

AN INNOVATIVE GEOTECHNICAL MONITORING SYSTEM FOR SOFT GROUND TREATMENT ON W2B PACIFIC HIGHWAY UPGRADE PROJECT

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ABSTRACT

This paper presents an innovative geotechnical monitoring system for soft ground treatment for the on-going Woolgoolga to Ballina (W2B) Pacific Highway Upgrade project. This \$4.3 billion project is Australia's largest regional infrastructure project and will upgrade about 155 kilometers of highway to four lane, divided road. The project starts about six kilometers north of Woolgoolga (north of Coffs Harbour) and ends approximately six kilometers south of Ballina.

One of the major challenges on this project is the construction of road and structures over soft compressible ground with a total length of over 25 kilometers in 1 to 2 years' time. During construction, the short term slope stability and settlement performance will be monitored by a total of 1500 instruments taking up to 10 million measurements. This will enable the team to take early preventive actions to maintain slope stability, to protect public safety and existing structures during construction, and to ensure that the projected long term settlement is within acceptable limits.

Following the standard file based approach, the instrumentation data was estimated to produce up to 80,000 files to be manually handled. To efficiently process the data, limit the potential for manual errors and reduce the turnaround time, Pacific Complete developed an instrumentation and monitoring (I&M) system using its project integration platform, automatically warehousing the data on the project servers and presenting real time dashboard to the team using Qlik Sense and its GIS extension. In addition to providing high availability, transparency and reliability of the information, this system is expected to realize savings of \$2.5M in manual handling of the information alone. The system can be progressively extended to support direct data download from automated instruments, more instrument types, single and multiple instruments alerts, and refined graphs to suit the requirements of linear infrastructure geotechnical monitoring.

Compared to the traditional copy and paste method using Excel, the benefits of this I&M system include fast processing of massive data on a daily basis, automatic integration with GIS maps, chainage, instrument type and locations, lateral displacement plots, settlement plots (both predicted and measured) in longitudinal sections, ratios of lateral to vertical displacement and fill height plots, pore pressure plots and existing road/structure movement plots.

1 INTRODUCTION

Roads and Maritime Services (RMS) has engaged Pacific Complete, comprising Laing O'Rourke and Parsons Brinckerhoff, to partner with the RMS Pacific Highway Office to deliver the project. Pacific Complete will deliver the project using a Delivery Partner model similar to the approach used for the construction of the London Olympics infrastructure.

The 155 kilometre upgrade between Woolgoolga and Ballina is Australia's largest regional infrastructure project and the last Pacific Highway link between Hexham and the Queensland border to be upgraded to four lanes. The

Woolgoolga to Ballina project will upgrade about 155 kilometres to four-lane divided road from about six kilometres north of Woolgoolga (north of Coffs Harbour) to about six kilometres south of Ballina.

When complete, the project will:

- Save 13 kilometres in travel distance by reducing overall length from 180 kilometres to about 167 kilometres
- Reduce travel time from 130 minutes to about 105 minutes, saving 25 minutes
- Allow a higher posted speed limit of up to 110 km/h
- Reduce crash rates by an expected 27 per cent due to divided carriageways
- Improve travel reliability through better flood immunity, fewer incidents and more readily available alternative routes.

There are a total of 11 sections from Woolgoolga to Ballina. Figure 1 shows the entire route of this project. Construction is on-going at sections 1 and 2 from Woolgoolga to Glenugie. Early works construction (preloading of soft ground) is also on-going at Section 5 and 11. Detailed design is being done by four consultants from section 3 to 11. Site investigation for detailed design and early enabling works construction are also on-going across the whole project.



Figure 1: Woolgoolga to Ballina project map (courtesy of RMS)

One of the challenges on this project is the construction of embankments over deep soft clays that require ground treatment to solve the long term settlement issues. There are a total of 11 soft soil sites and the majorities are covered in the Early Works package, which is divided into 5 Waves as shown in Table 1 below. Soft soil treatment design for the remaining soft soil sites is done by Profession Services Contractors (PSCs) in 4 portions.

Table 1: Soft Soil Sites and Waves

Portion	Section	Soft Soil (SS) Site	Description	Chainage (SPIR)		Wave Package
				From	To	
A	3	SS-01	Champions Creek	56415	56710	Wave 5A
A	4	SS-02	South of Shark Creek	72835	74325	Wave 3
		SS-03	McIntyres Lane	77150	77450	
		SS-04	South and North of Maclean Interchange	78635	80800	
B	5	SS-05	Koala Drive to Yamba Road	83400	85150	Wave 1
				85192	85770	
		SS-06, 07	Harwood and Serpentine Channel	87255	87680	
				87840	89310	
				89415	90740	
				90860	91100	
93000	93700					
C	8	SS-08	Tuckombil Canal	129520	130850	Wave 4
D	11	SS-11	Whytes Lane to Pimlico Road	160040	163800	Wave 2

Early works design was carried out by AECOM/Coffey. The following criteria were adopted in the design:

- 1) Total Residual Settlement (pavement settlement in 40 years): within 100mm and 200mm for rigid and flexible pavement respectively for general embankment; within 50mm in the 20m structural zone from a bridge abutment.
- 2) Differential settlement: 0.3% and 0.5% in both directions for rigid and flexible pavement respectively;
- 3) Slope stability: Factor of Safety (FOS) of any batters not less than 1.2 for short term end of construction, flooding and earthquake cases; not less than 1.5 in the long term drained case.
- 4) Culvert settlement: within 150mm in 100 years.

Soft ground treatment methods adopted in Early Works design are as follows.

- 1) Preload only (no surcharge, no wick drains)
- 2) Surcharging (no wick drains)
- 3) Surcharging with wick drains

Instrument type and purpose for monitoring of soft ground are listed below.

- 1) Settlement plate for settlement monitoring near ground surface
- 2) Multi-depth magnetic extensometers for settlement monitoring at depth
- 3) Hydrostatic profile gauge (HPG) for settlement profile across the embankment
- 4) Standpipe piezometer for monitoring baseline ground water table
- 5) Vibrating wire piezometers for monitoring pore pressures due to embankment loading
- 6) Inclinometer for monitoring horizontal ground displacement
- 7) Settlement marker at embankment top, existing structures and pavement

Pacific Complete established an innovative dashboard system for instrumentation monitoring. The details of this system will be discussed in Section 3 later. Assessment of short term slope stability to control the filling rate in

order to maintain a minimum FOS of 1.2 will be discussed in Section 4. Review and back analysis on settlement performance and long term creep will be discussed in Section 5.

2 GROUND CONDITIONS AND SOFT GROUND TREATMENT DESIGN

The project traverses a number of floodplains which are underlain by significant depths of soft and compressible soils. Construction of embankments over these soils would cause significant settlement issues during construction and in the long term if the foundation is not treated prior to pavement. Figure 2 below shows the interpreted geotechnical long section and design parameters at Yamba, south of Clarence River. This is one of the worst soft ground areas on this project.

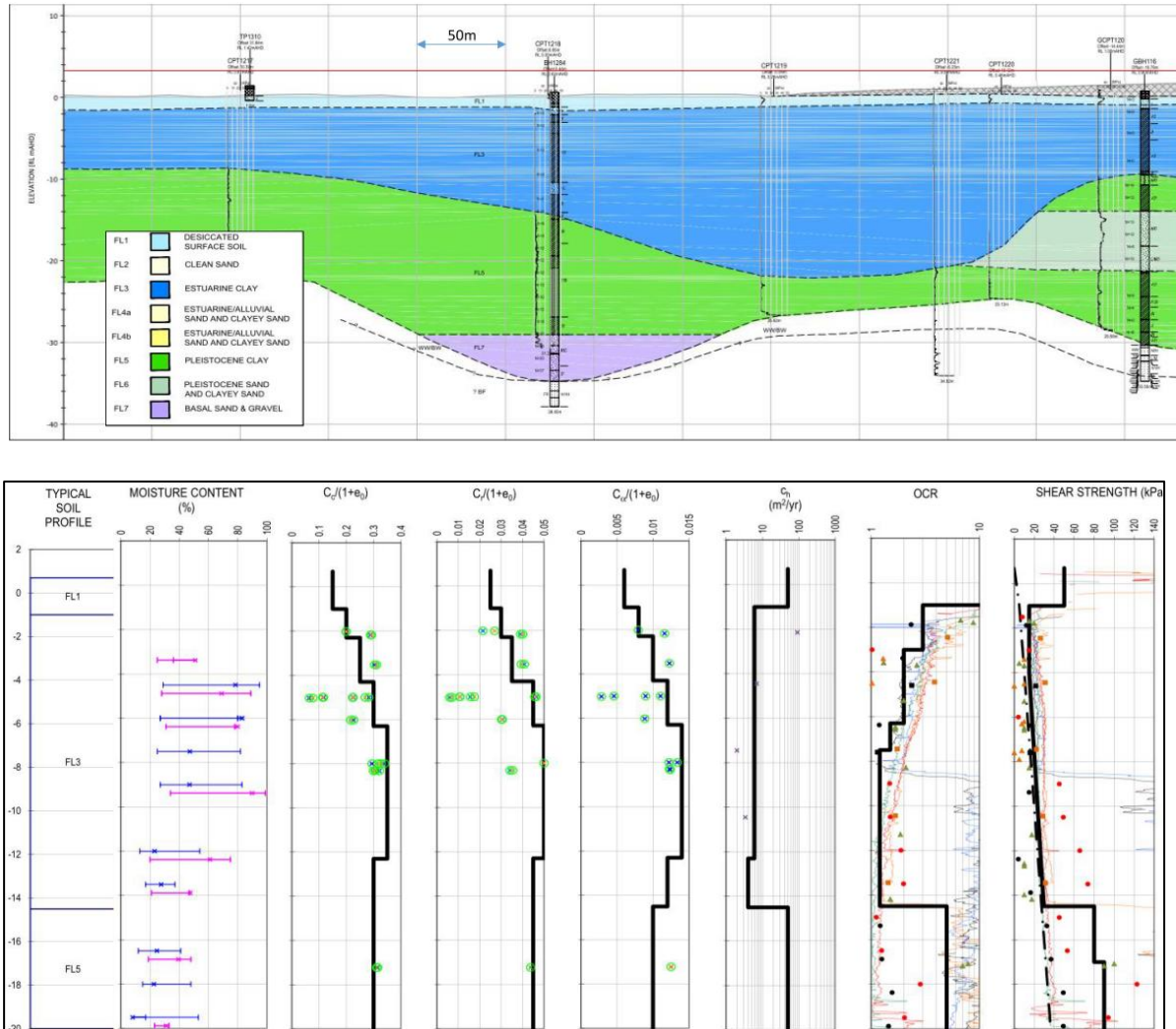


Figure 2: (top) Geotechnical long section; (bottom) Design parameters

3 INSTRUMENTATION AND MONITORING

Pacific Complete estimated that the instrumentation on the project would produce between 80 000 and 100 000 data files from all instruments, containing around 10 million data points¹. Based on the average manual processing time, automating the processing of the data would generate savings in the order of \$3M AUD.

As part of the process and system development, Pacific Complete undertook a comparison of existing data management software solutions on the market with the development of an in-house system. Although there are existing data management systems with strong capabilities already, the in-house solution has been preferred principally because of:

- the bespoke nature of the project, with long linear soft soil areas requiring customisation of the software outputs, and
- the opportunity to use existing software and hardware infrastructure on the project realising further cost saving.

Without these factors the use of an existing solution could have been preferred.

The solution developed by Pacific Complete involves a custom application for data upload called “I&M Portal”², a Microsoft SQL Server database and the Qlik Sense dashboarding platform with the QlikMap GIS extension.

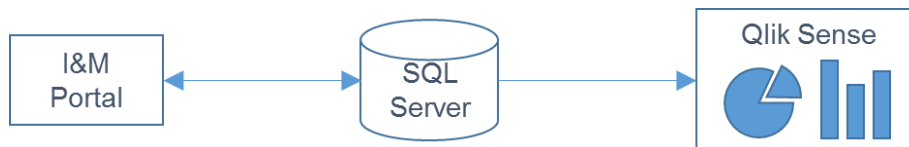


Figure 3: Pacific Complete I&M in-house system

3.1 I&M Portal

The portal manages all inputs into the database:

- Create, edit, deactivate or delete instruments,
- Upload, deactivate or delete measurements
- Download data from external instrumentation servers or the project mail box
- Close alerts and alarms

The portal can be used manually, but can also be configured to automatically pick up data from a given mailbox or to download data from external web server at regular frequencies. Email attachments are loaded onto the system based on the subject line; if there is error in invalid subject line, attachment format or data format are rejected and sent back to the users with an error description. Data is also downloaded every day for all piezometers from the instrument supplier web site. Automatic settlement plates and accelerometers are now also being tested.

The implementation of this automatic upload process led to a reduction of data turnaround time from 5 days down to 1 day, with most of the remaining lag time being the time between data collection on site and accessibility to a work station for upload to the portal. Once the data is sent to the system, the turnaround time is under 1 hour, with an on-demand refresh rate of under 5 minutes.

3.2 SQL Database

¹ Estimate based on the anticipated number of instruments for the project and RN99 specification for monitoring frequencies per instrument. Although it is common practice to have multiple instruments in a separate sheet of the same file, this is counting one file per instrument.

² The solution is developed using the Net Framework

The database runs all calculations, unit conversions, data reductions and alerts. It also calculates checksum and standard deviation for all baseline measurements enabling a quick quality check. Based on predefined trigger levels, it sends alert emails to email distribution lists based on the project area and alert level.

3.3 Dashboard

Qlik Sense reads data from the database on a set frequency and presents it to site and geotechnical engineers via a web portal with interactive dashboards. The dashboard portal also allows users to download both the raw and reduced data for any instruments, and print graphs to a file with pdf format. The layout of the dashboard has been designed by site and geotechnical engineers to best present the relevant information for site operations. Users can however create their own dashboard pages to present that data differently.

The dashboard application is made of multiple sheets presenting data for single instrument types or grouped instrument types for alerts such as slope stability.

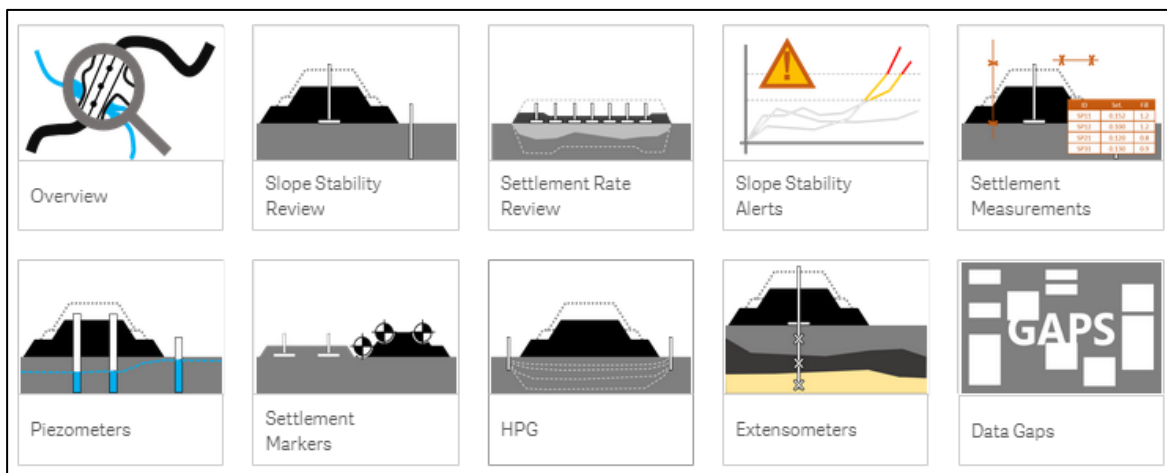


Figure 4: Geotechnical dashboards

The tables, charts, graphs and maps – generically called ‘controls’ – used on every sheet are interactively linked to the underlying data, so that selecting a project area, period, instrument type or instrument, will automatically filter the data being displayed on every control. The same session being open on multiple pages, screens or even computers and mobile devices will maintain a link to this dynamic filtering.

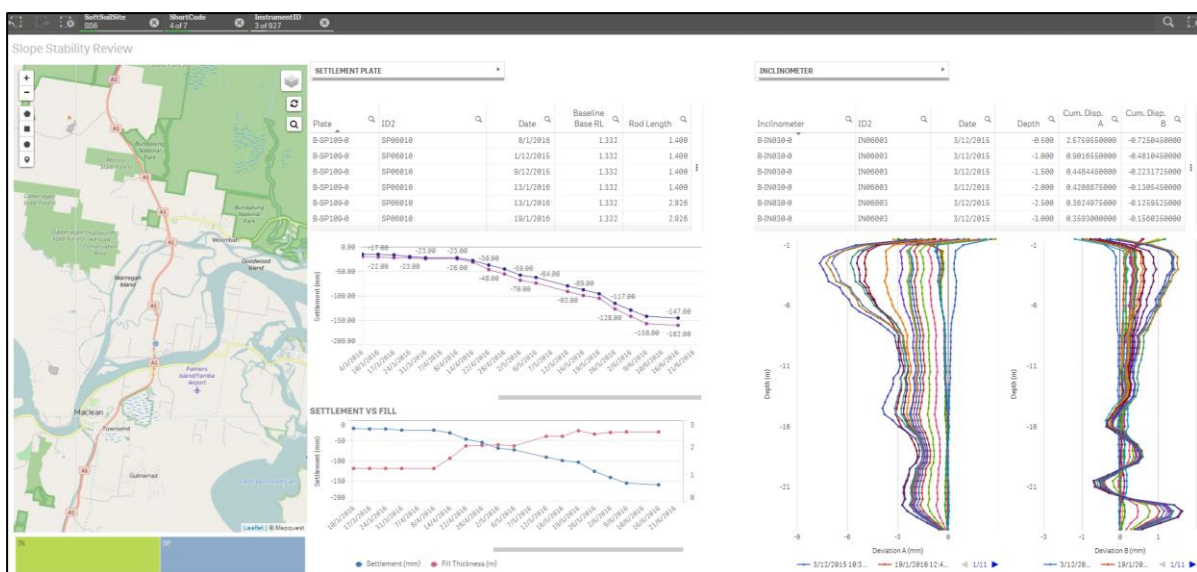


Figure 5: Fill height, settlement and horizontal displacement time plots

The map control is linked to the project GIS server enabling the display of layers of data, imagery, design, survey results etc.

Other controls display settlement long sections with both predicted and actual settlement, horizontal displacement from inclinometer as a proportion of settlement for stability alerts, piezometer pore pressure for consolidation monitoring, HPG, extensometers and settlement plate performance etc.

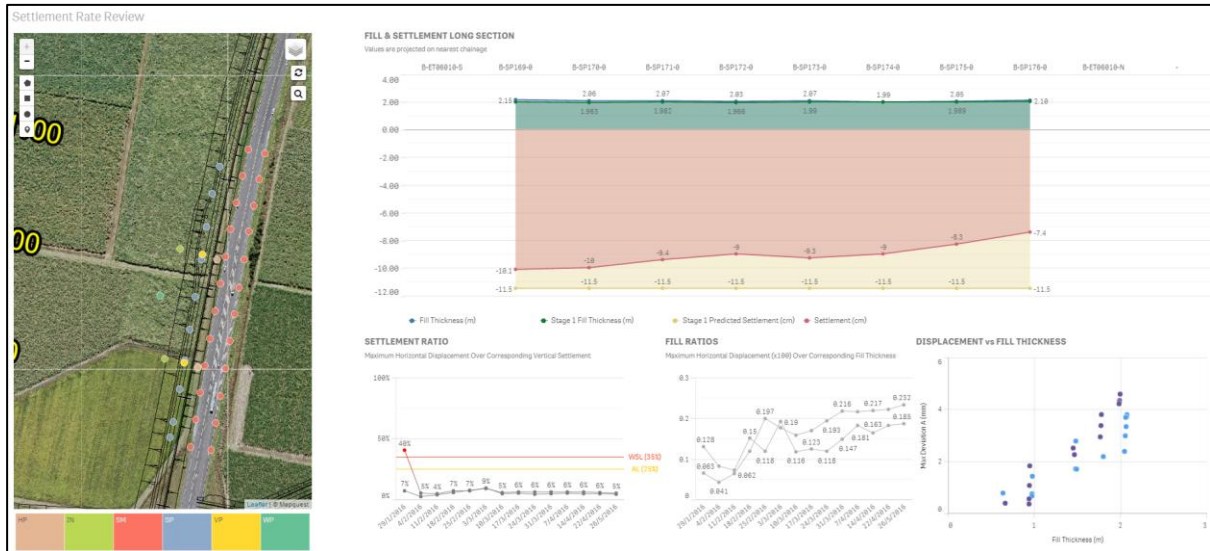


Figure 6: Fill height/design height, monitored/predicted settlement longitudinal section, deformation ratio plots

The system also provide access to the lowest granularity of information, down to the date emails where received, the name of sender and files attached, the frequency of monitoring of every instruments etc., thus providing a clear audit trail for every measurement presented in the dashboard. Invalid measurements, outliers or errors can be deactivated from the I&M Portal in order not to disrupt the table and plots.

The implementation of these geotechnical dashboards has provided an audit tool that has identified errors and gaps enabling early resolution by correction or re-measurement that would not have been possible at a later stage. Data quality has thus been improved, up to doubling for some instruments, from 45 to 88%³.

4 SHORT TERM SLOPE STABILITY ASSESSMENT

Short term slope stability is monitored and managed by Pacific Complete. Trigger levels for short term slope stability are shown in Table 2 and 3 below.

Table 2: Trigger levels for embankments with wick drains

Parameter	AL	WSL
hm/S (=DR)	0.25	0.35
$\delta hm/\delta t$ (mm/day)	10	15
Action	Increase measurement frequency	Stop filling

Notes: hm = max horizontal displacement from an inclinometer; S = settlement from adjacent settlement plate to the inclinometer; t = time in days; AL = Alert Level; WSL = Work Suspension Level

Table 3: Trigger levels for embankment without wick drains

³ Based on the number of days for which the data was provided for an instrument over the period of activity of the instrument, before and after implementation of the system.

Parameter	AL	WSL
hm/S	0.5	0.7
$\delta hm/\delta t$ (mm/day)	10	15
Action	Increase frequency	Stop filling

The above levels were based on a minimum FOS of 1.2 (the requirement of W2B project specification) based on the recommendations provided in the following references and previous project experience.

- Figure 26 of Ladd (1991),
- Table 1 of Saye & Ladd (2004),
- Figure 13 of Tavenas et al. (1979),
- Figure 9.2 & 9.3 of CIRIA Report C185,
- Figure 15 of Matsuo and Kawamura (1977), and
- previous Pacific Highway Upgrade projects e.g. Cooperook to Herons Creek and Nambucca Heads to Urunga

In addition to the trigger levels in Tables 2 and 3 above, the trend of max lateral displacement versus fill height is also monitored when a decision is made to slow down or stop filling. An accelerating trend is considered to be a indicating a potential local instability due to contained undrained plastic flow in the foundation soil. A typical screenshot of slope stability monitoring is shown in Figure 6.

5 HOLD POINT RELEASE FOR PRELOADING/SURCHARGE

Pacific Complete established a process for review and releasing Hold Points for preloading/surcharging. Once the full height of the embankment is reached, and short term slope stability is no more a concern, regular review of settlement, pore pressures, ratio of lateral to vertical displacements are conducted to check whether settlement performance is expected and targeted degree of consolidation (DOC) is reached. A decision is then made on whether extra surcharge or time is required. Once the targeted DOC is achieved as indicated from Asaoka plots, excess pore pressures against the applied load and DR, a back analysis is conducted to match the monitored settlement and to ensure that the projected TRS is within limit.

Back analysis is normally carried out by the soft ground designer and/or PC Geotechnical Team using 1-D spreadsheets. However, for high embankments over deep soft ground, which fall\ in a high risk category in terms consequences of failure, a more rigorous finite element analysis using an advanced soil model is performed. This is to mitigate the following limitations of 1-D spreadsheets:

- difficulty/inability to consider stress dependent permeability (or rate of consolidation), especially in the stress range of approximately 75% of the yield stress to 100% yield stress and beyond for lightly over-consolidated clays
- shear induced movements due to contained plastic flow at low FOS against slope failure (1.2 to 1.5) typically associated with staged construction
- difficulty/inability to consider undrained creep thus tending to underestimate settlement during construction

Two typical examples of back analysis are given below.

Case 1 - monitored settlement exceeded the predicted settlement but no extra surcharge was required. Figure 7 below shows the overall monitoring results.

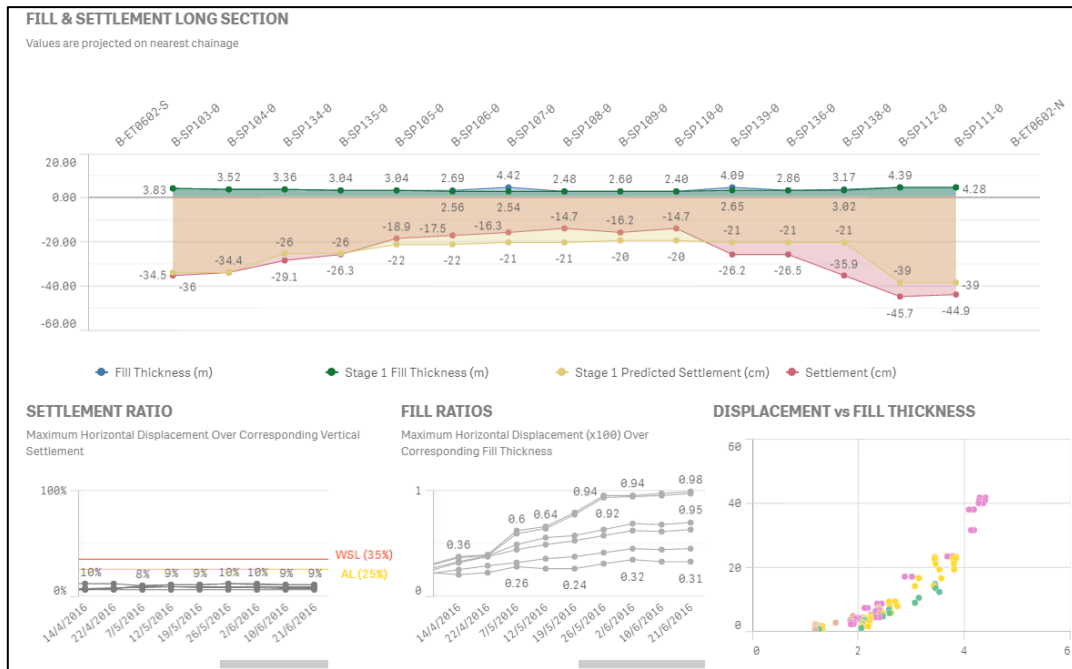


Figure 7a: Case 1 (no extra surcharge required) – settlement profile in the longitudinal direction

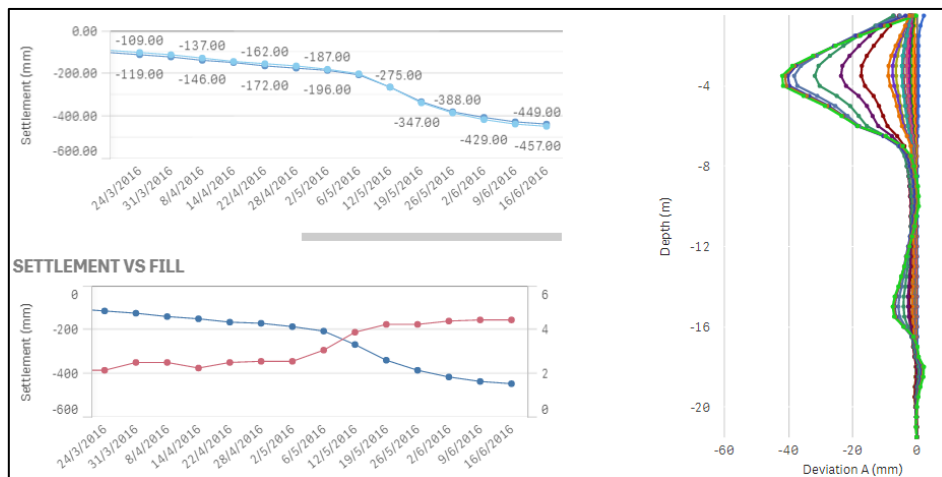


Figure 7b: Case 1 (no extra surcharge required) – settlement vs fill height and lateral displacement

The design allowed for surcharging of the second layer soft clay at 14 to 16.5m in depth. Monitored lateral displacement and early extensometer (stopped working at later stage) data indicated it was in an over-consolidated (OC) state and thus no surcharge was required.

Case 2 –monitored settlement exceeded predicted and extra surcharge was required. Figure 8 below shows the overall monitoring results. The design prediction (with predicted pavement of 50mm) was exceeded due to the following:

- field soft clay is more compressible, or
- the thickness of the soft clay is greater,
- or the combination of the two above

Back analysis indicated an extra 0.6m surcharge was required to meet the pavement settlement with 50mm.

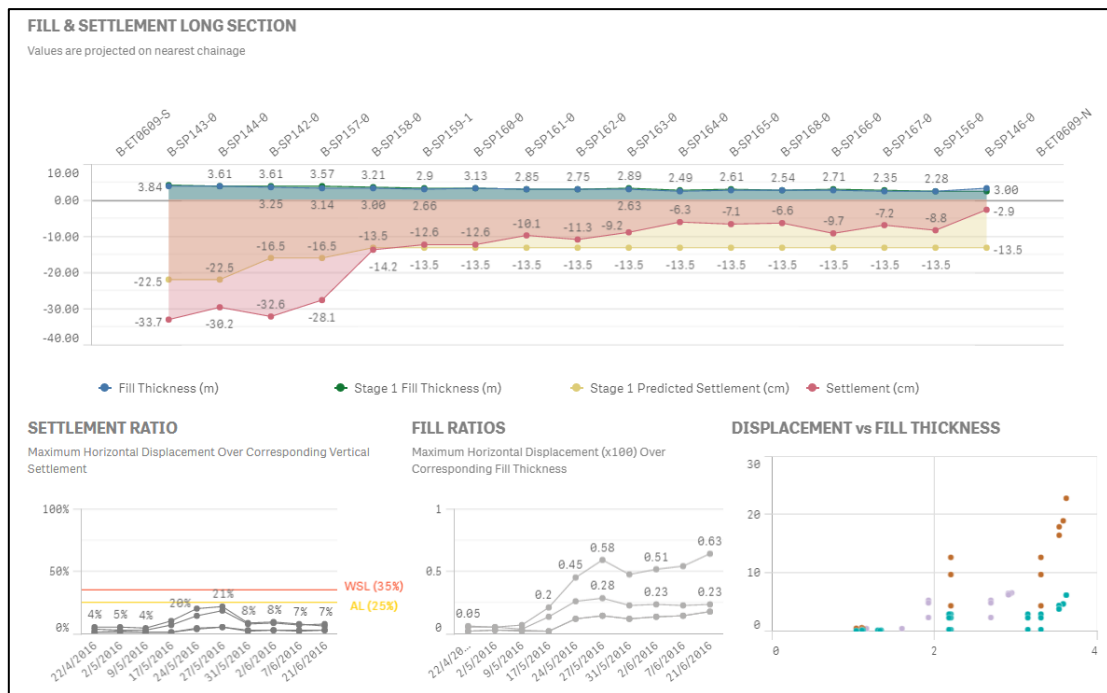


Figure 8a: Case 2 (extra surcharge required) – settlement profile in the longitudinal direction

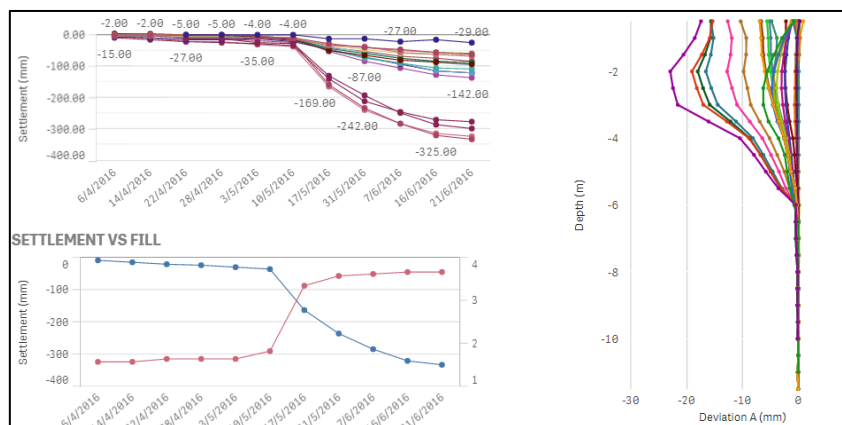


Figure 8b: Case 2 (extra surcharge required) – settlement vs fill height and lateral displacement

6 CONCLUSIONS AND RECOMMENDATIONS

An innovative Geotechnical I&M system has been established by Pacific Complete for managing the short-term slope stability and long-term settlement performance for a cumulative length of over 25 km of soft ground treatment on the Woolgoolga to Ballina Pacific Highway Upgrade project. The advantages of this system are essential to the successful delivery of the soft ground treatment on time and on budget. Key features of the system are as follows:

- short turnaround time from reading to uploading to the dashboard system: real time to 1-3 days depending on instrument data collection process
- Real time, user friendly, customisable dashboard to the whole team
- comprehensive presentation of settlement, lateral displacement, pore pressures to facilitate early decision-making, quicker, on a bigger picture compared to conventional Excel methods
- fast processing of massive data, automatic data warehousing
- reliability of system and data quality and availability

- automatic alarm messaging to relevant parties for early intervention on site to mitigate the risks of slope instability
- Easy combination of data from different instrument types
- Extensible platform to new instrument types and graphs
- Additional functions e.g. curve fitting and projecting of future settlement based on monitored data, projecting of future settlement based on Terzaghi' consolidation theory using monitored settlement versus time plots

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