STUDY ON CONSOLIDATION OF ALLUVIAL CLAY IN NORTHERN QUEENSLAND

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ABSTRACT

In low-lying areas along the coast of Northern Queensland the superficial geology is usually a combination of alluvial, coastal and estuarine sediments of soft clay which can be more than 50m deep. Road embankment built on soft clay usually imposes various risks where large settlement associated with prolonged consolidation time is particularly of interest. To well predict the settlement and work out a competitive consolidation design scheme, consolidation parameters such as compression and recompression indices, pre-consolidation pressure, coefficients of primary and secondary consolidation need to be reliably characterized. In this paper the consolidation properties of soft clay in the region of Northern Queensland are investigated based on Townsville Port Access Road (TPAR) project and were evaluated from three approaches, which are: i) oedometer tests; ii) CPTU with pore pressure dissipation tests; and iii) back analysis of instrumentation data. Derivation of the parameters from the above approaches was discussed, with the results compared and assessed.

INTRODUCTION

Townsville Port Access Road (TPAR) is a project funded by Queensland Department of Main Roads, which will link Stuart Drive and the Bruce Highway to the Townsville Port precinct in South Townsville, Northeast of Australia. The project comprises approximately 10 km of roadway, 6 bridges and 13 culverts. The proposed 2-lane highway is nominally 11m wide, and the height varies from 0 to 9.0m.

The alignment of the project is located in low-lying areas, where very soft to soft clay is encountered near ground surface at most locations. Thickness of the soft clay can be up to 7.0m. To reduce the risk in the road embankment design, comprehensive ground investigations were carried out with various insitu and laboratory tests performed such as CPT, CPTU with pore pressure dissipation, Tbar, SPT, vane shear, oedometer, natural moisture content, index test, partical size distribution, and so on.

In addition, a geotechnical test pad (GTP) or trial embankment was built in a representative soft clay area on the project alignment with the aim to refine consolidation parameters and verify assumptions made in the consolidation evaluation. The GTP is located adjacent to Racecourse Road between CH3230m to CH3340m along the alignment of Eastern Access Corridor (EAC) of the project. Height of the GTP varies from 3.0m to 3.6m. A total of 4 CPTs probing were performed at approximate 30.0m spacing along the centreline of the project alignment.

Instrumentations of 12 settlement plates and 6 vibrating wire piezometers were installed along the GTP to capture the vertical displacement and pore pressure variation. Monitoring of the settlement and pore pressure dissipation commenced in last December and completed in September 2009.

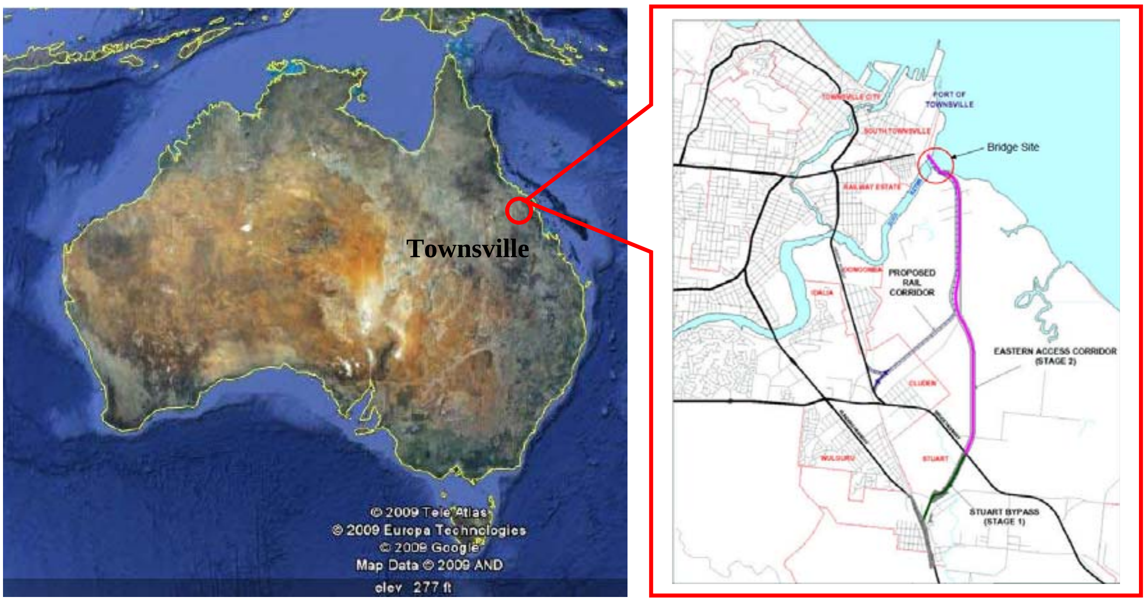

Fig. 1 Location and Layout Plan of Townsville Port Access Road Project (Courtesy of Google Earth)

SUBSURFACE PROFILE OF GEOTECHNICAL TEST PAD (GTP)

Subsurface profile at GTP consists of 500mm to 800mm very stiff clay as crust layer beneath existing surface. Followed by a soft clay layer extends to a depth of approximately 2.0m to 4.6m. This soft clay layer appears to sandwich 2 or 3 relatively thin sand layers, and underlain by loose to medium dense sand and silty sand to sandy silt. The summary of the subsurface profile is presented in Figure 2.

Soft clay is defined as material with CPT tip resistance q_c < 0.5MPa. The drainage thickness (2 H_{dr}) is defined as twice the drainage path length for the thickest soft clay layer. Groundwater level was generally approximately 1.0m below existing surface level as inferred from observations in the piezometer boreholes and from the CPTU probing. However, during the duration of the GTP monitoring exercise heavy rain fell with local flooding in the nearby creek, Stuart Little Creek. Flood water may have extended to above ground level around the GTP.

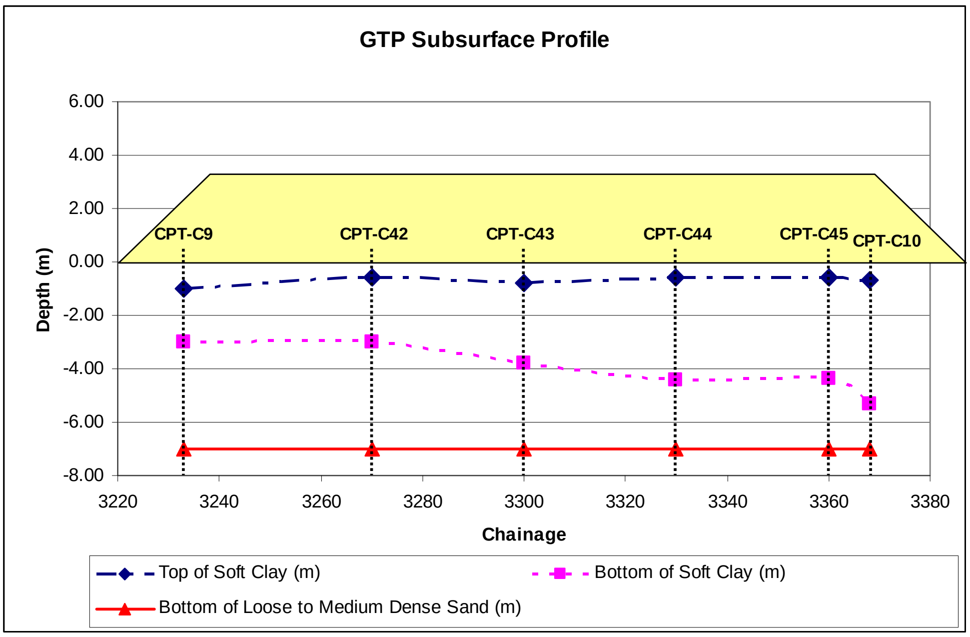

Fig. 2 Summary of GTP Subsurface Profile

Undrained shear strength (Su) at the GTP area was assessed based on insitu and laboratory vane shear tests, results from TBar tests, and end bearing results from the CPTs probing. The shear strength values inferred from the CPTs tip resistance are unrealistically low as demonstrated in Figure 3. Summary of undrained shear strength (Su) variation with depth at GTP is also demonstrated in Figure 3 below.

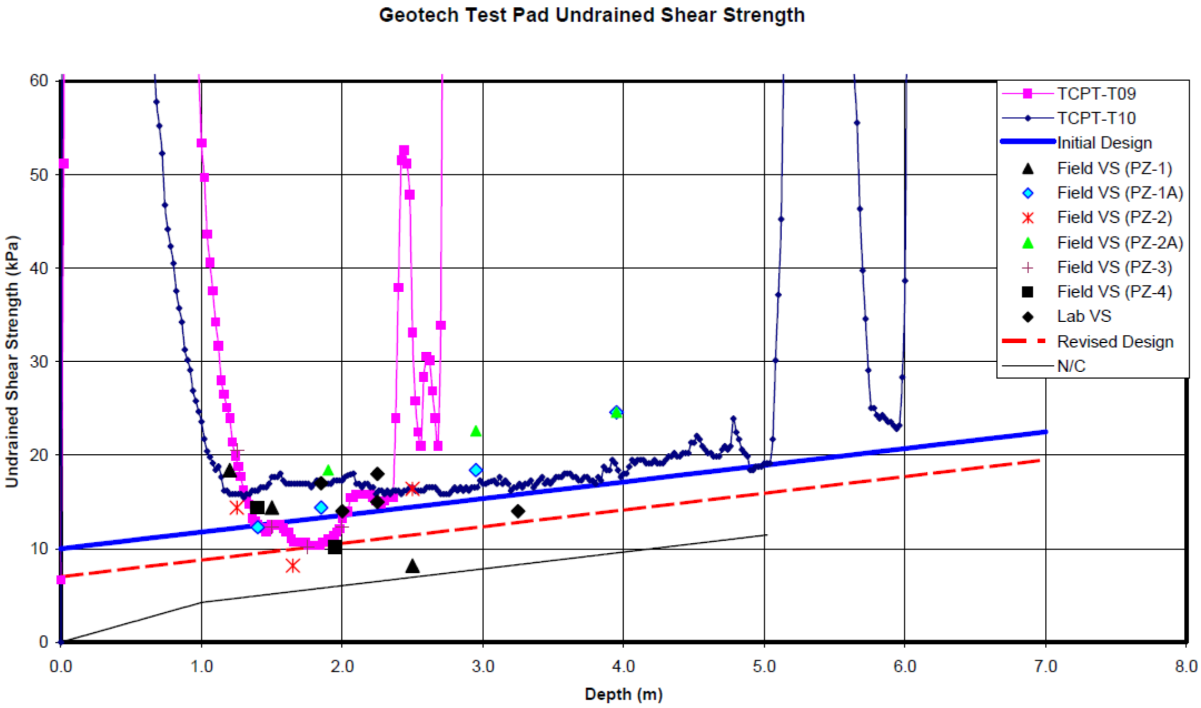

Fig. 3 Summary of Undrained Shear Strength (Su) Variation with Depth at GTP (Coffey Geotechnical Report - TPAR, May 2009)

INSTRUMENTATION AND MONITORING

The geotechnical test pad or trial embankment was constructed from 8th November to 4th December 2008, with the height of embankment varying from 3.0m to 3.6m. The fill material consists of clayey sandy gravel quarry product, each layer of 300mm thickness fill was placed and compacted in accordance with designer specification. The following figures showed the construction activities and completed GTP.

Fig. 4 Installation of Instrumentation and Construction Activities for GTP

Fig. 5 Completed GTP on Townsville Port Access Road Project

As discussed in previous paragraphs, instrumentation for the GTP consists of 12 settlement plates and 6 vibrating wire piezometers located in 4 cross sections as shown in Figure 6. Settlement plates and vibrating wire piezometers were monitored at the interval of 3 times a week during construction and first 3 months of preload period. The interval of monitoring was reduced to weekly basis until the completion of monitoring period. Location and depth of the instruments are shown in Table 1 below.

Table 1 Location and Depth of Piezometers and Settlement Plates

Chainage	CPT	PZ / SP	Depth (m)	Embedded Soil Type
3330	CPT-C44	PZ1	2.75	Soft Clay
		PZ1A	4.75	Sand
		SP3330 L, M, R	0.00	Ground Surface
3300	CPT-C43	PZ2	2.50	Soft Clay
		PZ2A	4.00	Sand
		SP3300 L, M, R	0.00	Ground Surface
3270	CPT-C42	PZ3	2.00	Soft Clay
		SP3270 L, M, R	0.00	Ground Surface
3240	CPT-C9	PZ4	2.00	Soft Clay
		SP3240 L, M, R	0.00	Ground Surface

Notes: PZ – Piezometer, SP – Settlement Plate, L, M, R – Left, Middle, Right

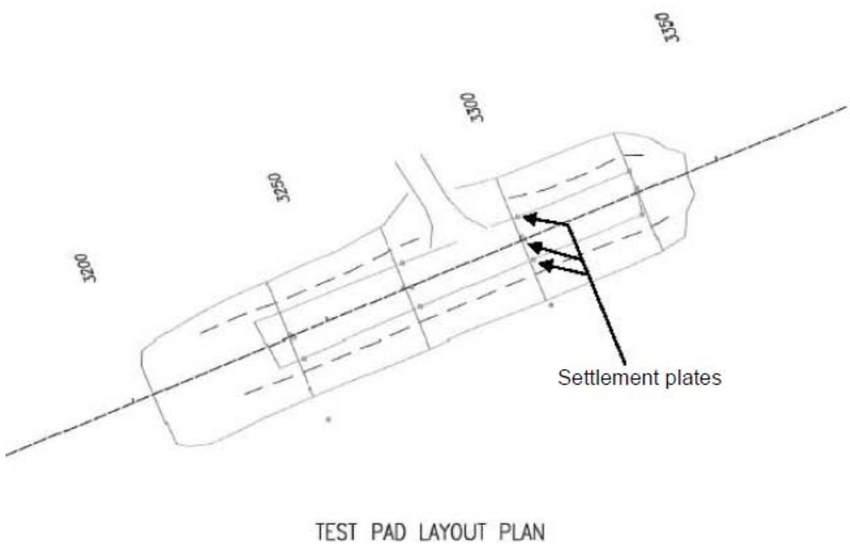

Fig. 6 Layout Plan of GTP

BACK-ANALYSIS APPROACH OF CONSOLIDATION PARAMETERS

The primary objective to build a geotechnical test pad or trial embankment in this project was to refine the coefficient parameters based on observed instrumentation monitoring data. A preliminary assessment was made using a simplistic curve-matching technique based on published solutions (Terzaghi, Peck and Mesri, 1996). A speadsheet was developed to capture all the observed field data from settlement plates to produce settlement-time curve. These measured data will then be compared with the predicted settlement-time curve.

Coefficient of vertical consolidation, Cv was varied to provide a good match between the predicted and observed settlements, assuming all of the observed settlement was due to soft clay consolidation. The corrected or varied Cv values based on the monitoring data will then be assessed and compared with the CPT dissipation test results at the nearest location to ensure the conclusion is consistent.

This curve-matching technique was extended to the values of modified compression index (Ccε), modified recompression index (Crε), preconsolidation pressure (σ'p) and coefficient of secondary compression index (Cαε). All these parameters were varied in an attempt to provide a better fit to the observed data.

RESULTS OF INSTRUMENTATION AND MONITORING

Settlement plate readings are plotted on a settlement-time curve with fill height since the commencement of fill activities on a log scale as shown on Figure 7 to 10. The centreline settlements observed range from 212mm to 413mm over a period of 3 months, and 170mm to 299mm at settlement plates on both sides of embankment. It is common to notice that the settlement at the centreline of embankment is generally greater than the settlement plates located at both sides, due to different loading condition. Settlement ratio of left and right side compared to centreline are approximate 71% and 87% respectively. An insignificant variation of less than 10% is noticed for left and right side of recorded settlement.

Refer to Figure 7 to 10, the shape of the plots indicates 90% to 100% of primary consolidation settlement occurred at some time between 30 to 90 days. Approximately 50% to 70% of the primary consolidation had taken place by the end of fill placement. Data from 90 to 130 days suggests that creep is occurring at a rate of approximately 25mm to 75mm per log cycle time.

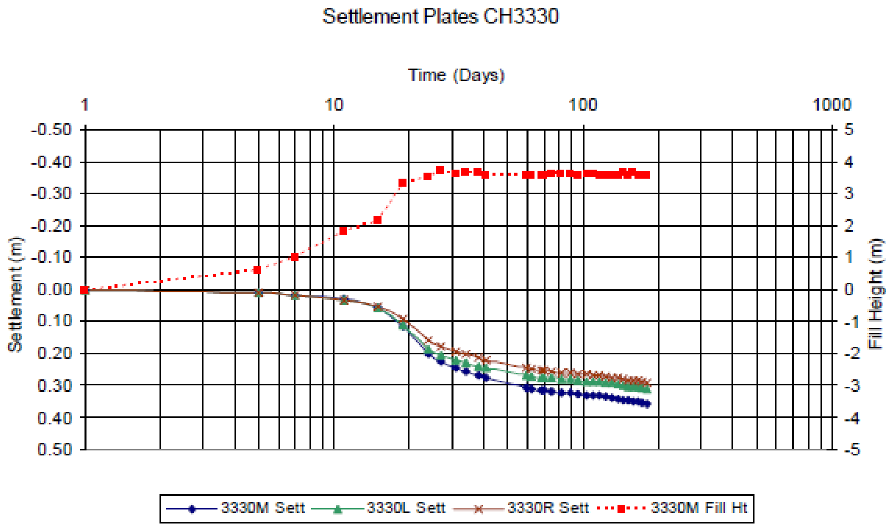

Fig. 7 Settlement-Time Curve at Cross Section CH3330 (Monitoring Data provided by Abigroup & Seymour Whyte Joint Venture)

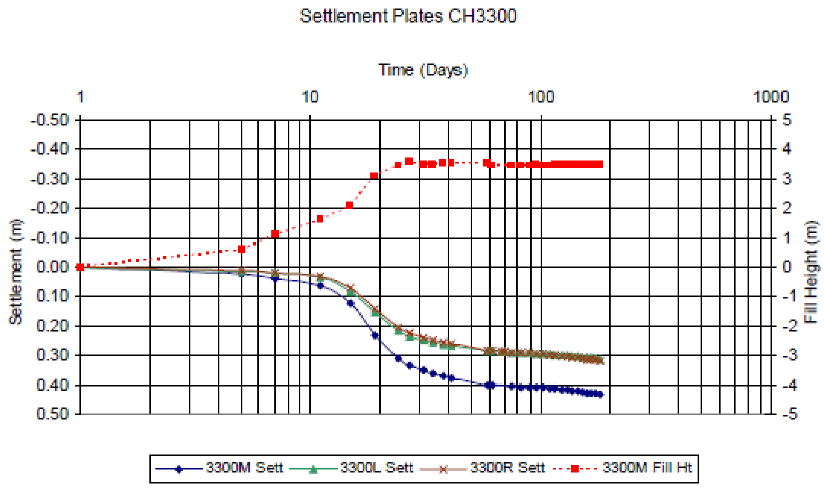

Fig. 8 Settlement-Time Curve at Cross Section CH3330 (Monitoring Data provided by Abigroup & Seymour Whyte Joint Venture)

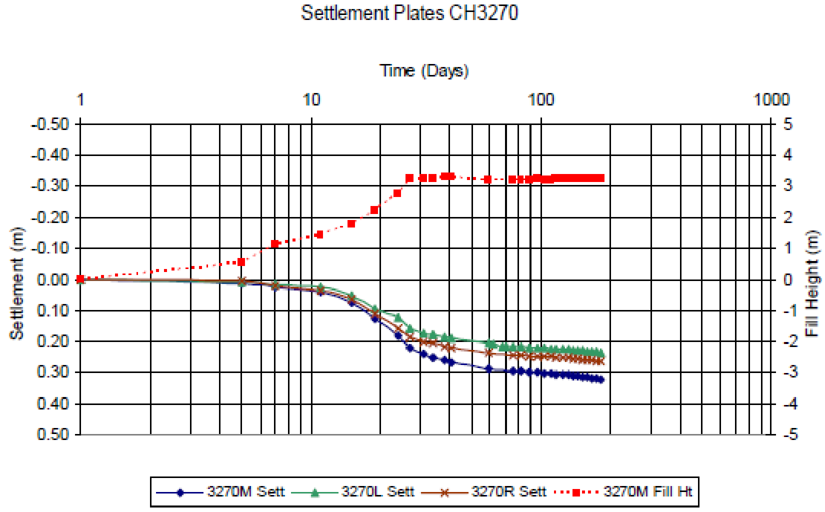

Fig. 9 Settlement-Time Curve at Cross Section CH3270 (Monitoring Data provided by Abigroup & Seymour Whyte Joint Venture)

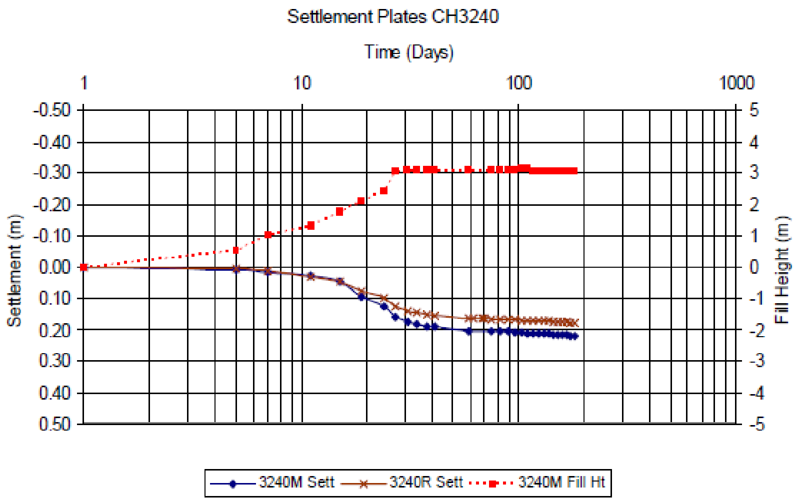

Fig. 10 Settlement-Time Curve at Cross Section CH3240 (Monitoring Data provided by Abigroup & Seymour Whyte Joint Venture)

Pore pressure readings recorded by vibrating wire piezometers are plotted on a pore pressure-time curve with fill height since the commencement of fill activities on a normal scale as shown on Figure 11 and 12. Piezometers PZ1, PZ2, PZ3 and PZ4 show responses with significant excess pore pressure development during the commencement of fill activities. The maximum excess pore pressure at PZ1, PZ2 and PZ3 corresponds to 40% to 50% of the vertical stress increase from the fill, and 30% at PZ4.

Therefore, degree of consolidation recorded had been more than 90% between 30 to 90 days , which is consistent with the settlement plates results. It is also noticed that substantial dissipation of excess pore pressure derived from embankment loading had taken place during the period of embankment construction.

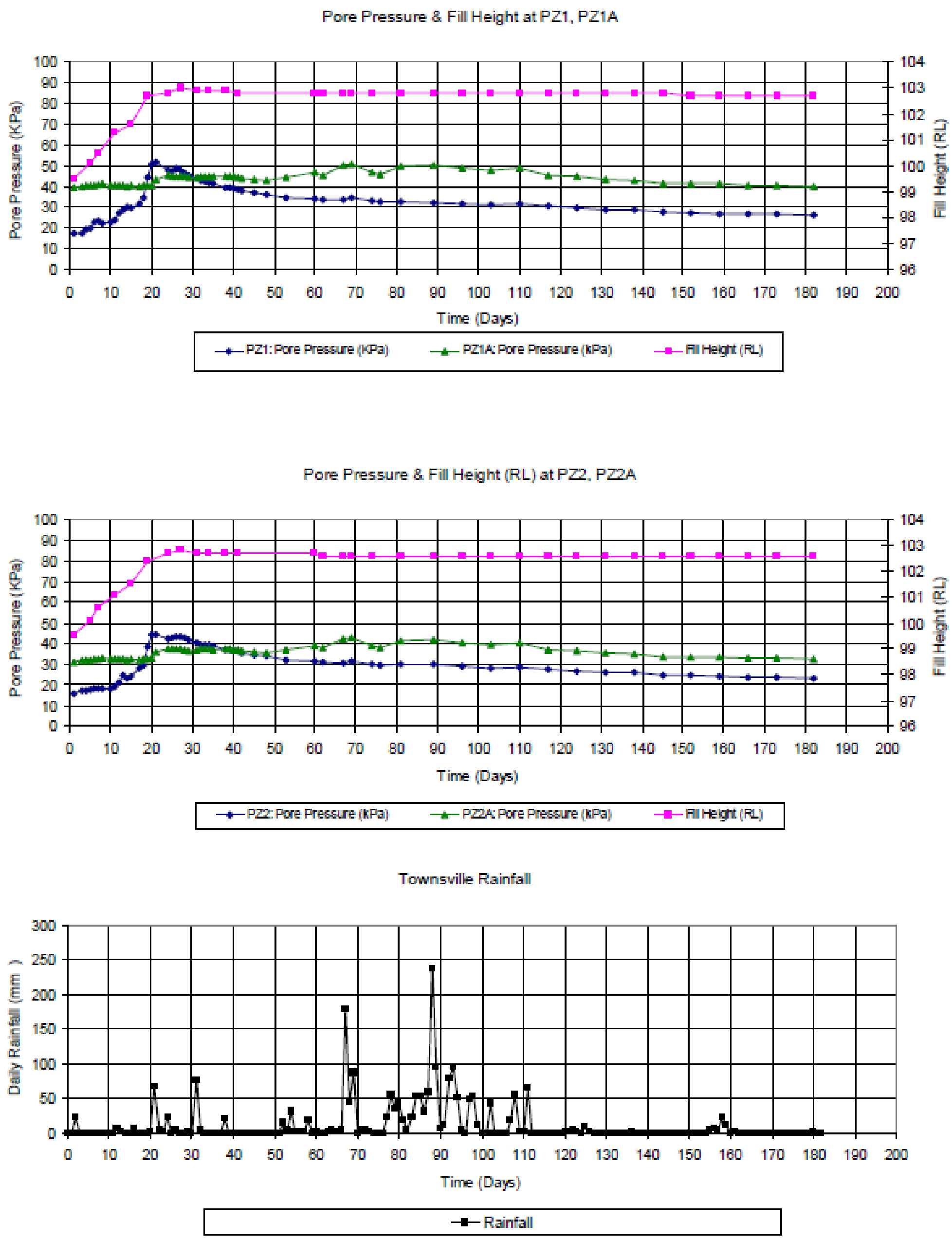

Fig. 11 Pore Pressure-Time Curve with Fill Height and Rainfall Data at PZ1 and PZ2 (Monitoring Data provided by Abigroup & Seymour Whyte Joint Venture)

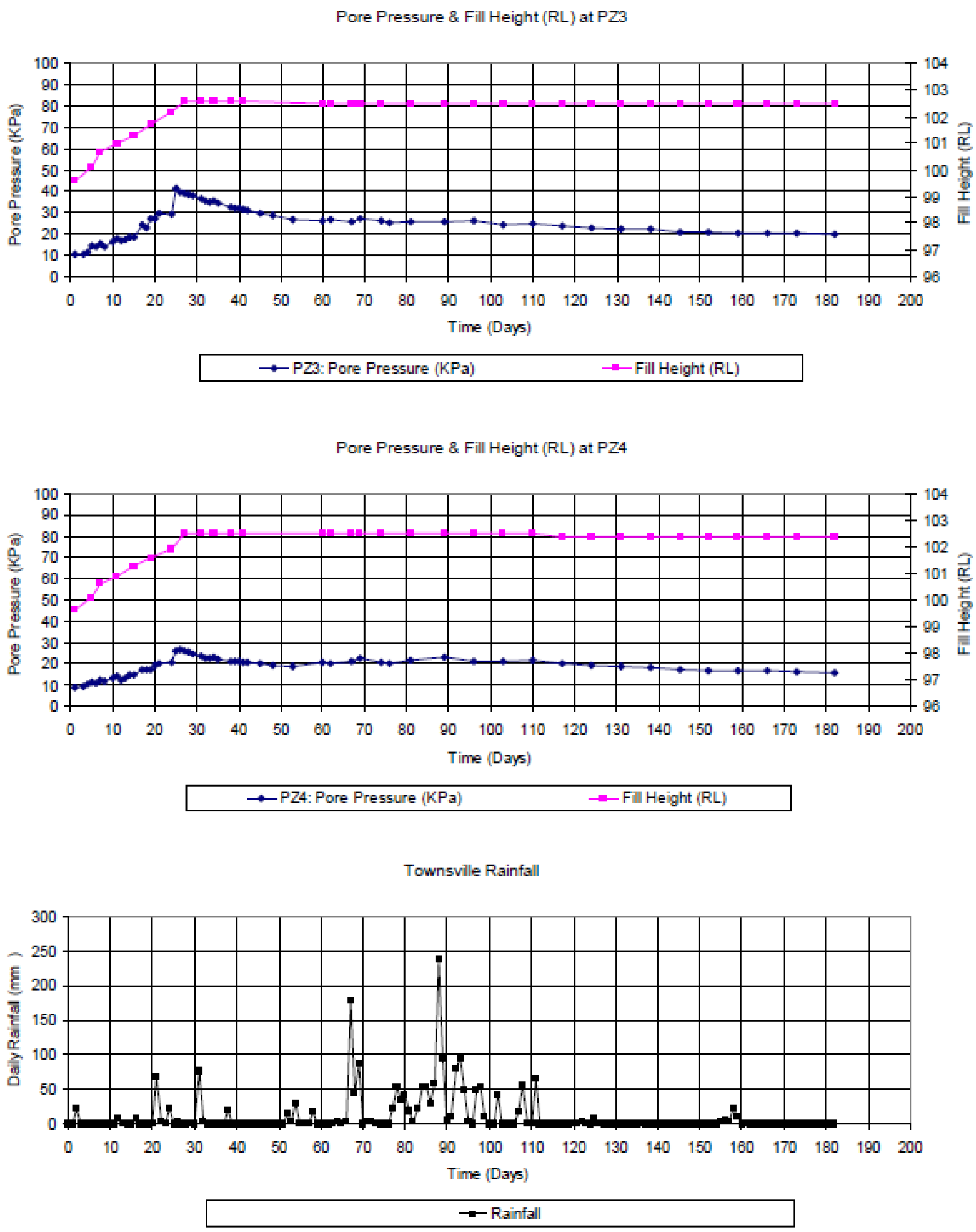

Fig. 12 Pore Pressure-Time Curve with Fill Height and Rainfall Data at PZ3 and PZ4 (Monitoring Data provided by Abigroup & Seymour Whyte Joint Venture)

RESULTS OF BACK-ANALYSIS APPROACH OF CONSOLIDATION PARAMETERS

From the observed instrumentation monitoring data of GTP, measured settlements increased faster than preliminary expectation. The acceleration in excessive pore pressure dissipation is exhibited by steeper settlement-time curves.

An overall review suggested a new set of consolidation parameters as indicated in Table 2 based on the back-analysis from recently concluded GTP monitoring. However, bulk unit weights of insitu material and embankment fill remain unchanged at 17 kN/m^3 and 21 kN/m^3 respectively.

The outputs of the curve-matching technique are shown in Figure 13 to 16 with the variation of Cv = 10, 20 and 30 m^2/yr plotted with measured settlements in an attempt to provide a best possible fit. The comparison indicates the preliminary design parameter of Cv = 4 m^2/yr appeares to be conservative, and a Cv = 30 m^2/yr is reasonable at the test pad location. This suggested value is also consistent with results from CPTs pore pressure dissipation tests at that location. The dissipation test results indicated coefficient of horizontal consolidation (Ch) values ranging from 42 to 48 m^2/yr. The factor of 1.5 is adopted to relate vertical and horizontal coefficient of consolidation.

Table 2 Consolidation Parameters for Preliminary Design and Back-Analysis Results

	Modified Compression Index (Ccε)	Modified Recompression Index (Crε)	Preconsolidation Pressure (σ'p)	Coefficient of Secondary Compression Index (Cαε)	Coefficient of Vertical Consolidation (Cv)
Preliminary Design	0.25	0.025	σ'v0 + 30 kPa	0.015	4 m^2/yr
Back-Analysis Results	0.23 to 0.28	0.023 to 0.028	σ'v0 + 20 kPa	< 0.01	30 m^2/yr

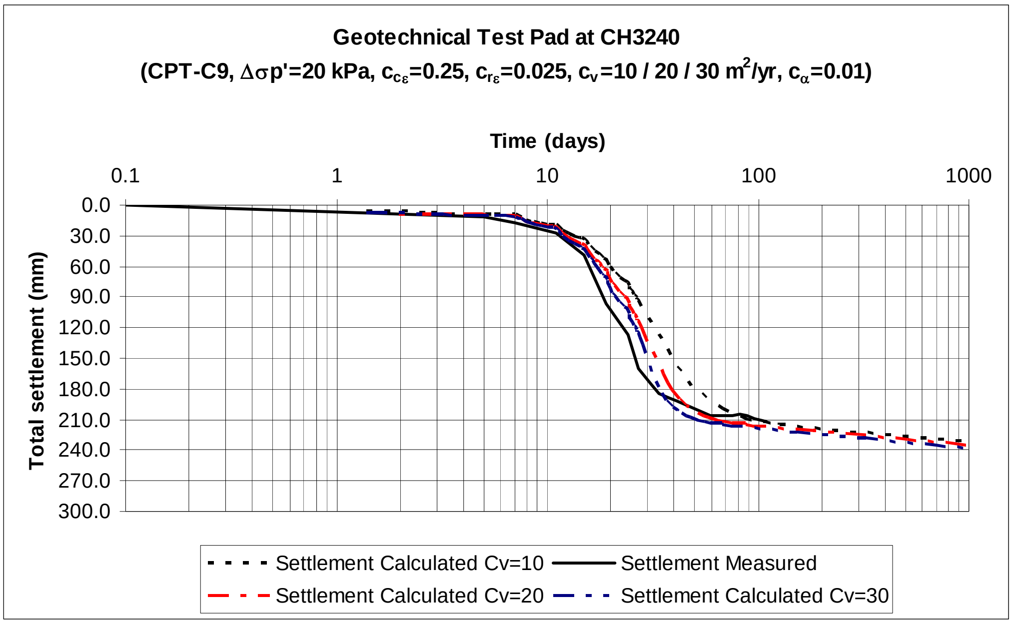

Fig. 13 Back-Analysis of Cv for Cross Section CH3240

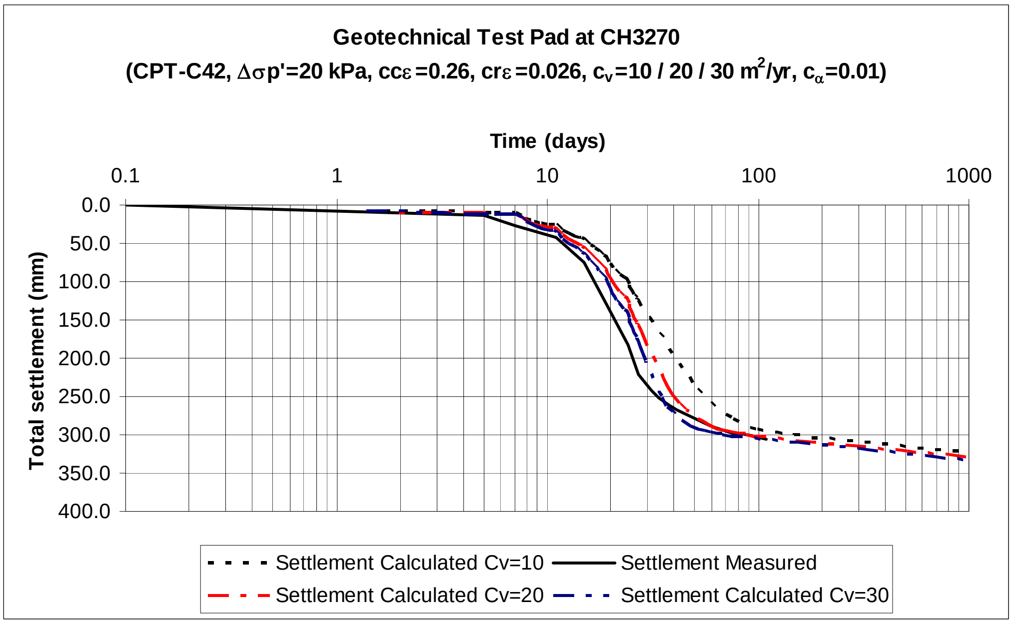

Fig. 14 Back-Analysis of Cv for Cross Section CH3270

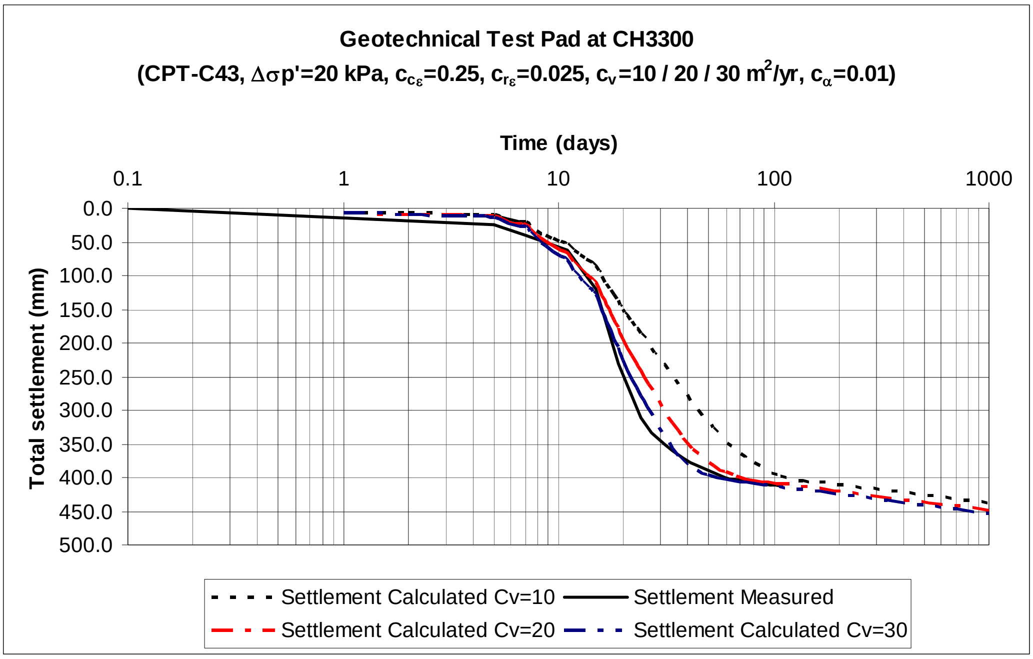

Fig. 15 Back-Analysis of Cv for Cross Section CH3300

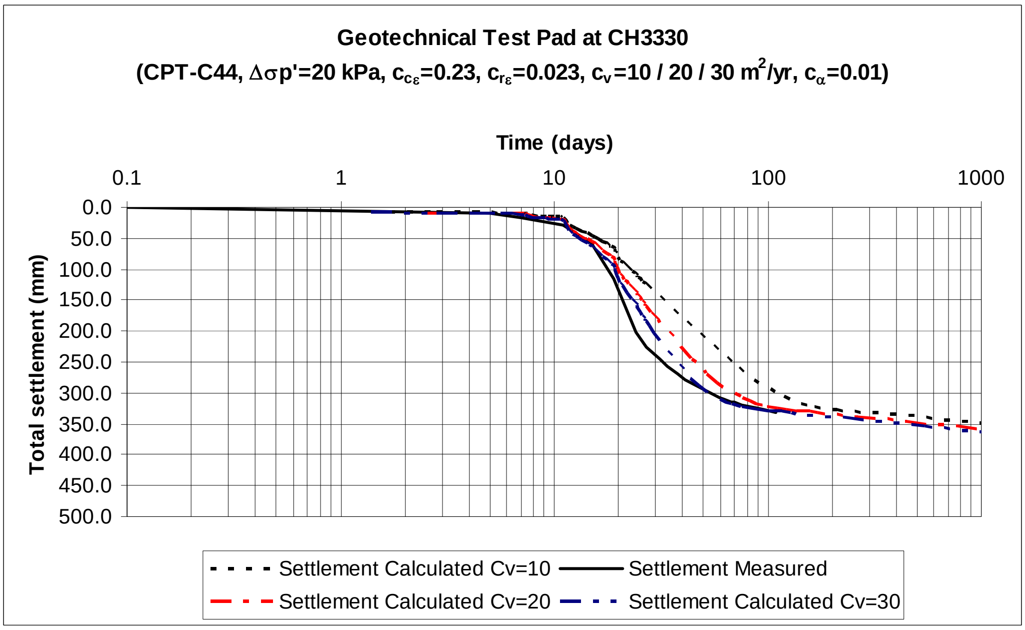

Fig. 16 Back-Analysis of Cv for Cross Section CH3330

Values of pre-consolidation pressure and compressibility parameters were therefore varied in an attempt to provide a better fit to the observed settlement plates data. The basis of the adjustments was based on undrained shear strength from TBar tests and laboratory consolidation oedometer test data. The test results suggest that the pre-consolidation pressure and undrained shear strength relationship may represent an over-estimate value. Therefore, it was considered prudent to make adjustments to pre-consolidation pressure and compressibility parameters rather than arbitrarily adjusting one parameter only. The combination of estimations provides a resonable overall match to the observed data.

CONCLUSIONS

Consolidation parameters of the soft clay in Townsville Port Access Road Project were reassessed based on observational approach and back-analysis of monitoring results from the Geotechnical Test Pad. Curve matching technique by comparing the predicted design values to the field measured values was the primary approach leading to the realistic and reasonable revision of preliminary design parameters. This primary approach was supported by the consistency check from oedometer tests and pore pressure dissipation tests to reinforce the findings.

However, the study acknowledged the design uncertainty due to possible variability in consolidation parameters. While the consolidation parameters assessed are considered to provide a more realistic approach for the design, geotechnical observational approach during construction is considered to be essential.

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