moreton Bay Rail Link, QLD (A$650m as at August 2013)
- Sydney Metro Northwest, NSW (A$1.15bn as at June 2017)
- WestConnex New M5, NSW (A$4.3bn as at November 2015),
- Torrens Road to River Torrens project, SA (A$896m as at July 2015),
- CityLink Tulla Widening, VIC (A$1.3bn as at February 2015),

- Transmission Gully, NZ (NZ$1.0bn as at July 2014),
- East Kowloon Cultural Centre, HK (HK$436m as at May 2017)

2.2 KEY FEATURES

In addition to providing automated data processing, monitoring and tracking of construction status, the key features of EIC GeoView are listed below in Table 1.

Table 1: Key features of EIC GeoView

Features	Characteristics
Customisable and scalable to meet project specific requirements	Offer users the flexibility to adapt to new instrument technologies. EIC GeoView can reformat input data from any survey or monitoring source into a standard that is consistent with EIC GeoView's database format
Automated alarm notification	Upon reaching pre-determined trigger limits for instruments, EIC GeoView will automatically generate SMS and/or email notifications to nominated recipients. The trigger limits are setup as Alert (Green), Alarm (Amber) and Action (Red). Once the trigger limits are applied to the monitoring points, the limits will be illustrated on graphs, colour coded data tables and reports. An example is provided in Figure 3. In the event anomalous data is entered into EIC GeoView, e.g. due to human error, or erroneous instrumentation data, EIC GeoView will alert users of such entries.
Web-based system	EIC GeoView is accessible from anywhere via the internet and web browsers. No additional software is required to be installed by users on local computers.
Availability and stability	EIC GeoView uses Cloud Services allowing for 24/7 operation and processing as well as to achieve 99.9% uptime. The centralised data storage uses the Microsoft SQL Server which has an unlimited capacity and regular data backup facilities
Integration with digital forms	Digital documents and forms which contain project data can be integrated to automatically upload onto EIC GeoView, allowing acquired information to be relayed to all members of the project team almost instantaneously. Examples include, collation of site inspection records, geological mapping, environmental quantity records etc.
GIS services integration	EIC GeoView can be integrated with interactive GIS maps with the most recent imagery, allowing users to visualise the location and records of the monitored instruments.
Account authentication system	EIC GeoView offers different levels of access and data manipulation to different users, enhancing protection of project data. For example, project administrators have the right to manage their own user access without any constraints. Restricted access may be provided to project clients to view the data and presented outcomes without affecting the underlying data operation.
Data presentation and reporting	There are four standard outputs provided in EIC GeoView: graphs, status map views, data tables and reports. The Grouping feature in EIC GeoView allows users to combine, arrange and produce combined charts and reports from multiple instruments and monitoring points. This feature provides an efficient means of viewing the trends of multiple data points for comparison. All reports and outputs can be setup to be automatically generated at specified frequencies, e.g. daily, weekly and monthly.

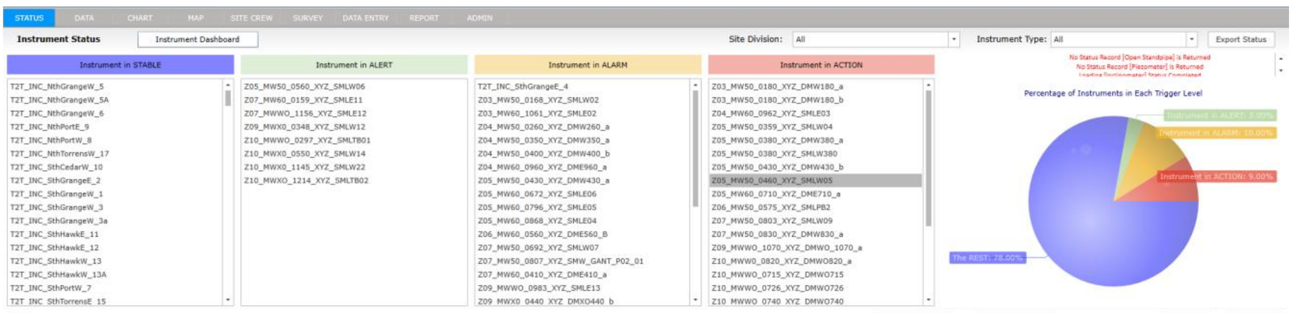


Figure 3: Snapshot of monitoring point status relative to trigger levels, Alert, Alarm and Action

3 I&M CASE STUDIES

The case studies below focus on examples of EIC GeoView used as a database management tool for instrumentation and monitoring only. However, EIC GeoView has also been used extensively in other projects such as Lam Tin Tunnel (Hong Kong), and Transmission Gully (NZ), where it was used as a construction and environmental data management tool.

3.1 TORRENS ROAD TO RIVER TORRENS PROJECT, SOUTH AUSTRALIA

Torrens Road to River Torrens project (T2T) is a road project currently being delivered by alliance partners CPB Contractors, York Civil, Aurecon Australia, and Department of Planning, Transport and Infrastructure in South Australia. One of the key features of the project is a depressed roadway 3km in length with a retained soil height of up to 8.9m. The retention support is partly provided by soil nails designed using unsaturated soil mechanics theories. The designed nail lengths are approximately 4m, which is significantly shorter than soil nails designed using conventional soil mechanics. The design was made particularly challenging due to the proximity of the excavation to an adjacent Arterial Road, South Road, located immediately upslope of the wall. This necessitated a project criterion of less than 30mm maximum lateral and vertical deformation at the excavation face.

More than 250 survey markers and 20 inclinometers were installed along the soil nail wall to monitor wall movement. Surveying of the monitoring points was captured using total stations and lowering of inclinometer probes. The data was then manually entered into spreadsheets and delivered as individual files to the design team on a daily or weekly basis. A typical cross section of the marker and inclinometer placement is provided in **Figure 4**.

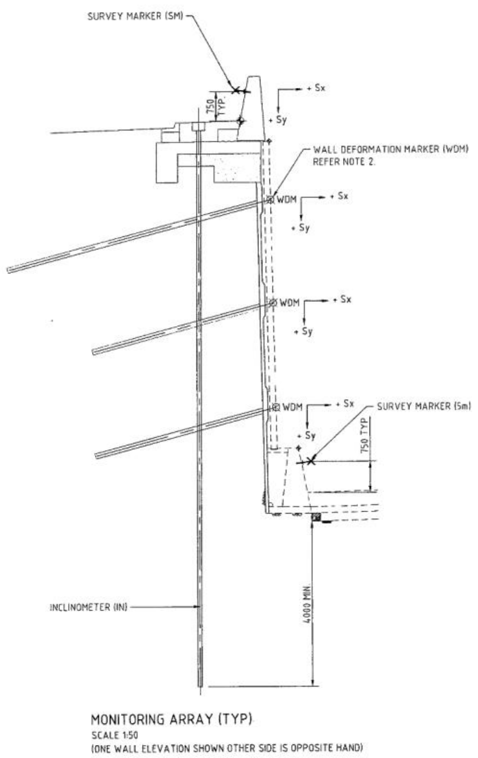


Figure 4: Typical cross section of survey markers and inclinometer placement on T2T

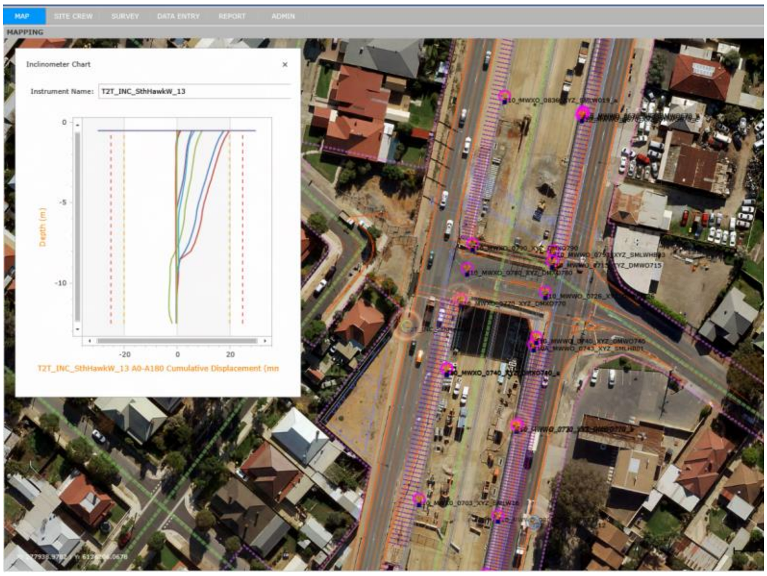


Figure 5: Example of aerial imagery overlain on top of instrumentation plan from T2T

In recognising the logistical challenges with handling and processing large volumes of survey data from multiple survey sources EIC GeoView was deployed, whereupon all survey data was uploaded into a consolidated online database. The automated formatting feature enabled survey data from different surveying companies (often adopting different data formats) to upload their data into EIC GeoView's unified database. The processor core allowed the uploaded data to be collated, processed and graphed almost instantaneously. Aerial imagery was overlaid onto the instrumentation plan allowing users to easily identify the location of the survey markers and view up-to-date survey results by selecting the marker point, such as that shown in **Figure 5**.

Use of EIC GeoView on T2T eliminated many hours of manual data processing and collation, thereby diminishing the risk of human error in what is, normally, a manipulation-heavy process. The automated notification system and status point summary portal allowed the movements of all monitoring points to be viewed at a glance, allowing the engineering team to focus their efforts in the required structures or areas.

3.2 SYDNEY METRO NORTHWEST TSC, NEW SOUTH WALES

Sydney Metro Northwest – Tunnels and Station Civil (TSC) formed part of the A$8.3bn (as at June 2017) Sydney Metro Northwest project located in the north-western suburbs of Sydney (formerly known as North West Rail Link, NWRL). TSC was delivered by the CPB Contractors, John Holland, and Dragados consortium and the works were completed in 2016. The key features of this project comprised 15km of twin TBM driven rail tunnels between Bella Vista and Epping, and civil works for five new stations and two services facilities.

Due to the scale of the project, up to 4700 instruments were deployed to monitor the numerous structural and geotechnical elements along the alignment. Use of EIC GeoView allowed significant volumes of instrumentation data to be stored in a single online database. Moreover, the centralised system allowed survey data from numerous surveying and monitoring parties (up to five parties), including manual and automated real-time data sources, to upload their data into a unified format.

The key feature of the project was the 15km twin 7m diameter tunnel constructed using four tunnel boring machines (TBM) which were mobilised simultaneously. The tunnel was up to 30m beneath heavily built up areas of suburban Sydney. Most of the tunnel alignment traversed through Sydney Sandstone and Siltstone, and beneath densely populated infrastructure such as Castle Towers Shopping Centre and Norwest Business Park, and came within close proximity of the existing rail crossing at Epping station where it had only 5m of rock cover.

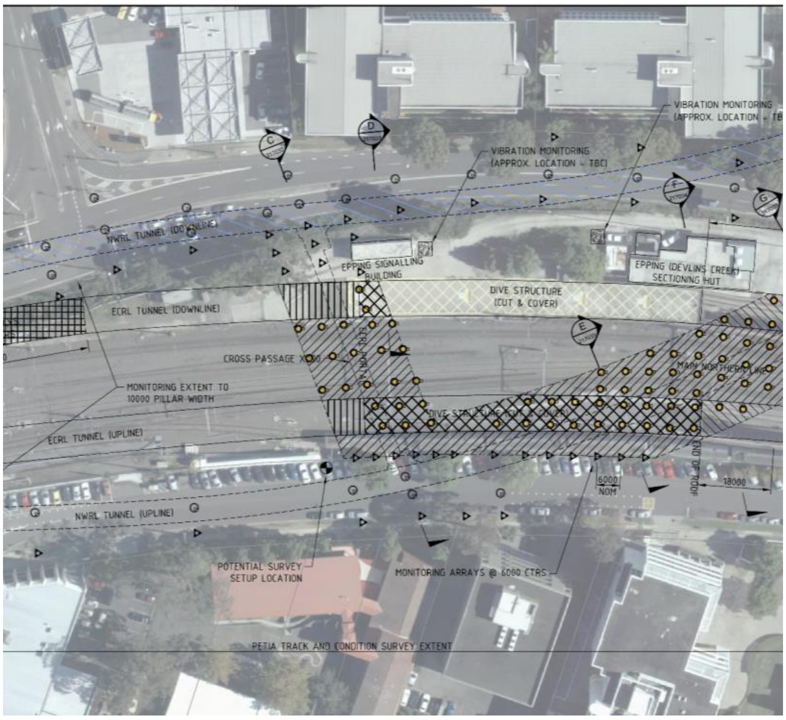


Figure 6: Survey markers and targets proposed close to Epping train station where the tunnel alignment of Sydney Metro Northwest TSC (NWRL) crosses beneath the existing train tracks of the Northern Line and Epping to Chatswood Rail Link (ECRL)

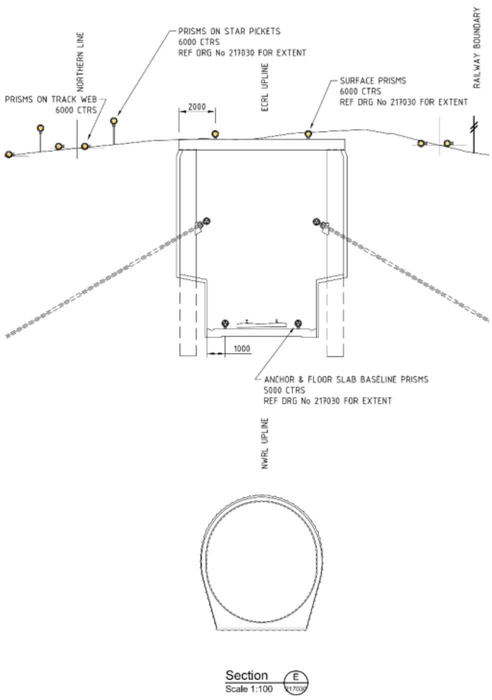


Figure 7: Cross section through Section E of Figure 6, illustrating relative elevations of the Sydney Metro Northwest TSC tunnel (NWRL) and the existing train tracks of the Northern Line and Epping to Chatswood Rail Link (ECRL)

The benefits of EIC GeoView were particularly apparent in the monitoring and assessment of tunnel induced deformation. As the tunnel alignment was constructed beneath well-established suburban areas, the impact of the tunnel construction on existing structures had to be captured with accuracy and efficiency. Instruments such as survey markers/targets, crack pins and tilt beams were installed upon various structures located at the ground surface within the predicted zone of influence of the tunnel. An example of the monitoring plan for surface structures is provided in **Figure 6** and **Figure 7**, where TSC (NWRL) crosses beneath two existing rail lines at Epping, NSW (Northern Line, and Epping to Chatswood Rail Link, ECRL). Using EIC GeoView's customisable grouping function, the monitoring points at the ground surface could be viewed relative to the progress of the tunnel excavation. For example, **Figure 8** provides an illustration of the recorded settlement at the ground surface relative to the progress of the tunnel face passing beneath Edward Bennett Drive at Cherrybrook. This information allowed the engineers to assess whether the recorded settlements were related to the tunnel excavation, and whether the rate and magnitude of settlement were expected to trend along their predicted trajectory. As all records were time stamped it was simple for the engineers to determine the date/time at which certain monitoring values were registered. Moreover, the records provide the details of the user responsible for loading the input, fostering accountability and traceability of data. This degree of multi-point data assessment, efficiency and transparency could not have been done without the capabilities of an advanced instrumentation and monitoring data management system such as EIC GeoView.

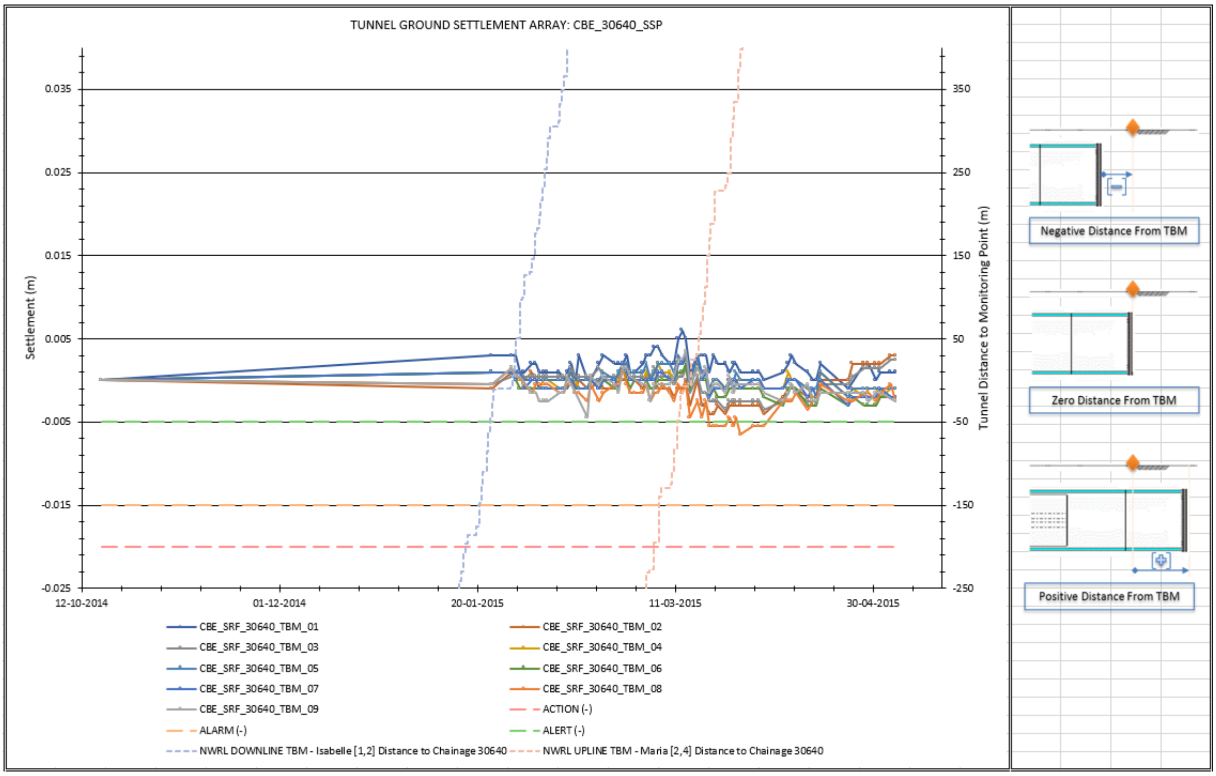


Figure 8: Illustration of recorded settlement at ground surface relative to the progress of the tunnel face at Edward Bennett Drive, Cherrybrook

Tunnel convergence was measured using optical prisms arranged around the internal perimeter of the tunnel excavation. The points were measured using automated total stations providing real-time records of the movement, allowing engineers to formulate an assessment of the tunnel stability. Once the tunnel face had progressed a certain distance from the convergence array and the magnitude and rate of deformation had dwindled the monitoring would then be ceased. An example of the monitoring records from a convergence array is provided in **Figure 9**.

On Sydney Metro Northwest ground investigation databases and associated functionalities were incorporated into EIC GeoView. This feature of the program allowed the plan locations of all the available ground data, such as boreholes, cone penetration tests and environmental test locations, etc., to be overlain onto aerial imagery and a plan of the alignment. A filtering function was incorporated to help the user search for the desired ground data. By selecting the ground investigation icon the investigation logs and related log files (such as laboratory test data) could be shown. **Figure 10** provides an example of the available ground investigation data overlain onto an aerial image at TSC. Further, with the inclusion of monitoring data in the same database, engineers could easily associate the available ground data with available monitoring information, e.g. correlating piezometer readings with the ground strata found in the borehole logs.

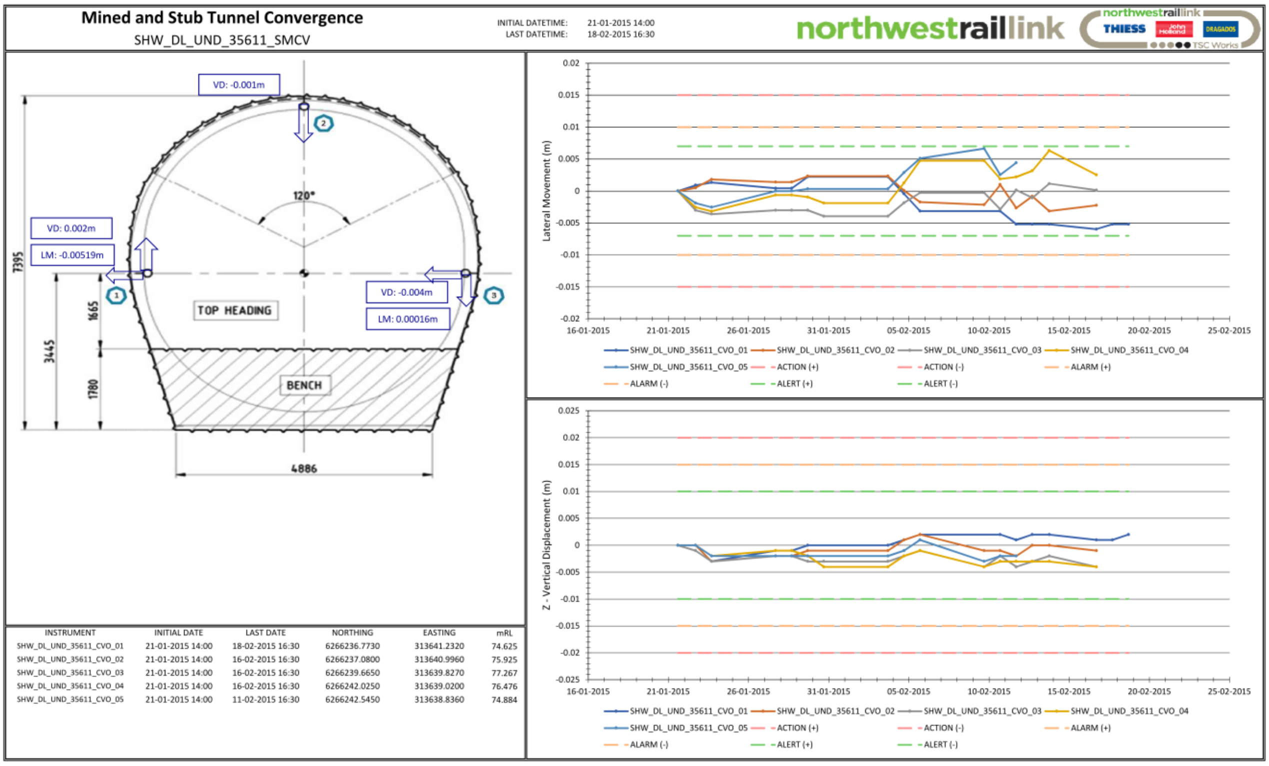


Figure 9: EIC GeoView portal illustrating outputs from tunnel convergence measurements adjacent to Showground station. VD: vertical displacement, LM: lateral movement

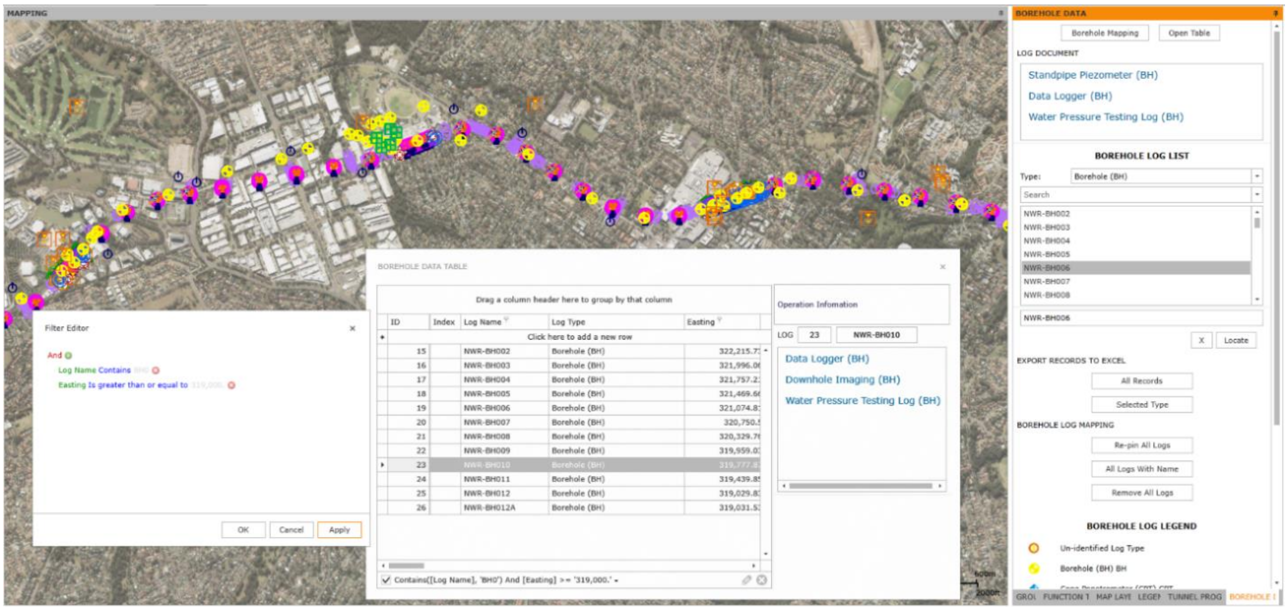


Figure 10: Illustration of ground investigation locations shown in the aerial map. Inset: Illustration of available logs associated with the user-selected investigation icon

Integrating the ground investigation data and instrumentation monitoring data into a single, easily accessible database brought unparalleled efficiencies to the engineers and the project as a whole.

3.3 FREDERICKTON TO EUNGAI PACIFIC HIGHWAY UPGRADE, NEW SOUTH WALES

Thiess Contractors were engaged by Roads and Maritime Services (Roads and Maritime) to deliver the Frederickton to Eungai Pacific Highway Upgrade (F2E) project which involved the upgrade of 26.5 kilometres of highway between

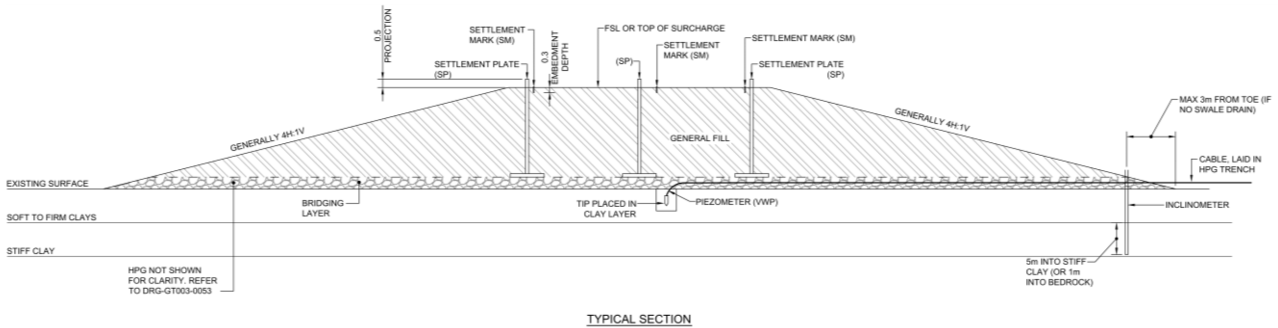
Frederickton interchange and Eungai Rail in New South Wales. Roads and Maritime were the principal for the design-and-construct contract worth A$762m (as at November 2012). The project was jointly funded by the Australian and NSW governments. One of the most geotechnically challenging aspects of the project was the treatment of soft soils covering up to 5km of the alignment. Road embankments up to 8m height were proposed upon these soft soils, placing the road pavement at risk of exceeding the residual settlement criteria of 100mm total settlement and 0.3% differential settlement, arising from long term compression of the underlying soft soils. In order to reduce post-construction settlement ground treatments using a combination of wick drains and surcharge were selected to accelerate consolidation of the soft soils prior to constructing the pavement. The additional weight of the surcharge on the embankment would hastened the consolation process, forcing the soils to consolidate more quickly than they otherwise would have under the embankment fill only.

The success of such ground treatments required the settlement of the soft soil layers to have achieved a certain degree of consolidation prior to removing the surcharge; whereupon the pavement would then be constructed on top of the embankment. Prediction of soft soil settlement is a particularly challenging and risky process, as numerous variabilities exist in soft soil geologies and treatment processes, many of which can significantly alter the consolidation rate and settlement magnitude.

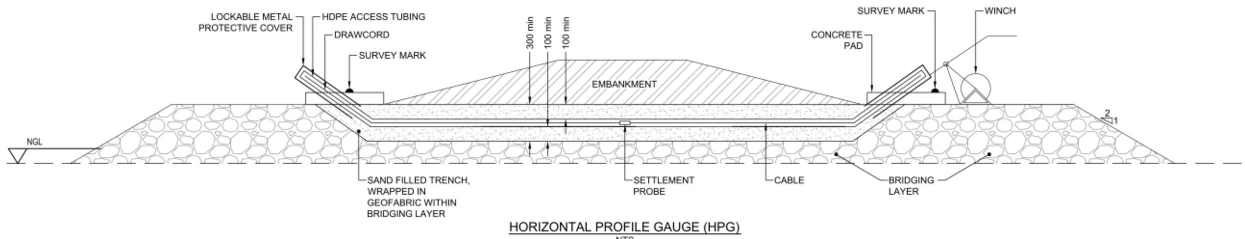
To capture the settlement progress a series of instruments were installed as listed below. Typical cross sections illustrating the instruments and their placements in the embankments are provided in **Figure 11**.

- Horizontal profile gauges to measure settlement profiles at the base of the embankment;
- Settlement plates to measure settlement at the base of the embankment;
- Settlement markers to measure settlement;
- Vibrating wire piezometers to measure pore water pressure in the soft soils; and
- Inclinometers to measure lateral movements of the soils.

The "Observational Method" was adopted by the project engineers in the soft soil areas as an additional means of managing the risk posed by post-construction settlement magnitudes. This method relied on close monitoring of the instruments during construction, using the results of the monitoring to adjust the settlement predictions as construction progressed. The Observational Method affords early detection of an eventual settlement issue, allowing alterations to the ground treatment to suit the observed behaviour if deemed necessary.



(a)



(b)

Figure 11: Typical cross section of instrumentation beneath embankments on soft soil, (a) settlement plates, vibrating wire piezometers and settlement markers and (b) horizontal profile gauge

This continual process of monitoring and refining the settlement prediction relied heavily on the monitoring records supplied by EIC GeoView. The Grouping function allowed numerous instruments to be viewed simultaneously to inform the engineers of the embankment performance, such as that shown in **Figure 12**. For example, determining the degree of consolidation in the soft soil could be assessed by observing behaviour in the settlement plate curves, then verified by the vibrating wire piezometer records.

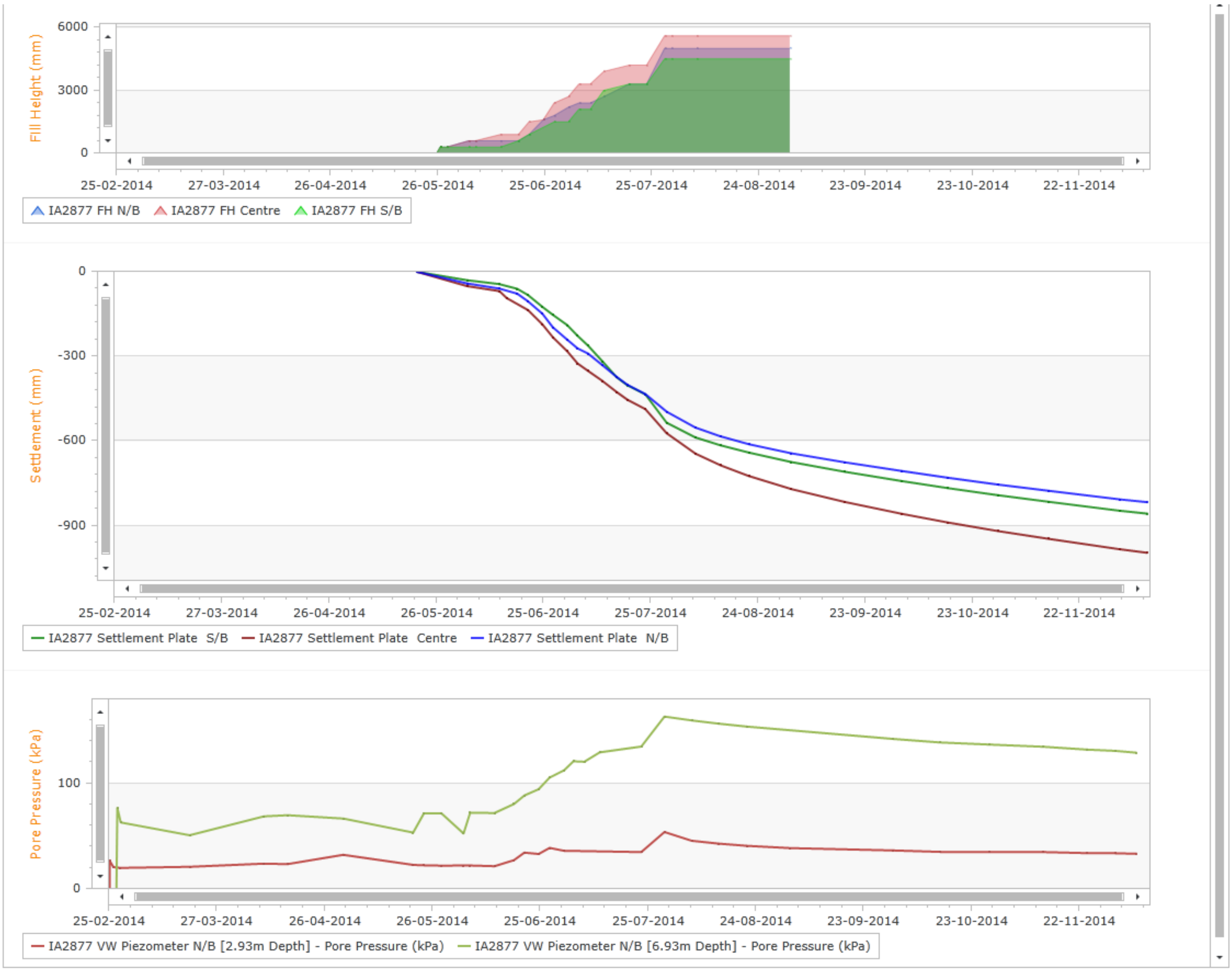
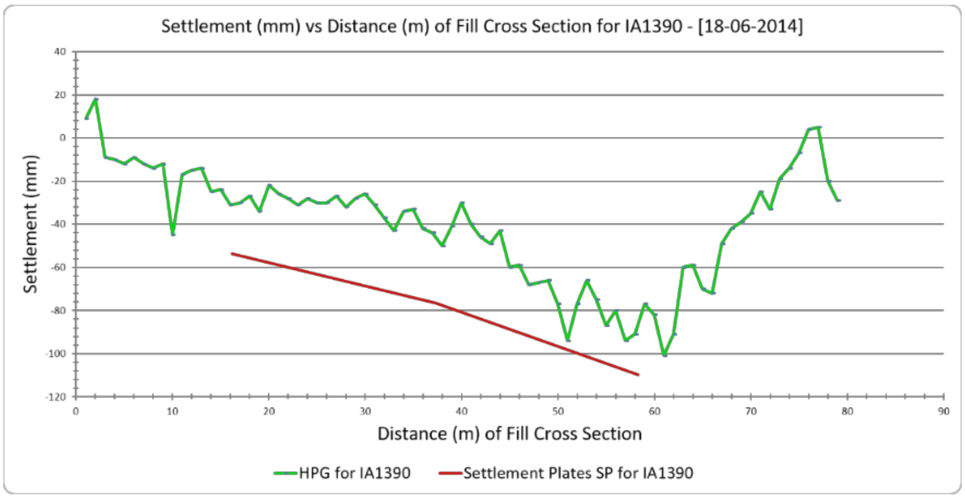
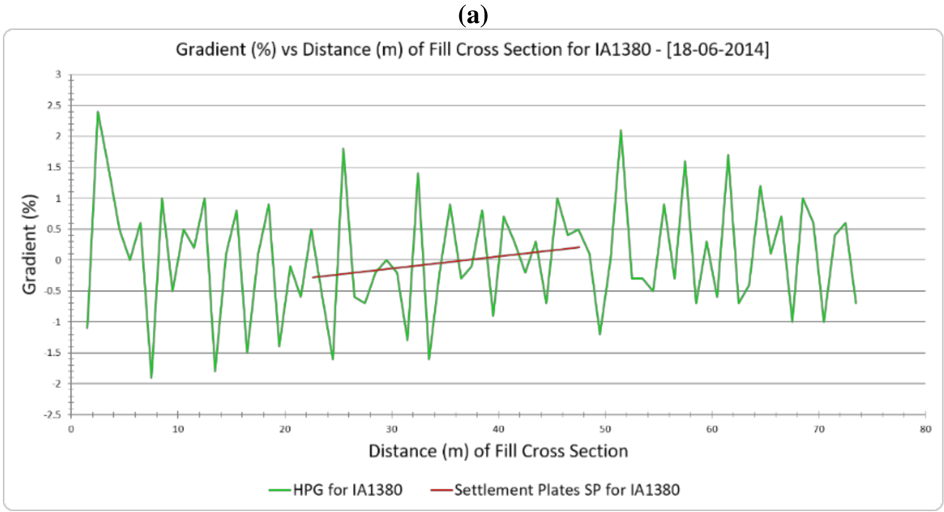


Figure 12: Viewing portal in EIC GeoView illustrating how multiple data sets from numerous sources can be viewed simultaneously to facilitate engineers with settlement predictions using the Observational Approach to soft soil treatment

Further, the automated processing core in EIC GeoView provided instantaneous calculations of differential settlement between the monitoring points each time the settlement data was updated. This resulted in significant time savings by the engineer to undertake manual assessments which would be prone to human-error. Graphs of total and differential settlement are provided in **Figure 13**.



(a)



(b)

Figure 13: Graphs illustrating, (a) settlement versus distance and (b) differential settlement versus distance

Heat maps could also be automatically created based on the magnitude of the recorded values. On F2E heat maps such as that shown in **Figure 14** could be used to easily observe the magnitudes of settlement recorded at the settlement plate arrays.

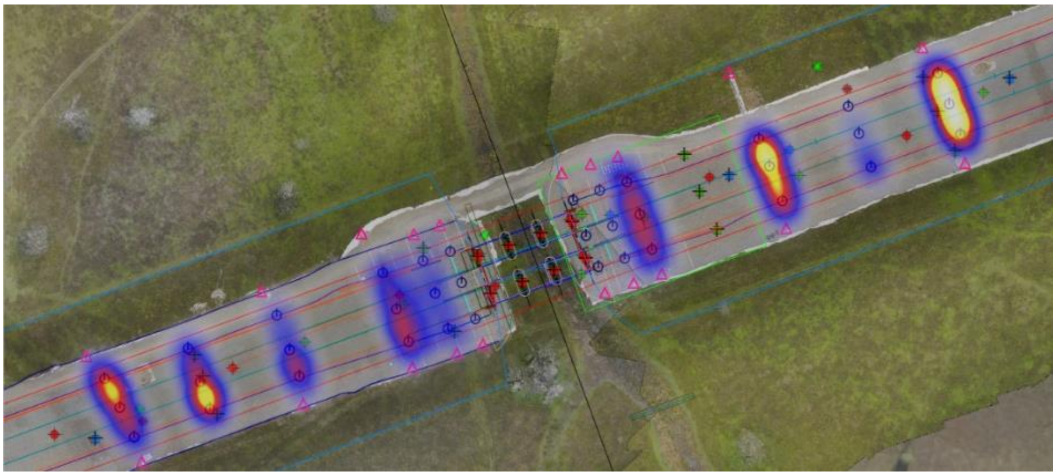


Figure 14: Heat map based on settlement values recorded from each settlement plate array on F2E

Given that the data was uploaded regularly and could be viewed simultaneously to inform the continual feedback loop required by the Observational Approach, EIC GeoView gave the engineers a degree of efficiency and up-to-date data which could not have been achieved by conventional manual methods of monitoring data management.

4 CONCLUSIONS

EIC GeoView is an advanced database management system which has been developed by EIC Activities to provide automated data processing, storage and visualisation of recorded data. This software has helped raise the transparency, processing efficiency and usability of recorded data allowing engineers to make informed decisions during and after construction. EIC GeoView has been used on numerous large-scale infrastructure projects in Australia, covering various built structures on road and rail projects. Use of the software provided the project teams with up-to-date performance of the as-built structures with unparalleled clarity and efficiency that could not have been achieved using conventional manual data collection and processing methods.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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