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Mercer to Longswamp Expressway (Mercer) and Project PJK (Tauranga) Instrumentation and Monitoring

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Abstract:

This paper discusses the practical application of geotechnical instrumentation on two of the larger roading projects undertaken in New Zealand in recent years. Both projects are in areas susceptible to high settlements where a range of instruments have been installed and preloads applied.

The Mercer to Longswamp project involves the construction of 10 km of four-lane expressway, a large proportion of which lies in close proximity to the Waikato River, with high water tables and highly compressible soils.

The PJK roading project in Tauranga consists of just over 8 km of new roads, the majority being constructed in an estuarine environment along the Kopurererua Stream in very soft compressible soils subject to high pore water pressures and settlement.

The effect of settlement and pore water pressures in the foundations, especially on the Mercer to Longswamp project, have been significant, with long pre-load periods required, to allow pore pressures to dissipate and settlement to reach an acceptable level.

This paper examines the practicability of various types of instrumentation and downhole testing in these environments and illustrates the many challenges encountered by the instrumentation practitioner.

Also discussed is the importance of appropriate instrument selection to withstand the rigorous physical environment and the various monitoring methods and techniques employed to ensure high quality data is obtained.

1.0 INTRODUCTION

The Mercer to Longswamp Expressway in the Northern Waikato and the PJK Expressways project in Tauranga are two of the more significant roading projects to be commissioned in New Zealand in recent years.

During the investigative phases of both projects, it became very clear that the geology and ground conditions would prove to be extremely challenging and would play a major role in design decisions and construction costs.

With this in mind, the requirement for monitoring became paramount and the project specifications reflected this with the inclusion of a wide ranging and detailed instrumentation installation and monitoring programme.

Geotechnics was awarded the Instrumentation subcontract to supply, install and provide ongoing monitoring services to both projects.

The Mercer to Longswamp Expressway is being constructed for Transit NZ with Stage One awarded to Stevensons Construction Ltd and the subsequent second and third stage contracts won by Fulton Hogan Ltd.

Geotechnical instrumentation has been supplied and installed in all three stages and a comprehensive monitoring programme and associated database established from day one. Stage Three is due to be completed by August 2003 with the fourth and final stage (with a construction period of three years) programmed to be awarded in September 2003.

The PJK Expressways project, which began in 1999, was completed in July 2003 and was awarded to the Fulton Hogan/Smithbridge JV.

The Tauranga District Council and Transit NZ were joint clients for this project as the roads under construction were from both the regional and national networks.

This paper describes (with both projects in mind) the rationale for instrumentation, instrument selection and type, installation challenges and the benefits gained from the data collected.

2.0 PROJECT DESCRIPTIONS

2.1 MERCER TO LONGSWAMP EXPRESSWAY (MERCER)

This section of expressway is 12 km long and is the northern most sector of the Waikato Expressway, which will eventually provide four lanes of highway between Cambridge and Auckland.

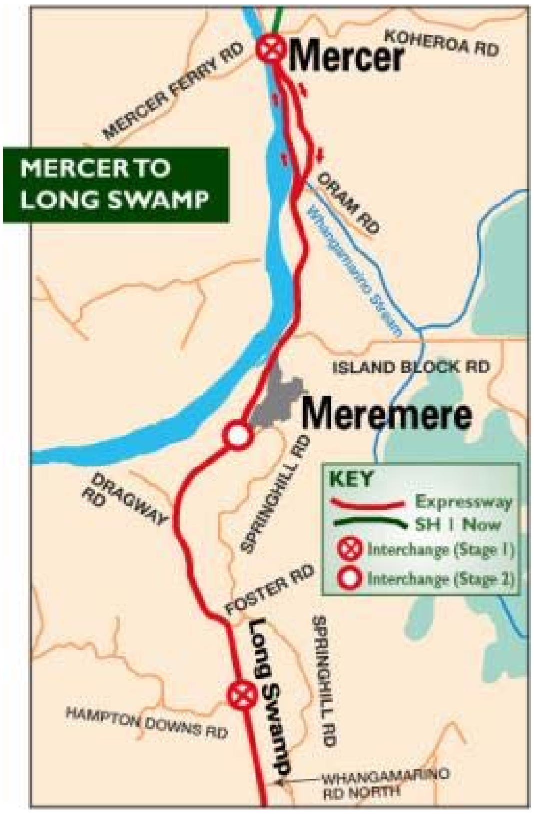


Figure 1. MLSE Site Map

The Mercer to Longswamp section includes large areas of swampy ground throughout its length and requires several sizeable cuts, the construction of a 160 m long bridge over the Whangamarino river and includes two major interchanges at Mercer and Hampton Downs Road.

A significant aspect of this project was the requirement to mitigate the effects of the very swampy ground and highly compressible soils, which in places were up to 30 metres deep. To achieve this, thousands of wick drains have been installed, and embankment preloads applied to speed up consolidation. These features let water escape up through the wick drains and through a soil drainage blanket, which deposits the water outside of the roadway footprint. To add to this, numerous deep-seated landslides were discovered along the proposed route and these required stabilisation by dewatering and other methods.

Transit NZ is the client for this project, which is being constructed in four stages to allow for the very long periods of settlement and consolidation and for stabilisation works to be completed.

2.2 PJK EXPRESSWAYS (TAURANGA)

The PJK Expressways project in Tauranga consists of eight kilometres of expressway, with seven bridges, over 1.4 million m³ of earthworks, embankments up to 14m high and cut slopes to 25m high. At the time of contract award, it was the largest roading project to be undertaken in New Zealand.

The project consists of three main arterials, being:

Route P 0.5 km long and links Tauranga City to the interchange

Route J 3.1 km long link from the north to the interchange

Route K 4.5 km long toll road, which links SH29 from Matamata to the interchange.

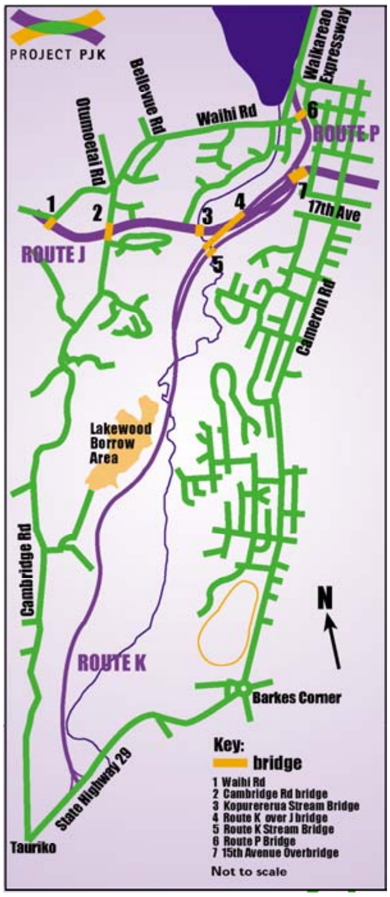


Figure 2. PJK Site Map

The route chosen by the designers for this project was such that considerable attention had to be paid to the geotechnical aspects associated with the various foundation conditions. These conditions included cuts in sensitive volcanic ashes, building embankments on highly compressible fine-grained soils and mitigating the effects of artesian groundwater pressures.

3.0 RATIONALE FOR INSTRUMENTATION

Following extensive subsurface investigations for both projects, it became patently clear that the range of geological conditions encountered, required a cautious approach involving the measurement of a variety of parameters.

The rationale to establish a comprehensive instrumentation network was based on:

- Factors of Safety – Without instrumentation and measurement, design parameters would be calculated based on certain assumptions. These assumptions would need to be conservative and would result in high factors of safety, resulting in increased construction costs.

- Reduction of Costs – An appropriate and reliable instrumentation programme would greatly reduce the risks associated with road construction in these environments. This reduction of risk should provide a higher level of confidence to the construction process and result in reduced construction costs.

- Construction Programme – Regular and accurate results obtained from well-selected and positioned instruments, would provide an invaluable construction tool. This information would allow the designer and constructor to determine filling rates, cut volumes and pinpoint areas requiring special attention or programme changes.

- Design Changes – Instrument data from the initial phases of the projects may reveal the need to modify the design in later phases.

- Performance – Instruments could be used to monitor the in-service performance of structures and whether or not wick drains or dewatering systems are having the desired stabilising effects.

- Safety – Instruments would provide early warning of impending failures (particularly on some of the larger cut slopes). This would allow time for safe evacuation of the area and time to implement remedial action.

4.0 SUBSURFACE TESTING AND INVESTIGATION PROGRAMME

4.1 MERCER TO LONGSWAMP EXPRESSWAY

Tonkin & Taylor's involvement with the Mercer to Longswamp Project began in early 1999. This followed earlier investigations by Works Consultancy Services (OPUS) and Earthtech Consultants.

In the proposed cut slope areas the investigation programme identified existing and potential slip locations, many clearly visible from the ground and aerial photographs. This identified 13 major slides in the first 2 km of expressway south of the Mercer Township.

Figure 3. Whangamarino Diversion.

In early 1999 a programme of augers, test pits (53) and investigation boreholes (36) provided further geological data for the engineers, identifying underlying geology, slip planes and providing material for extensive laboratory testing. The testing programme included gradings, compactions, consolidation testing and effective stress triaxial testing. This programme was backed up by CPT testing in 70+ locations along the planned route, providing further strength/stiffness data.

Part of the investigation programme was the installation and monitoring of inclinometers and piezometers in the cut slopes. A total of 12 inclinometers (463 m in total) were installed in the identified slip zones to monitor the rates of lateral movement and depths of slip faces. Of these, two sheared during the first two years of monitoring.

Piezometers were also installed to identify and monitor water levels and pore pressures in the underlying ground, targeting specific water bearing layers. These consisted of 29 pneumatic piezometers (12 installed at the base of the inclinometer holes), 33 standpipe piezometers, and 29 maximum water level indicators (MWL). The MWL's provided peak water levels at times of heavy rain outside of the scheduled monitoring visits. This data was combined with local rainfall data kindly provided by a local farmer (McGraths).

The piezometer data showed how the water levels and pressures changed through time. Coupled with the inclinometer data this provided a greater understanding of the mechanics affecting the slopes and allowed for further planning and design changes.

The process also identified sites where further investigations would be required to fill knowledge gaps and areas where more instrumentation would be needed.

Stage 1 enabling works began in January 2001 on the Longswamp Crossing and Gully 2 site (1 km south of Mercer Township). A programme of subsurface testing was carried out consisting of Geonor Vanes and CPT testing. A total of 74 vanes and 99 CPT tests were performed in addition to the 71 commissioned during the investigation stages.

The rational was for CPT and Geonor Vane tests to be performed on all embankment sites prior to the start of filling operations.

This would provide further baseline strength/stiffness data. At later stages these tests were repeated at the same locations and comparisons made. The CPT data was also combined with laboratory consolidation testing to calculate estimates of settlement for the ground underlying the embankments.

Figure 4. Installing Inclinometer / Sondex System

4.2 PJK EXPRESSWAYS

Extensive investigation programmes were undertaken for the PJK project prior to award of the construction contract and then subsequently by the JV and their designers, Tonkin & Taylor Ltd.

From these investigations, which included numerous boreholes, test pits and Cone Penetration tests, it was clear that the stratigraphy in certain areas would require special treatment.

Route of both routes J and K had to allow for extremely sensitive volcanic soils, very soft estuarine sediments, landslide debris and organic soils (up to 0.5 m thick).
The estuarine sediments were typically the weak link here, with less than 40 kPa shear strengths.

The Interchange design needed to allow for highly compressible sedimentary deposits up to 19 metres thick and typically less than 20 kPa in strength.

All in all, large settlements and subsurface movement were inevitable and numerous and varied instruments were specified to monitor and measure the quantity and extent of these.

5.0 INSTALLED INSTRUMENTS

5.1 MERCER TO LONGSWAMP

Figure 5. MLSE Gully 2 Instrumentation lines and monitoring locations.

▪ INCLINOMETERS

In the cut slopes a further five (235 m in total) inclinometers were installed to complement the existing investigation instruments.

All holes were cored and logged providing further valuable geological information for modelling the slopes.

All the inclinometers on site were 70 mm OD ABS plastic slope indicator casing. They were monitored using a slope indicator probe and data logger, and processed using Digi Pro windows software. The system allowed the technician to quickly download data onto a laptop and check the results in the field. This eliminated lengthy manual data entry and processing, and errors were immediately identified in the field and repeat readings taken.

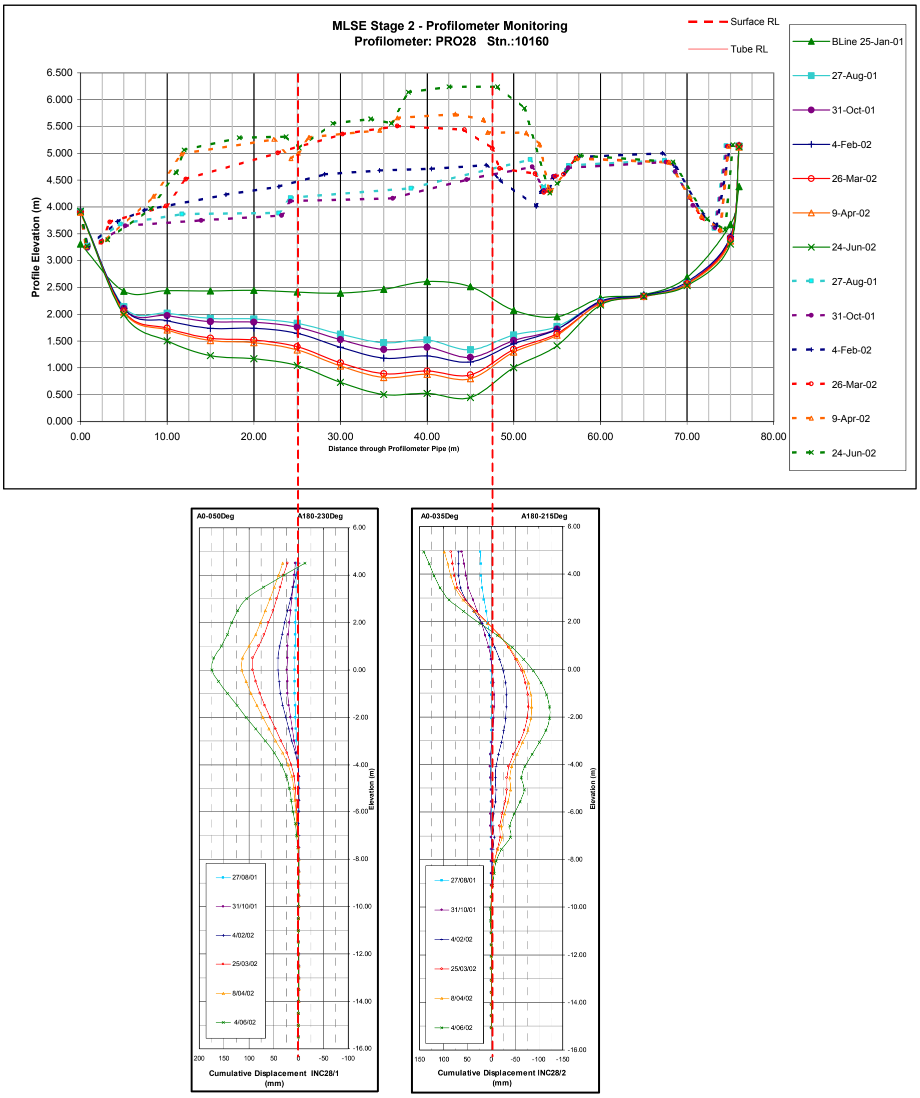


Figure 6. Comparison of Profilometer and Inclinometer data.
Longswamp Crossing.

Inclinometers were also installed in the embankments to monitor lateral deformation within the compressible layers. A total of five (120 m) were installed initially, with an additional two (2 x 16 m) installed on the Longswamp Crossing after cracks opened on the edge of SH1 (August 2001). These later inclinometers included telescopic tube sections within the compressible zone to allow for vertical settlement.

During the programme of works the inclinometers within batter slopes were cut down to allow monitoring to continue as cuts progressed. Those in the embankments were extended as the fill levels rose. Consistency of data was maintained throughout this process without the need to re-baseline the holes.

Within the cut sections major slip planes were identified from inclinometer data in four of the sites since monitoring began in 1999. Two of the inclinometers (Spring Slip and Williams Slide) have sheared off completely.

To date, as cuts have progressed in the Whangamarino slip zone, no deep movement has been detected.
On one site a shallow slip sheared the standpipe piezometer tubes which were used to confirm the depth of the slip surface.

Within the fill embankments lateral movements were observed. The underlying softer compressible materials flowed outwards from the centre line of the embankments. The displacements decreased with depth and corresponded closely with CPT and Geonor Vane strength results. (The situation closely resembled a marshmallow being compressed - Refer Figure 6.)

Figure 7. Monitoring of Inclinometer, Sondex and Profilometer Installations.

- **SONDEX SETTLEMENT SYSTEM**

In combination with the inclinometers, Sondex settlement systems were installed in the embankment fill sites at seven locations.

These consisted of stainless steel sensing rings, fixed to a corrugated plastic pipe at ~1 m intervals. This pipe was sealed at the bottom, with the inclinometer fixed inside for access and support. The corrugated pipe slips along the inclinometer tube and allows the rings to move with the surrounding ground. A sensing probe detects the relative positions of the rings, providing both total and "incremental" settlement at the depth of each ring.

The vertical settlements observed, again closely mirrored the lateral movements within the inclinometers, with the zone of greatest compression and lateral movement corresponding.

The instruments were positioned adjacent to the profilometer settlement tubes to enable further cross-referencing of data.

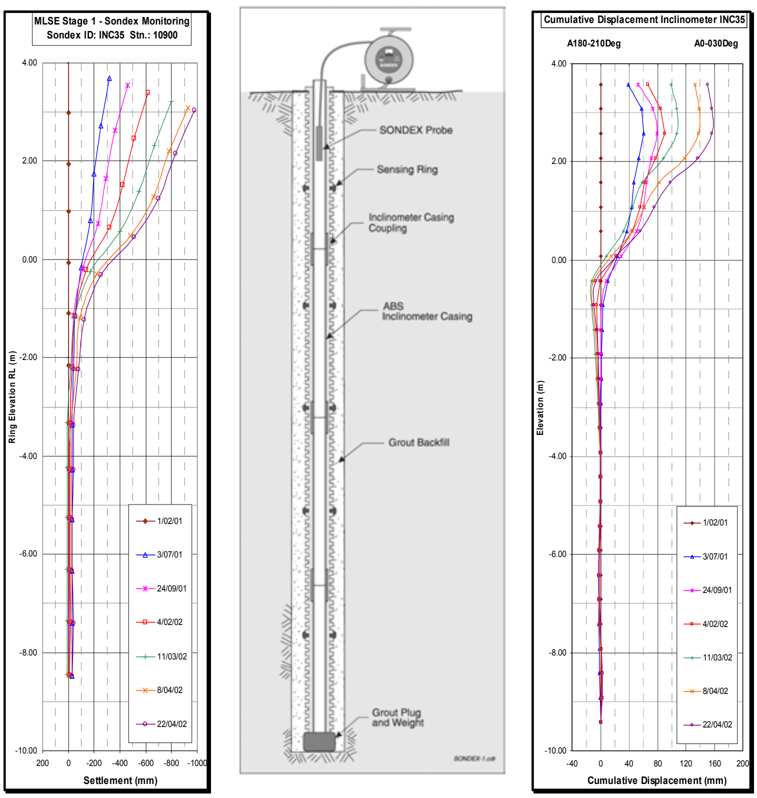


Figure 8. Comparison of Sondex Settlement and Inclinometer data.
Longswamp Crossing.

- **HYDROSTATIC PROFILOMETER SETTLEMENT SYSTEMS**

At nineteen locations along the MLSE project, profilometer settlement tubes were installed prior to the commencement of filling operations. A total of 1,250 m of tube was laid, ranging from 34 m to 113 m in length.

The settlement tubes consisted of semi-rigid MDPE 63 mm ϕ pipe, installed in as straight a line as possible between two reference points and mounted inside manholes. The tube was installed in a sand filled trench cut into the natural ground. A galvanised steel cable was installed in each profilometer tube to act as a draw cord.

The monitoring gauge consists of a reel assembly wound with two lengths of pressurised tubing, one containing air and the other de-aired water. These terminate at a differential pressure transducer/readout unit at the reel end and a stainless steel probe assembly containing a membrane interface at the other.

The basic principle of the pressurised hydrostatic profile gauge is to "hang" a column of water from an electrical pressure transducer. The bottom of the column is unsupported and ends in a probe. The elevation of the probe determines the height of the water column and thus the pressure measured by the transducer. The system is pressurised to prevent break-up of the liquid in the column and to ensure positive fluid pressure throughout the working range.

The system is designed to measure the relative elevation of the installed horizontal pipe. As the probe is pulled through the pipe, it's elevation with respect to the pressure transducer, fixed to the reel, changes and is indicated on the readout unit.

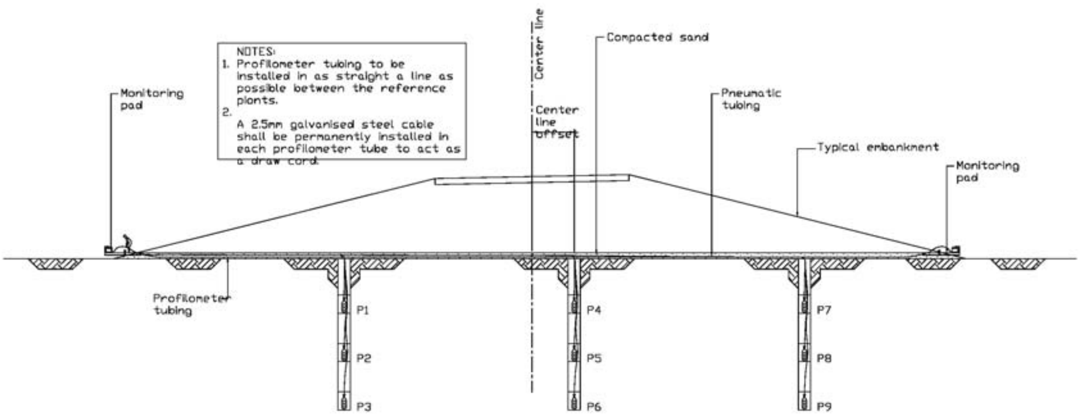


Figure 9. TYPICAL PROFILOMETER TUBING INSTALLATION BENEATH AN EMBANKMENT (INCLUDING PIEZOMETERS)

The profilometers installed on this project were all designed to ensure minimum disruption to the construction works. The monitoring points were kept well clear of any construction activity and once installed, the surface works proceeded without interruption.

This is in contrast to settlement plates which are normally dotted around the site and require extending as the fill progresses.

Readings were taken at 5 m spacings along the length of the settlement tubes and on surface reference pins at either end.

These pins were surveyed at the time of each monitoring visit and relative levels calculated for the reading points through the tube. The changes in elevation of these points produced a detailed cross-section of settlement.

At the same time the surveyor provided spot surface heights (fill heights) along the line of the settlement tube.

This data, combined with the tube readings, allowed engineers to monitor settlement at each point as filling progressed, and to calculate the degree of consolidation of the ground.

Fill rates could be closely controlled to avoid long pre-consolidation periods.

The flexibility of the system allowed for tubes to be thrust under the existing highway, allowing monitoring to continue unimpeded throughout the complete construction period.

One of the settlement tubes at Site One (Longswamp) was installed, bracketed to the roof of a stream diversion culvert. This and one other thrust tube continue to be monitored under the now completed highway.

Settlements observed over the nineteen sites, ranged from 2.5 m at Site 28 with a fill rise of 3.3 m above existing ground. The least being 0.1 m settlement with a fill rise of 3.4 m above existing ground.

- **PIEZOMETERS**

Piezometers at the MLSE project, were installed in both the cut slopes and under the fill embankments to monitor pore pressure.

A total of twelve pneumatic and seven standpipe piezometers were installed in the cut areas to complement the existing sixty-two investigation instruments.

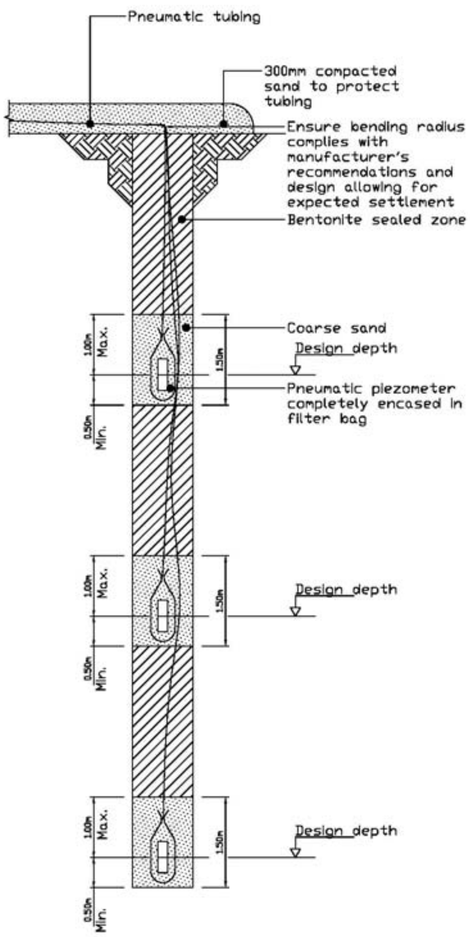


Figure 10. TYPICAL PNEUMATIC PIEZOMETER INSTALLATION

In the embankment areas, 117 pneumatic piezometers were installed at various depths, often beneath the lines of the profilometer tubes. This allowed correlation of settlement, fill volume and pore pressure data. The piezometer lines were trenched out to the boundaries of the site in sand filled trenches, or laid within the sand blanket. Tubes were 'snaked' to allow for localised differential settlement.

In spite of this, the failure rate of those piezometers that were installed in areas of high settlement was much higher than would normally be expected. These instruments all worked well for a period of time, but as the settlements became larger, many of them 'died' and were no longer readable.

On average, just over 30% of the installed pneumatic piezometers failed due to the effects of high settlement.

The piezometers provided valuable data indicating the build-up of pore-pressure in the underlying ground layers as filling progressed, and showed pore-pressure dissipation with time.

5.2 PJK EXPRESSWAYS

Figure 11. The completed PJK Interchange, showing instrumentation lines and monitoring locations.

- Inclinometers – Twelve inclinometers were installed on the project at various locations. Most of these were for the purpose of measuring cut slope and embankment slope stability, with one instrument utilising telescopic couplings to allow for settlement of a bridge abutment fill.

  Another of the inclinometers was installed inside a shear pile to monitor displacement at the toe of the embankment.

- Pneumatic Piezometers – A total of sixty two pneumatic piezometers were installed to measure pore pressures under the embankments and in the cut slopes. The results from these supplied valuable information on the effectiveness of the wick drains and the effect of fill placement and embankment construction.

- Standpipe Piezometers – Twenty eight standpipes were installed both in the investigation phase and during construction for the purpose of performance monitoring. These were very useful in monitoring the effectiveness of dewatering systems in the cut slopes and to monitor groundwater levels throughout the project area.

- Settlement Cells – Fifteen cells were used at various locations (mainly in the foundations under the embankment) to provide settlement data at spot locations. One cell was placed on a daylighted 600 mm ϕ sewer pipe to monitor displacement through filling and pre-load operations.

  The accuracy of these cells was ±50 mm and they were useful in providing back up data to the profilometer measurements.

- Profilometers – A total of twenty two hydrostatic profilometers were installed during the life of the project. The deformation and settlement data obtained from these instruments was used on a daily basis by the designers and assisted greatly with decisions regarding design changes and fill placement rates.

  The profilometer had a specified accuracy of ±10 mm but this was typically ±5 mm in reality (from regular calibration information and surface survey measurements).

6.0 INSTRUMENT TYPES AND SELECTION

For both projects, instruments were selected to measure and monitor a range of parameters along the full length of the expressways. In nearly all cases the instruments chosen, provided complementary parameters so that correlations could be made between the measurements. This also provided a level of safety in that, if one instrument failed, data was always available from the others installed at that location.

Another consideration relating to instrument selection was the ability to withstand the effects of high settlement and very wet conditions. Selected parameters considered to be of critical importance were:

- Settlement
- Pore Pressure
- Shear Strength
- Bearing Capacity
- Slope Stability
- Groundwater Levels
- Lateral Subsurface Movement

The instruments chosen to monitor / measure these parameters were:

Settlement	-	Hydrostatic Profile gauge (Profilometer)
	-	Sondex Settlement System
	-	Settlement Plates
	-	Pneumatic Settlement Cells
Pore Pressure	-	Pneumatic Piezometers (Low Air Entry)
Shear Strength	-	Geonor Shear Vane (Rig mounted)
Bearing Capacity	-	Cone Penetrometer Testing (CPTU – 2.5 tonne & 10.0 tonne)
Slope Stability	-	Inclinometers
	-	Standpipe Piezometers
	-	Pneumatic Piezometers
Groundwater Levels	-	Standpipe Piezometers
	-	Maximum Water Level Indicators
Lateral Subsurface Movement	-	Inclinometers (standard)
	-	Inclinometers (telescoping)

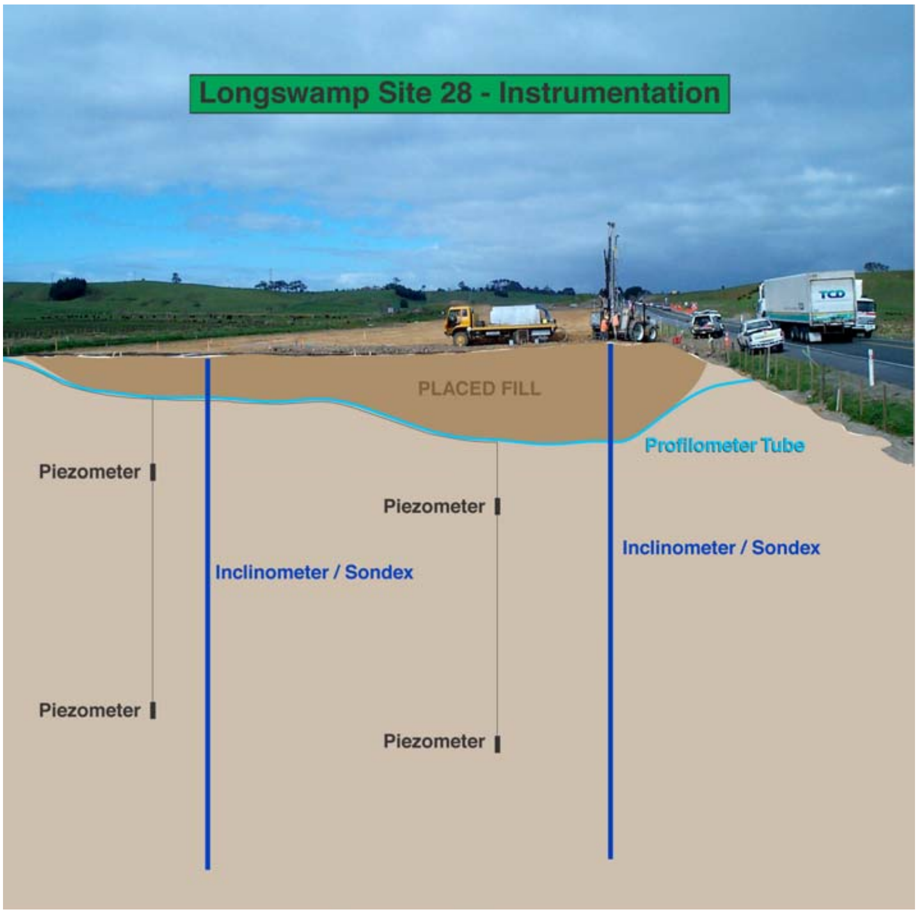


Figure 12. Cross-Section of typical instrument layout to provide data correlation.

7.0 MONITORING OF INSTRUMENTS

7.1 DATABASE

Due to the large number of instruments required for each project, an electronic database was developed to keep track of all instruments and associated information.

These databases made it easy for information to be retrieved and greatly assisted in the production of graphs and the collection of results.

7.2 MONITORING FREQUENCY

Although the specifications for both the PJK and Mercer to Longswamp projects stipulated monitoring frequency, it was our experience that other factors also dictated when various instruments should be read. One of the major factors relating to monitoring frequency was the rate of construction and the volume of fill being placed in the embankments, or the amount of material removed in the excavations and cuts. As fill was being placed, it was essential to measure pore pressures and settlement rates (especially in the very sensitive/compressible soils) to ensure that critical failure levels were not exceeded.

This was also the case in some of the major cuts, where large volumes of material were excavated. It was very important to increase the number of readings for the inclinometers and piezometers. This provided information on the stability of the upper and lower slopes of the cut.

Other factors affecting the monitoring frequency were:

Weather Patterns – High rainfall over a short period required additional readings to be taken.

Result Trends – Where readings had reduced or levelled off over a set period, frequency of monitoring was reduced and where readings were reaching critical levels, frequencies were increased.

7.3 QUALITY

As with any measuring or monitoring system, the quality of the data recorded can be compromised by any number of factors. It was found that on these instrumentation projects, the four most important variables affecting quality were:

1) Instrument Quality – Instruments should be of a high quality, sourced from a reputable manufacturer and supplied with a traceable and accurate calibration record.

2) Installation – Taking care in the installation process is essential and installers need to be experienced and follow documented methods to the letter.

3) Readouts – These must be calibrated regularly and operated by experienced and trained instrumentation personnel.

4) Continuity of Monitoring Personnel – All installed instruments have their individual characteristics and foibles and to have the same person or team regularly take the readings significantly increases the quality of the data.

8.0 RELATIONSHIPS

On the PJK and Mercer to Longswamp projects the instrumentation subcontractor was appointed by, and reported to, the main project contractor.

It was important however, to develop open and honest relationships with other project stakeholders. The designers required accurate information, promptly delivered, which allowed them to verify or change the design.

The earthworks subcontractors needed information from the instruments which affected filling and excavation operations.

The clients needed well presented summary reports at pre-determined intervals which assisted them to ascertain project progress and plan for delays.

It was our experience that the progress and success of the projects were greatly improved when these and other relationships were soundly based and of an honest and open nature.

9.0 RESULT PRESENTATION

The numbers of instruments and the frequency of monitoring on the projects, resulted in huge quantities of data and information being accumulated.

The way in which the results were presented had to cater for the requirements of the contractor, the designer and the client. With this in mind the information was assembled and presented in a variety of ways to suit the particular needs of each stakeholder. The important factors to be taken into consideration were, simplicity, correlation of data, trends over time, influencing factors, and location and position information.

To meet these requirements, results were presented and reported in either hard copy or by electronic means using tables, graphs, profiles, diagrams, cross-sections and trend plots. Refer to Figures 13 and 14 for examples of result presentation.

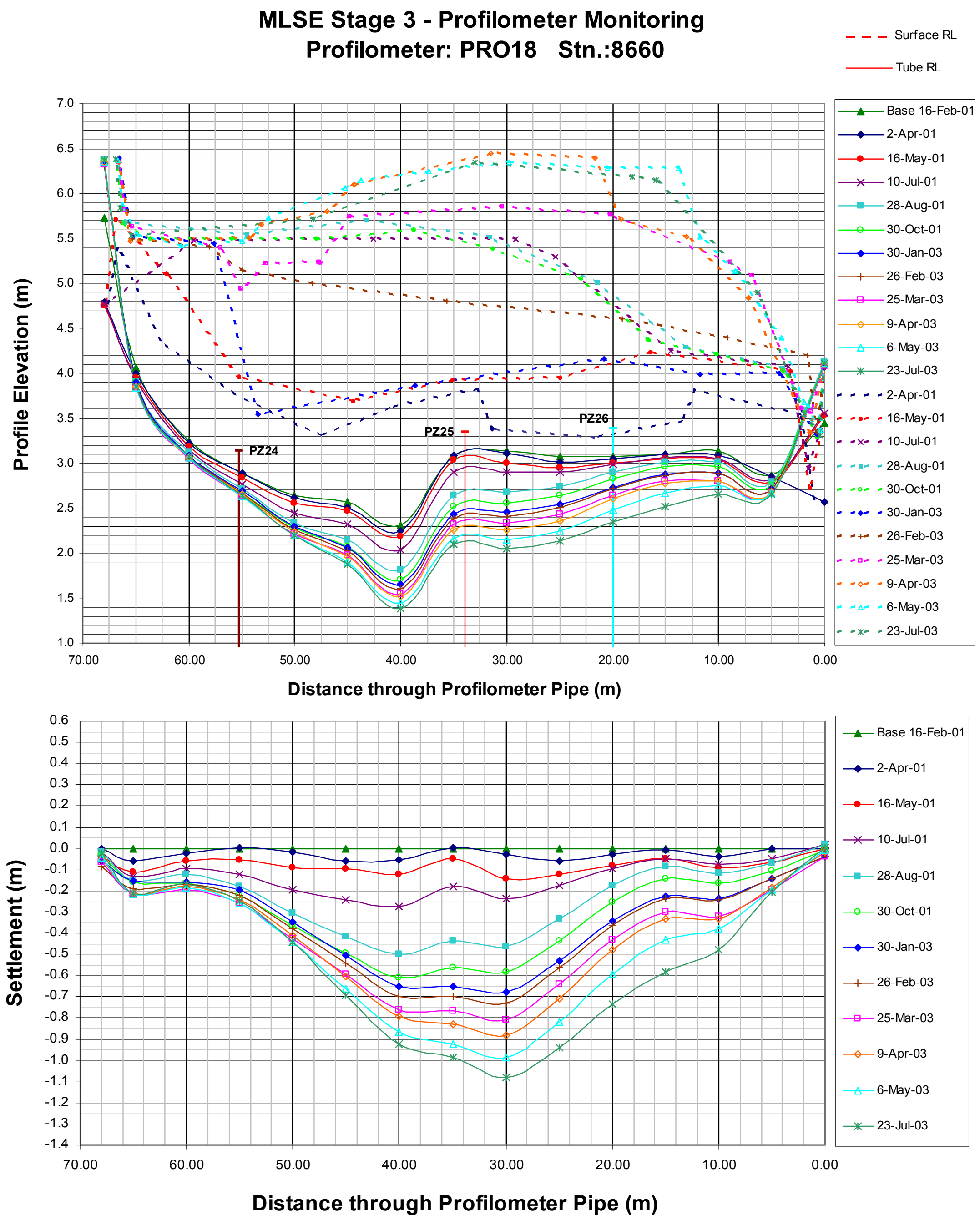
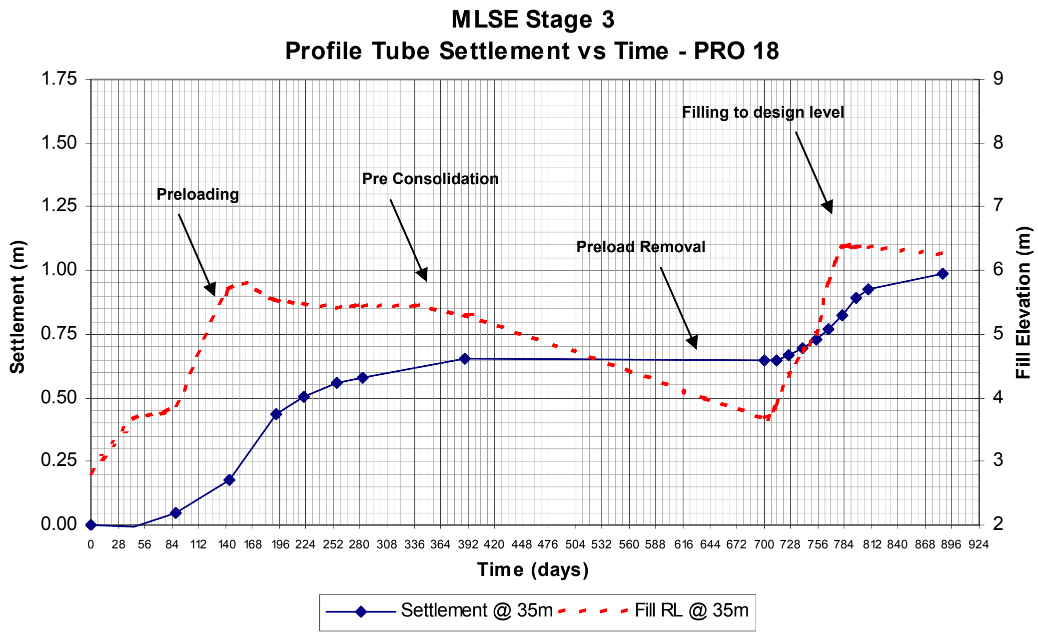


Figure 13. Graphs showing fill height and tube elevation with resulting settlement through profilometer tube. MLSE Site 3.



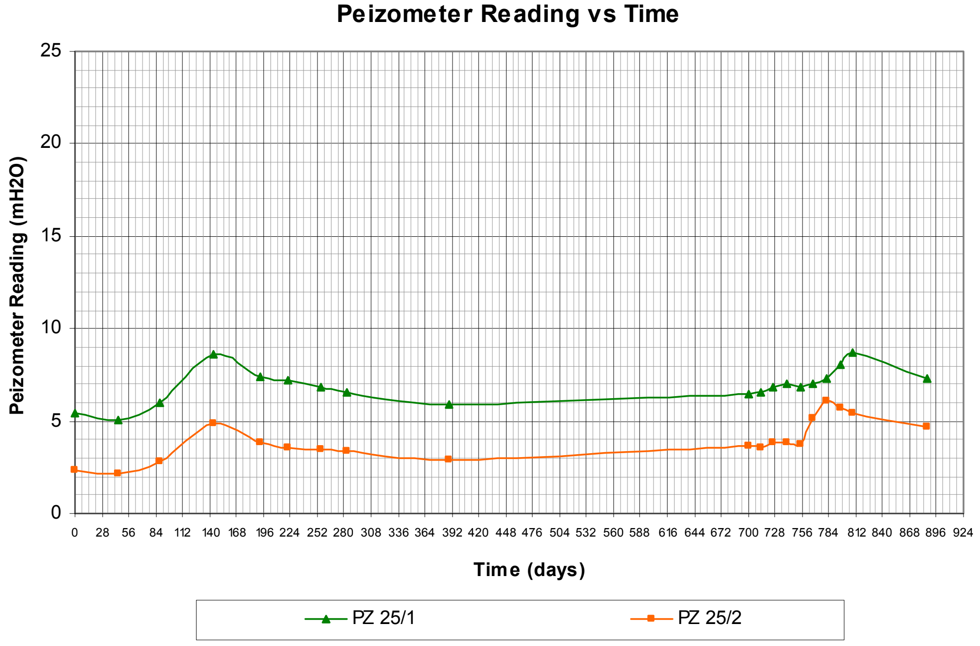


Figure 14. Graphs showing relationship between fill height, settlement and piezometric pressure. MLSE Site 3

10.0 CHALLENGES

Many challenges were presented during the course of these two projects with some of the more notable being:

- Loss of Instruments – A significant number of pneumatic piezometers failed after a period, due to the high settlements encountered. This necessitated re-installation that was costly in both materials and time.

- Access – The very soft and swampy nature of the ground created various access problems for the drilling rigs and on many occasions, sand fill accessways and platforms had to be constructed.

- Subsurface Testing – On the Mercer to Longswamp project, several sites were located on old swamps that were littered with tree stumps and large roots (some down to 20m). When testing with the 2.5 tonne CPT, these stumps were regularly encountered, which required the testing to stop and the instrument sent back for re-calibration.

- Taniwha Encounter – Due to the presence of a Taniwha on one of the sites, instrumentation work was stopped in that area while consultation with the local iwi took place. A slight re-design was required to ensure disruption to that particular area was minimised.

- Bovine Intervention – Several of the pneumatic piezometers installed during the investigation phase of MLSE were damaged by the local farmer's cows. They managed to knock down the borehole upstands and proceeded to eat the brass fittings and the tube lines (to ground level).

- Instrument Damage – Due to the nature of the wick-drain installation and soil nailing operations, inclinometers, profilometers and piezometer tube lines were occasionally punctured and required re-installation.

Figure 15. Soil Nailing / Inclinometer Installation. PJK. (K6 Cut)

11.0 CONCLUSIONS AND RECOMMENDATIONS

From experiences gained through involvement over a four year period (1999 to 2003) on two of the larger and more complex roading projects undertaken in New Zealand, the following conclusions and recommendations were made:

- Instrumentation can be extremely cost effective by optimising construction time, reducing factors of safety allowances and lowering risk exposure.
- In situations of very high settlement use vibrating wire piezometers and armoured cable to greatly reduce the likelihood of damage.
- The Geonor Vane is a very useful tool in determining strength gain at depth, achieved through consolidation and dewatering.
- Where possible, select instruments that 'daylight' outside of the construction footprint to avoid inevitable damage from construction machinery.
- In soft compressible soils (where high settlement is expected) install 20-30% more instrumentation than you need, to allow for failure and attrition.
- It is expensive to install instrumentation, so insist on high quality instruments, installed by an experienced practitioner.
- Accurate as-built location information for instruments and tube lines is essential to prevent damage from subsequent subsurface testing or construction work.

ACKNOWLEDGEMENTS

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