Australian Geomechanics Society

Sydney Chapter

Geotechnical Instrumentation for the Yelgun to Chinderah Freeway

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Mini-Symposium
Geotechnical Instrumentation and
Construction Works Compliance Testing

Presented at:

Eagle House, Milsons Point
Sydney, Australia
August 2003

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GEOTECHNICAL INSTRUMENTATION AND MONITORING FOR YELGUN TO CHINDERAH FREEWAY

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ABSTRACT

A large portion of the Yelgun to Chinderah Freeway was located in areas underlain by soft soils. Construction of the road embankments in these areas presented significant constraints and risks to the project, involving short term instability and long term settlement. Due diligence was carried out to ensure development of effective solutions, and control and reduction of risks. Geotechnical instrumentation and monitoring formed a crucial part of the soft ground treatment. The design and construction were constantly reviewed and modified as required in response to the field performance. This process allowed flexibility in design and construction and was proved to be successful and cost effective.

1. INTRODUCTION

Sections of the recently completed Yelgun to Chinderah Freeway in the northern region of New South Wales traversed flood plains and marshy areas. The subsurface consisted of mainly very soft and loose alluvial soils, imposing significant geotechnical constraints on the construction of the road embankments. Developing robust solutions and managing the risks were the most technical challenging features of the project.

Typical problems of constructing road embankments over soft ground include embankment instability, excessive ground settlement, prolonged construction time and large post-construction settlement. Extensive soft ground treatments are generally required to maintain embankment stability during construction and minimize ground settlement after project completion. The success of such treatments depends on the understanding of the soft ground behaviour and the accurate prediction of its performance. Failure to do so will render the work unserviceable and incur considerable cost overrun.

Soft ground related works generally involve substantial uncertainties, e.g. variation in soft soil profile and property, consolidation behaviour, soft ground treatment performance, etc. To reduce risks these uncertainties need to be eliminated as far as possible. Measures taken to control and minimize the risks for the Yelgun to Chinderah Freeway consisted of extensive geotechnical investigations, field trials, and instrumentation and monitoring. An integrated approach involving design, construction, and field trials and monitoring was implemented to ensure effectiveness of risk control. The information gathered from the site was used for calibration of design and modification of construction, as appropriate.

2. PROJECT DESCRIPTION

The Yelgun to Chinderah section of the Pacific Highway Upgrade provides a safe new four lane divided freeway bypassing the notorious Burringbar Ranges in the north of NSW. The 28.5 km long $348 million (AUD) motorway cuts through a series of very steep sided ridges and traverses a series of valleys before crossing the Tweed Valley flood plains.

The freeway commences just south of Yelgun Creek and rejoins the existing Pacific Highway west of Chinderah. The project route plan is shown in Figure 1. Key project features include:

- 4 lanes of median divided carriageway
- 4 major fauna movement structures including 2 cut and cover tunnels and 2 large arch underpasses
- 9 overbridges
- 39 freeway bridges over creeks and waterways
- High quality, concrete pavement carriageway with 110 km/hr design speed
- 3 grade separated interchanges located at Cudgera Creek Road, Clothiers Creek Road and Oak Avenue
- 6 million cubic metres of earthworks
- Over 50 fauna mitigation structures along the project

- 10 km of embankments constructed over soft ground with approximately 1.4 million lineal metres of wick drains used
- 134 m long twin tunnels under Cudgen Road, designed to avoid cane land and reduce rural impact

The Yelgun to Chinderah Freeway was awarded to Abigroup Contractors as a design, construct and maintain (DCM) project by the Roads and Traffic Authority of NSW, with SMEC Australia being the Principal Designer. The project commenced on 8th December 1999 with a contract completion date of 15th December 2002 and a contract maintenance period of 10 years after completion of construction. Substantial completion was achieved by June 2002 and the road was opened to traffic on 6th August 2002, 4 months ahead of the scheduled completion date.

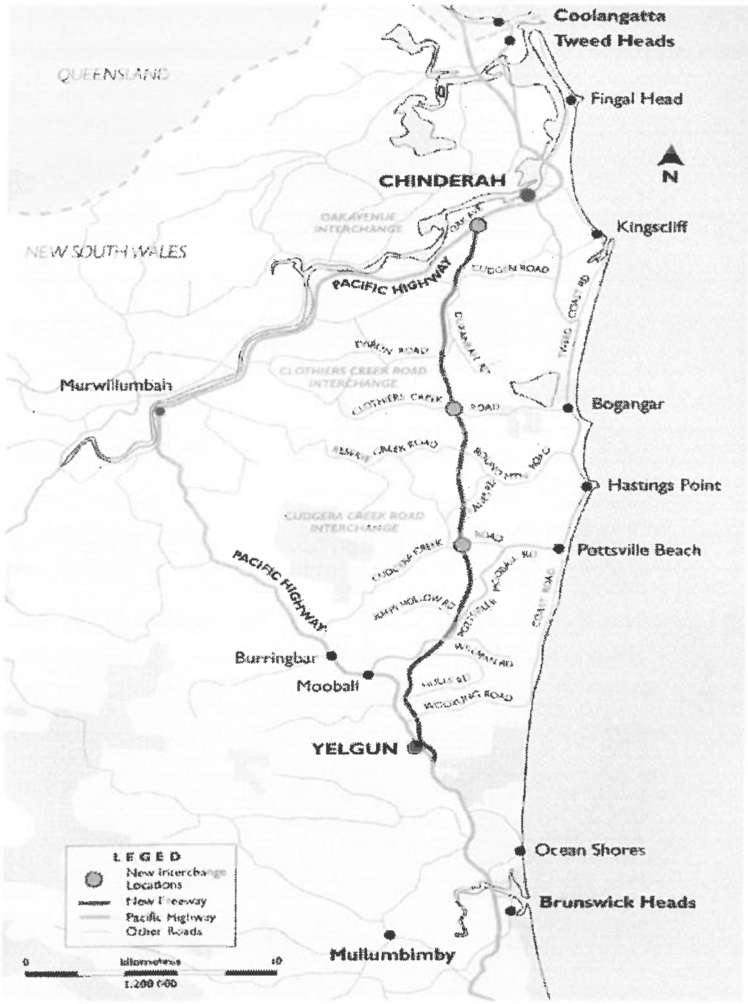

Figure 1: Project route plan

3. PROBLEMS AND RISKS

The soft soils underlying a large proportion of the project site comprised dark grey to black clays deposited under estuarine or marine conditions. The deposition of sediment in these areas was dominated by silts and clays transported in flood waters and deposited in thin layers on the flood plains and lagoons. Organic material mixed with the soft clays formed a soft, highly compressible material with a high water content. The soft soils of the project site extended up to 15 m depth and had the following characteristics:

- Low shear strength
- High compressibility
- Low permeability

It was recognized that the soft soils of the project site imposed major geotechnical risks on the project. These are described below:

- Embankment filling over soft ground. Associated problems involved excessive settlement of the embankment during construction causing an increase in fill quantity, long term total and differential settlement affecting the serviceability of the road and instability of the embankment during embankment construction. The slow consolidation nature of the soft soils would also have a major impact on the construction time and process.
- Approach embankments to bridge abutments and other structures. Differential settlement was a major concern in areas where the embankments were constructed over soft ground adjacent to bridge abutments and structures supported on piles. Settlement of the embankment would not only affect the pavement performance but also impose additional loads on the piles supporting the structure.

The problems of the project in relation to soft soils involved both short term and long term performance. The constructability of the embankment during construction and the serviceability of the road after the project completion were of major concerns. Photos 1 and 2 show large ground movement associated with construction of the embankment.

4. SOFT SOIL TREATMENTS

4.1 EMBANKMENTS

The embankments located over soft ground were designed in such a way that stability of the embankment was maintained during construction and the long term settlement of the embankment complied with the criteria.

To meet the time constraints of the project the embankment needed to be constructed as quickly as practically possible to allow for a maximum duration of preloading in order to achieve the required degree of consolidation during construction. However, speedy construction of the embankment might be followed by an embankment failure.

Measures considered to improve the embankment stability included the use of high strength geotextile placed at the base of the embankment and wick drains installed through the soft clays. The geotextile provided a restoring force against potential slip failure of the embankment, whilst the wick drains helped the ground to gain strength via the consolidation process. This system relied on the combined effects of the geotextile and the wick drains connected to a drainage blanket placed at the base of the embankment to achieve the required stability of the embankment. The ground water squeezed out via the wick drains and the drainage blanket was collected and treated before being discharged back to the ground. Photos 3 and 4 show the placement of geotextile below the base of the embankment, and Photos 5 and 6 show the installation of wick drains through the drainage blanket.

To satisfy the performance of the pavement as well as the drainage and flood requirements, the residual settlement of the embankment constructed over soft ground needed to be controlled to within a specified limit after completion of the project. Surcharging of the embankment with wick drains installed in the soft ground was used to generate early and speedy settlement in the ground. This approach allowed most settlement to occur during the period of construction and over-consolidated the soft soils to minimize the residual settlement after completion of the project.

4.2 BRIDGE APPROACHES

At bridge approaches where the embankments were constructed over soft ground the ground would settle during the course of construction and continue to settle after completion of the work. This embankment settlement would have an adverse impact on the adjacent piles supporting the bridge abutment and would also cause settlement of the pavement connecting to the bridge abutment resulting in loss of its serviceability.

To eliminate the impact of embankment settlement on the abutment piles a nest of driven piles consisting of timber piles and precast concrete piles was installed in the area adjacent to the abutment. A series of pile caps overlain by a layer of geotextile reinforced mattress was placed over the piles to form an effective bridging layer to transfer the embankment loads on to the piles. These piles then carried the full embankment loading and hence no ground settlement would occur. This method allowed for earlier construction of the abutment piles and hence earlier completion of the bridge to enable haulage and construction traffic through the alignment. Photos 7 and 8 show the installation of timber piles and the constructed pile caps.

There was a potential for large differential settlement at the interface between the piled and non-piled embankment. Heavy surcharge and closely spaced wick drains were used to over-consolidate the ground next to the piled embankment. This allowed for accelerated consolidation and reduction in long term creep settlement of the non-piled embankment. In addition, a layer of geotextile reinforced mattress together with reinforced concrete pavement was constructed across the piled and non-piled embankment to allow for smooth transitions of the pavement during its design life. Figure 2 shows the arrangement of the bridge approach treatment.

This was an integrated solution combining treatments of the foundation soil, the embankment and the pavement. The method overcame the differential settlement at the bridge abutment and allowed for early construction of the bridge. It was proved to be cost effective and satisfied relevant design criteria for bridge approaches.

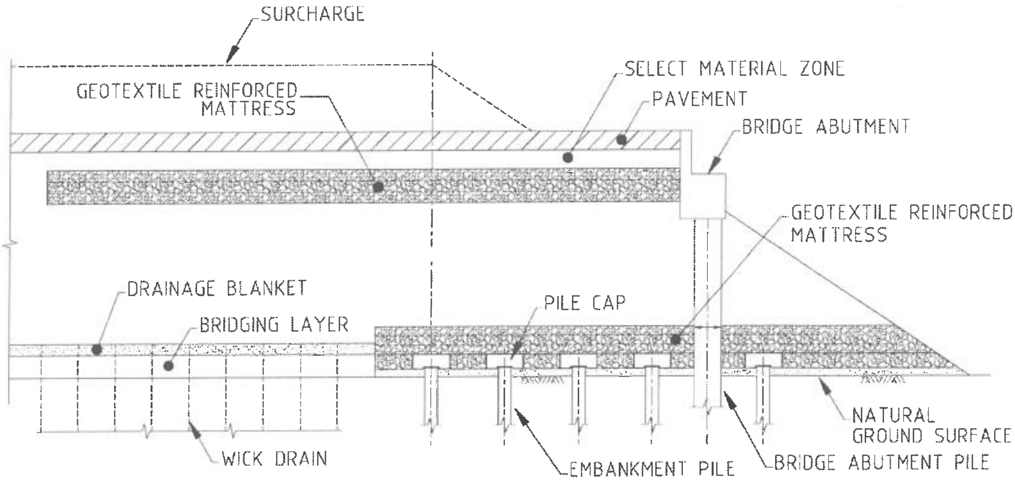

Figure 2: Bridge approach treatment

5. FIELD TESTING AND INSTRUMENTATION

5.1 GENERAL

Substantial uncertainties are generally present when constructing a road embankment over soft ground. These include variation of subsurface conditions, consolidation characteristics of the soft soil, long term creep settlement, wick drain performance, effectiveness of the drainage blanket, etc. To reduce the uncertainties and hence the risks, the following measures were adopted:

- Geotechnical investigations – to detect the subsurface conditions and the material properties
- Trial embankments – to assess the soft soil characteristics and effectiveness of the foundation treatment
- Instrumentation and monitoring – to confirm design assumptions and embankment performance

The investigation results and the field measurements were used to verify the ground conditions and confirm the design assumptions. When necessary the geotechnical models assumed in the design were further calibrated to reflect the actual ground behaviour. The calibrated geotechnical models were then used for the prediction of the long term performance of the embankment.

5.2 GEOTECHNICAL INVESTIGATIONS

Extensive geotechnical investigations were carried out for the project, including:

- Over 360 boreholes
- Over 120 electric friction tests (CPT)
- Over 70 piezocone tests (CPTU) with pore pressure dissipation tests (PPDT)
- Extensive test pitting
- Extensive field and laboratory tests

The investigations provided information on subsurface conditions and material characteristics of the site.

5.3 TRIAL EMBANKMENTS

The design of the embankment was initially based on the interpretation of limited geotechnical information available. Due to the complexity of the geology of the site, the actual ground conditions were expected to vary from the assumptions adopted in the design. Trial embankments were constructed at the early stage of the project to provide useful information for further calibration of the design assumptions and modification of the design.

The trial embankments were extensively instrumented with different arrangements of the soft ground treatments tested. These arrangements included:

- Different types of wick drains
- Different spacings of wick drains
- Different rates of embankment construction
- Different strengths of geofabrics

The arrangement of one of the trial embankments is shown in Figure 3. The performance of the trial embankments demonstrated the effectiveness of the ground treatment measures, as well as assisted in the determination of the construction program and method.

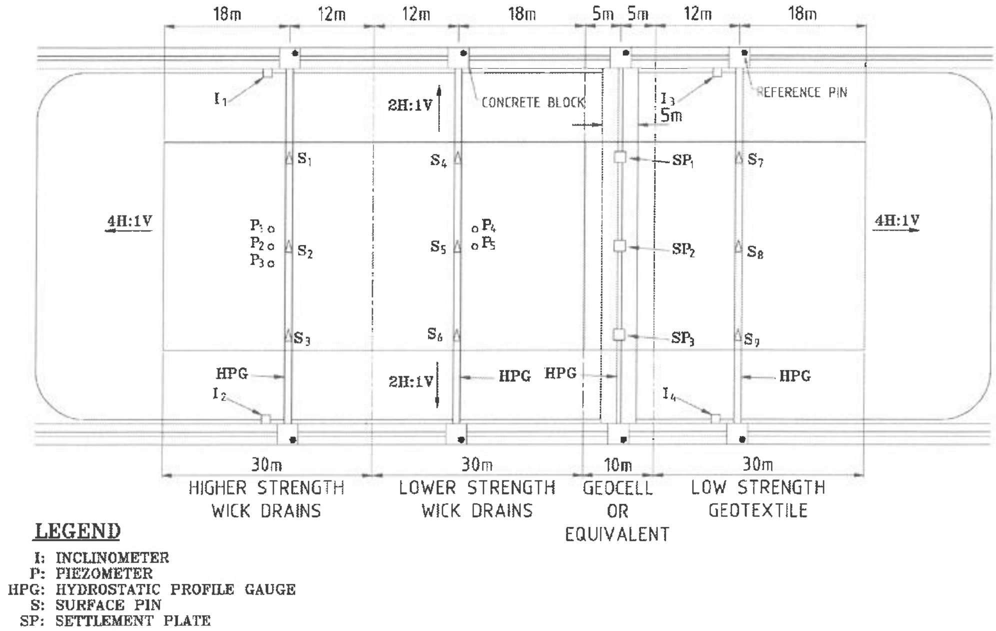

Figure 3: Arrangement of trial embankment

5.4 INSTRUMENTATION AND MONITORING

Extensive field instrumentation was implemented for the embankments located in the soft ground areas. A typical section of the instrumented embankment is shown in Figure 4. This included:

- Hydrostatic profile gauges – installed at the base of the embankments to measure the settlement profiles of the natural ground surface across the embankment
- Piezometers – installed at different depths in the foundation to measure pore water pressures in response to embankment construction
- Inclinometers – installed below the toe of the embankment to measure lateral soil movements as a result of embankment settlement
- Settlement plates – installed at the base of the embankment to measure settlements of the natural ground in relation to embankment construction
- Surface pins – installed at the surface of the preload embankment to measure the rate of settlement along and across the embankment

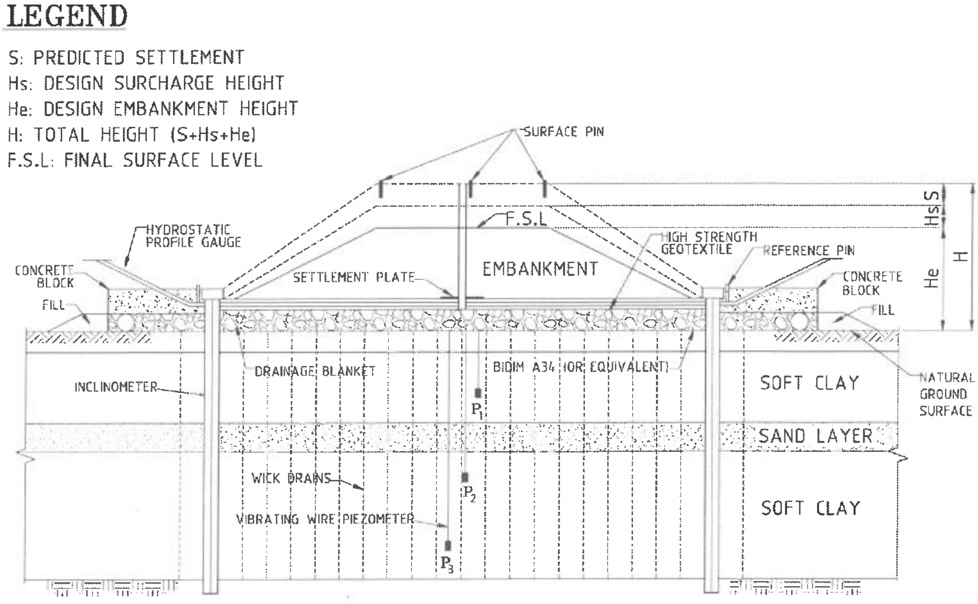

Figure 4: Instrumented embankment

A comprehensive computer data system was developed to manage and process the vast amount of monitoring data. This system was located on a designated network server which could be accessed by both the site staff and the designer. The information was periodically updated on site and was frequently monitored by the designer to assess the preload performance. Real time monitoring and review were possible through this system when the situation became critical.

The monitoring data were used by the designer for performing back analysis to match the predictions with the field measurements. The modified geotechnical models were then used for the forecast of the long term embankment performance, as well as for the determination of surcharge removal which was a crucial component of the construction program of the project.

6. FIELD PERFORMANCE

The performance of embankments during construction was assessed based on the extensive field instrumentation and monitoring. Adjustment of the construction method and the ground treatment measure was carried out accordingly to ensure that the design requirements were met.

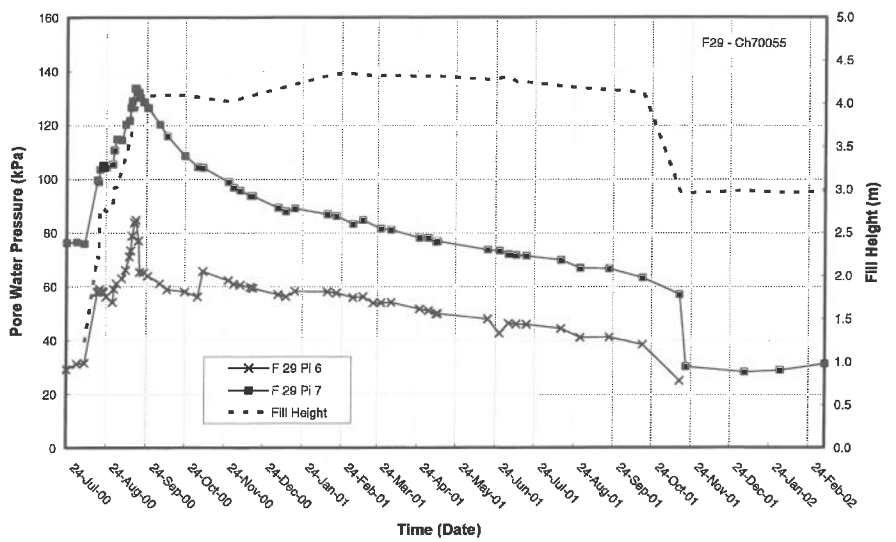

Figure 5: Pore pressure measurements

Performance of the soft ground treatment was measured by:

- Dissipation of pore water pressures showing the rate of consolidation. A typical example of measured pore water pressures in relation to the constructed embankment height is shown in Figure 5.
- Settlement of the embankment showing the rate and magnitude of consolidation. An example of measured settlement profiles below the base of the embankment is shown in Figure 6.
- Lateral deformation of soil showing the level of stability during construction. A typical example of measured lateral deflection profiles below the toe of the embankment is given in Figure 7.

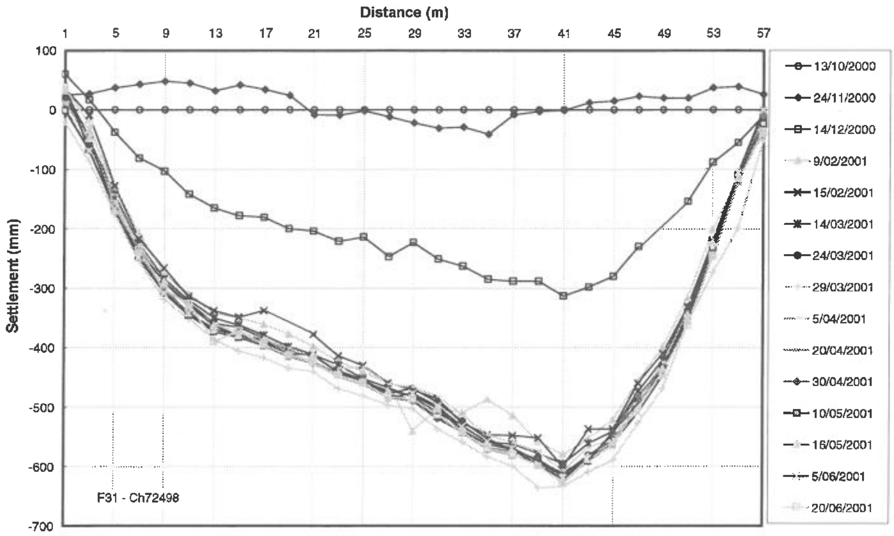

Figure 6: Measured settlement profiles

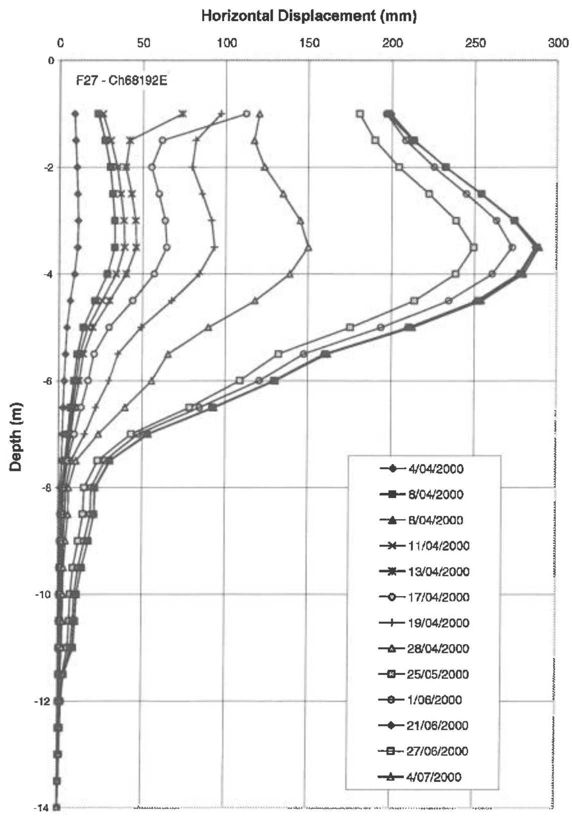

Figure 7: Measured lateral deflections

The settlement data from the settlement plates and pins were further back analysed to predict the long term total and differential settlements, as shown in Figures 8 and 9 respectively. Prior to the removal of surcharge and construction of the pavement, the predictions indicated that the long term settlement criteria, i.e., a residual settlement of 100 mm or 160 mm for specified locations in 40 years and a differential settlement of within 0.3% change in grade, were met.

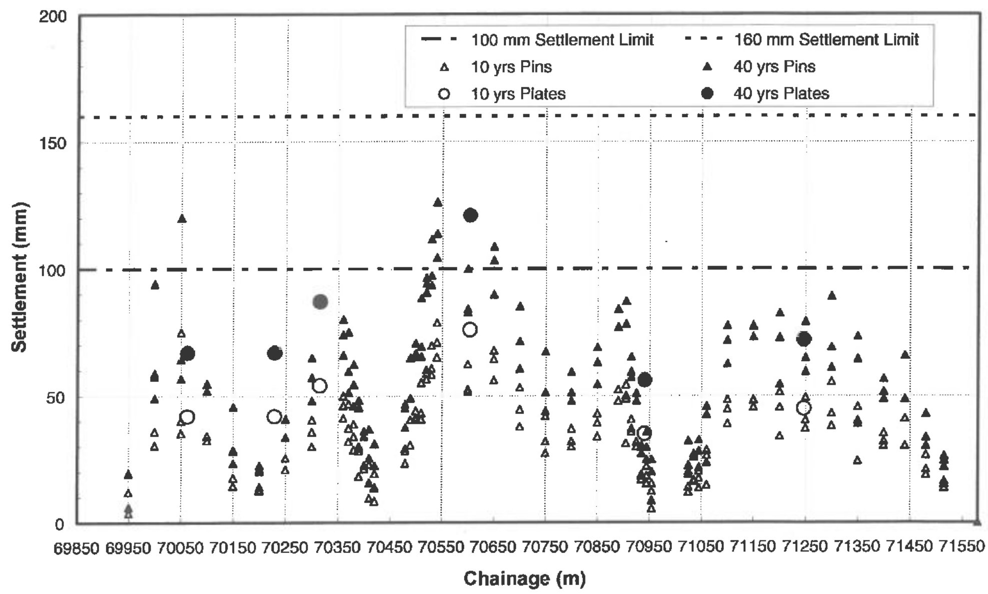

Figure 8: Predicted residual settlements

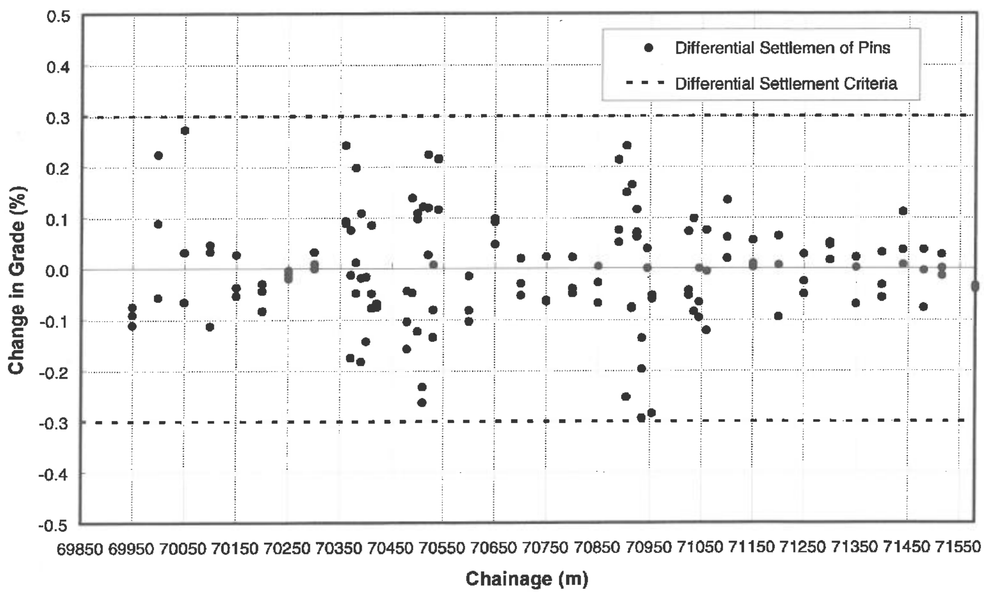

Figure 9: Predicted differential settlements

Further settlement measurements were taken after completion of the work. This information showed reduced rate of creep settlement which closely matched the predictions made prior to the removal of surcharge, as shown in Figure 10.

7. CONCLUSIONS

The 28.5 km long Yelgun to Chinderah Freeway was recently constructed and open to traffic, 4 months ahead of the contract completion date. The major challenges of the project were to construct the approximately 10 km long road embankments over soft soils. Specific soft ground treatment solutions were developed to ensure speedy construction and long term performance. Extensive geotechnical instrumentation was implemented to monitor the performance of the work. The field monitoring data were used to confirm the design assumptions and to modify the construction method as appropriate, as well as to reduce the uncertainties and risks. A computer data process system was set up on a network server which the contractor and the designer could access at all times allowing real time data update and review. This approach optimized the construction program and contributed to the early completion of the project.

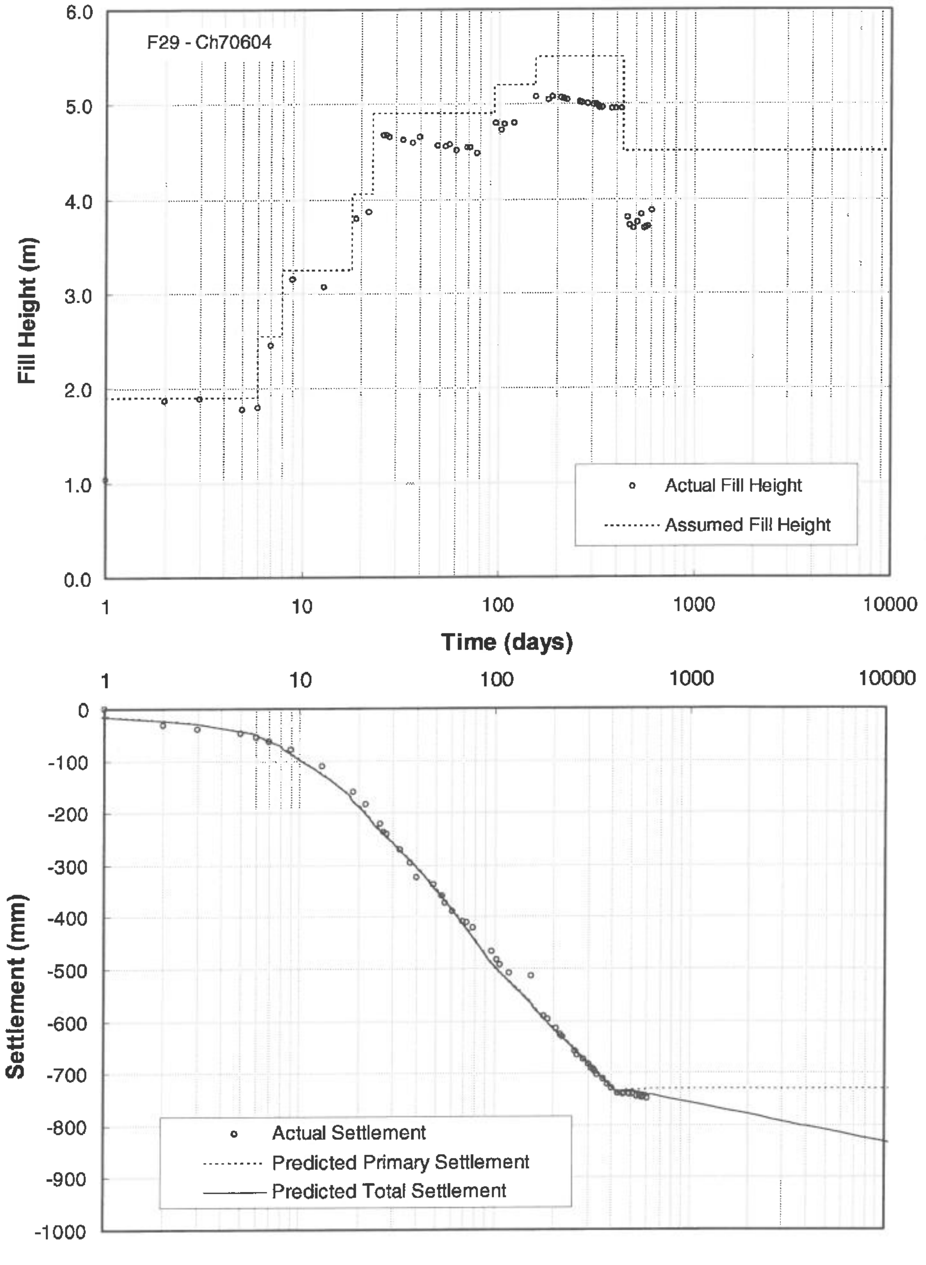

Figure 10: Measured and predicted settlements

8. ACKNOWLEDGEMENT

The author would like to thank the Roads and Traffic Authority of NSW and Abigroup Contractors Pty Ltd for permission to publish this paper.

Photo 1: Lateral soil movement adjacent to toe of embankment

Figure 2: Ground heaving adjacent to toe of embankment

Photo 3: Placement of geotextile over drainage blanket

Photo 4: Placement of fill over geotextile

Photo 5: Installation of wick drains

Photo 6: Close-up view of wick drainage rig

Photo 7: Installation of timber piles

Photo 8: Constructed pile caps