RESEARCH ONLINE

University of Wollongong
Research Online

Faculty of Engineering - Papers (Archive)

Faculty of Engineering and Information Sciences

2007

Soft Clay Stabilisation Using Prefabricated Vertical Drains and the Role of Viscous Creep at the Site of Sunshine Motorway, Queensland

Buddhima Indraratna
University of Wollongong, buddhima_indraratna@uow.edu.au

C. Rujikiatkamjorn
University of Wollongong, cholacha@uow.edu.au

V. Wijeyakulasuriya
Department of Main Roads, Queensland

Publication Details

This conference paper was originally published as Indraratna, B, Rujikiatkamjorn C and Wijeyakulasuriya, V, Soft clay stabilization using prefabricated vertical drains and the role of viscous creep at the site of sunshine motorway, Queensland, in Proceedings of the 10th Australia New Zealand Conference on Geomechanics, Brisbane, Australia, 21-24 October 2007, 2, 96-101.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

RESEARCH ONLINE

Soft Clay Stabilisation Using Prefabricated Vertical Drains and the Role of Viscous Creep at the Site of Sunshine Motorway, Queensland

Buddhima Indraratna and Cholachat Rujikiatkamjorn
University of Wollongong, NSW 2522, Australia
Vasantha Wijeyakulasuriya
Queensland Department of Main Roads, Brisbane, Australia

Keywords: Creep, Finite Element Analysis, Ground Improvement, Soft Soils, Vertical Drains

ABSTRACT
The Soft Soil Creep and the Soft Soil models are employed to analyse the behaviour of the Sunshine Embankment with and without prefabricated vertical drains. Details of the analysis are discussed in terms of settlements, excess pore pressures and lateral displacements. While both models can predict the settlement well, the Creep model gives a greater accuracy in the prediction of excess pore pressures and lateral movements. The analysis suggests that the undissipated excess pore pressures during consolidation may have been caused by the viscous nature of soils.

1 INTRODUCTION

Prefabricated vertical drains (PVDs) and preloading have been used widely to accelerate the consolidation process of soft clay by shortening the drainage path. The behaviour of soft clay foundations improved by vertical drains is usually analysed using a plane strain finite element method incorporating the elastoplastic Model such as the modified Cam-Clay model (Hird et al., 1995; Indraratna and Redana, 2000). In such analysis, the vertical deformation (settlement) can be easily predicted whereas the discrepancies between the predicted and measured results in terms of excess pore pressures and lateral displacements are significant (Wijeyakulasuriya, 1999; Indraratna and Redana 2000). Indraratna et al. (2006) and Yin and Zhu (1999) discussed that viscous (creep) nature of clay, which is often neglected in routine analysis, should be considered to investigate the phenomenon of the delayed excess pore pressure dissipation, even after embankment construction. In this paper, the elasto-viscoplastic and Soft Soil models were employed in the finite element analysis to analyse the consolidation of soft clay at the Sunshine Motorway. The results from the analysis are discussed in comparison with field behaviour. The benefits of the creep model in predicting the excess pore pressures and lateral movements are elucidated.

2 BASIC ELASTOVISCOPLASTIC MODEL

Under constant effective stress, Bjerrum (1967) pointed out that creep may occur both during and after primary consolidation. In this hypothesis, the settlement can be divided into 2 parts: (a) an instant compression due to a reduction in void ratio, and (b) a delayed compression representing the volume reduction at unchanged effective stress (Fig. 1a). Subsequently, Vermeer and Neher (2000) incorporated their Soft Soil Creep Model (SSC) in a finite element analysis. In this paper, the SSC model will be employed to investigate the effects of viscous nature of soils. The strain rate ($\dot{\varepsilon}$) at any given effective stress (σ') can be given by:

$$\dot{\varepsilon} = \frac{(1+\nu)\kappa^*}{3(1-\nu)}\frac{\dot{\sigma}'}{\sigma'} + \frac{\mu^*}{\tau}\left(\frac{\sigma'}{\sigma_p}\right)^{\lambda^*-\kappa^*/\mu^*} \quad (1)$$

where, κ^* is modified swelling index, ν is Poisson's ratio, σ' is vertical effective stress, μ^* is modified creep index, λ^* is modified compression index, τ is time and σ_p = preconsolidation pressure. It is noted that the above parameters in Equation (1) can be determined using multi-stage loading oedometer test.

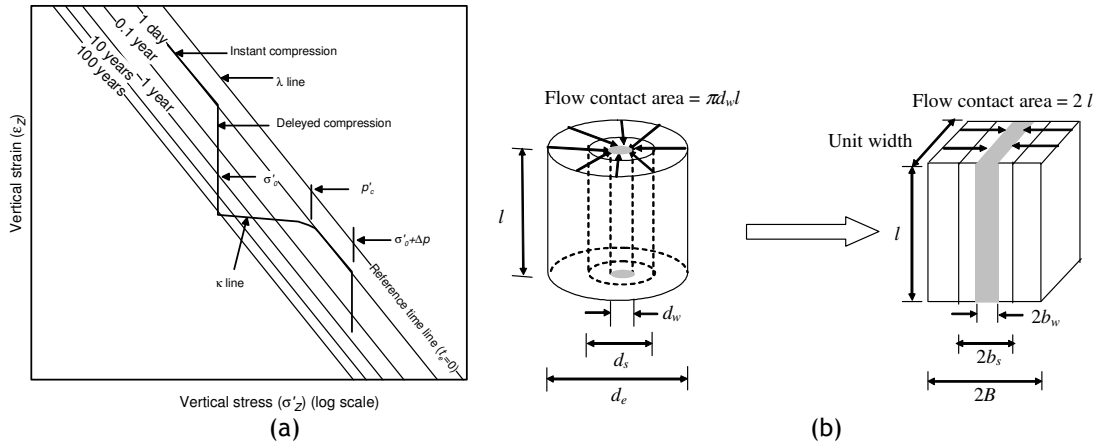


Figure 1: (a) Principle for evaluating creep model (Bjerrum, 1967) (b) Conversion of axisymmetry radial flow to plain strain flow (after Indraratna et al. 2005)

3 CONSOLIDATION MODELING OF SOIL BELOW THE SUNSHINE MOTORWAY

3.1 Site Characteristics and Embankment Details

The Subshine Motorway is located in Maroochy Shire, Queensland, Australia. Subsoil layer at this site is composed of very soft, highly compressible, saturated organic marine clays of high sensitivity. To investigate the foundation responses, a well insrtumented trial embankment was constructed with three different ground improvement schemes (i.e. Section A: PVDs @ 1m spacing, Section B: No PVDs and Section C: PVDs @ 2m spacing). The data was provided by the Queensland Department of Main Roads, as a part of an Australian Research Council linkage project (QDMR, 1992). In this study, only Sections B and C were analysed.

At this site, subsoil conditions were relatively uniform, consisting of sensitive silty clay approximately 10-11m thick, overlying a layer of sand approximately 6m thick. In the analysis, the soil profile was conceniently divided into 3 sublayers. The subsoil consists of a silty clay layer (2.5 m depth) overlying very soft to soft silty clay extending from 2.5 m to 5.5 m depth. A 5.5 m thick, medium silty clay layer underlies the soft silty clay layer. The groundwater level is at the ground surface. In Section C, PVDs were installed to a depth of 11m whereas a conventional surcharge without PVDs was constructed in Section B. The adopted parameters of 3 subsoil layers obtained from the standard oedometer tests are listed in Table 1. The modified creep index (μ^*) was determined using an oedometer test at the end of primary consolidation. The compression parameters ($\lambda^*$and κ^*) for both Soft Soil (SS) and Soft Soil Creep (SSC) models are assumed to be the same.

Table 1: Soil elastoplastic parameters used in the finite element analysis

Depth (m)	Soil type	M (Assumed)	λ^*	κ^*	ν Poisson's Ratio	e_0 (Initial void ratio)	μ^* (for SSC)	k_h ($x10^{-4}$m/day)	γ_s (kN/m^3)
0.0-2.5	Silty clay	1.20	0.27	0.027	0.3	1.85	0.012	12.66	16.4
2.5-5.5	Soft silty clay	1.20	0.48	0.048	0.3	3.10	0.02	7.06	13.7
5.5-11.0	Silty clay	1.18	0.26	0.026	0.3	1.75	0.012	5.46	15.9

The equivalent plane strain permeability for PVDs analysis was based on the revised method proposed by Indraratna et al. (2005). The equivalent permeability of the model is determined by (Fig. 1b):

$$k_{hp} = \frac{k_h\left[\alpha + \beta \frac{k_{hp}}{k'_{hp}}\right]}{\left[\ln\left(\frac{n}{s}\right) + \frac{k_h}{k'_h}\ln(s) - 0.75\right]} \qquad (2)$$

where, $\alpha = \frac{2}{3}\frac{(n-s)^3}{(n-1)n^2}$, $\beta = \frac{2(s-1)}{(n-1)n^2}\left[n(n-s-1) + \frac{1}{3}(s^2+s+1)\right]$,

$n = d_e/d_w = B/b_w \quad and \quad s = d_s/d_w = b_s/b_w$

In the above, k_h and k'_h are soil permeability for undisturbed and smear zone respectively. The half unit cell is B, half width of drains is b_w and half width of smear zone is b_s and they are taken to be the same as their axisymmetric radii of d_e, d_w and d_s, respectively.

The embankment load was divided into 3 stages up to a maximum height of 2.5 m (the unit weight of surcharge fill = 19kN/m^3), and the loading stages are shown in Fig. 2a. The locations of filed instrumentation are illustrated in Fig 2b. The ratio between the horizontal and vertical permeability within the smear zone was set to 1. Outside the smear zone, the horizontal permeability was taken to be twice that of the vertical permeability, and the diameter of the smear zone was assumed to be 5 times the equivalent vertical drain diameter (Indraratna and Redana, 1998).

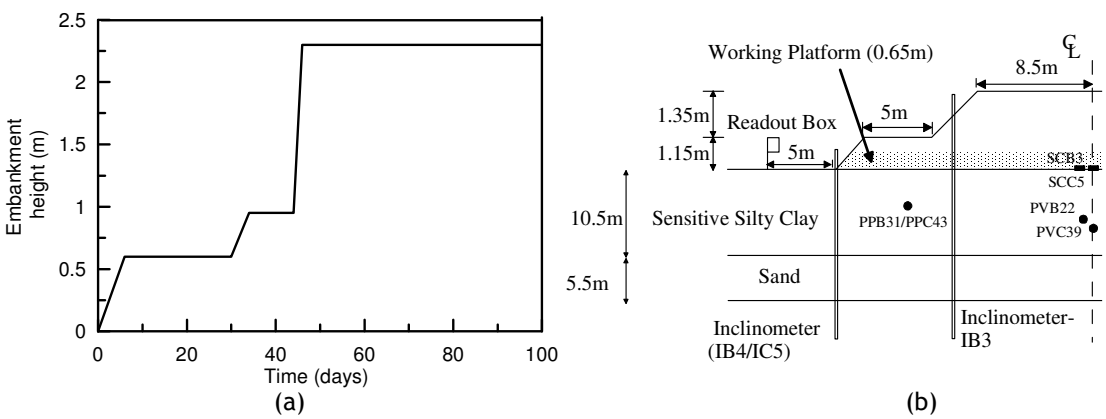


Figure 2: (a) Multistage loading for embankment and (b) Embankment cross section with locations of instrumentations

The numerical analysis was based on the Soft Soil Creep model and the Soft Soil model incorporated in the finite element code, PLAXIS V. 8.4 (Brinkgreve and Vermeer, 2006). The mesh discretization with 6-node triangular elements (6 nodes and 3 Gaussian integration points) is shown in Fig. 3. The outer boundaries were considered as closed consolidation boundaries.

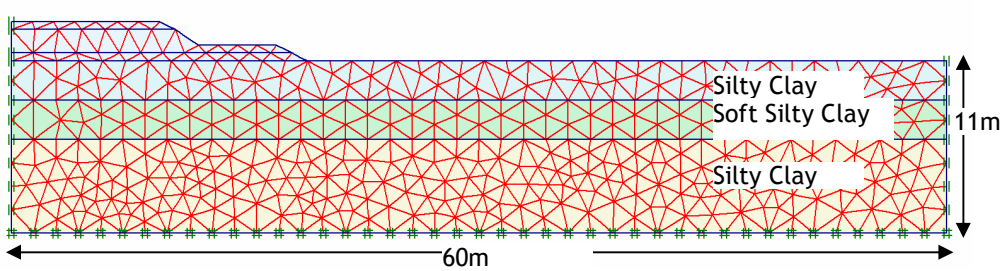
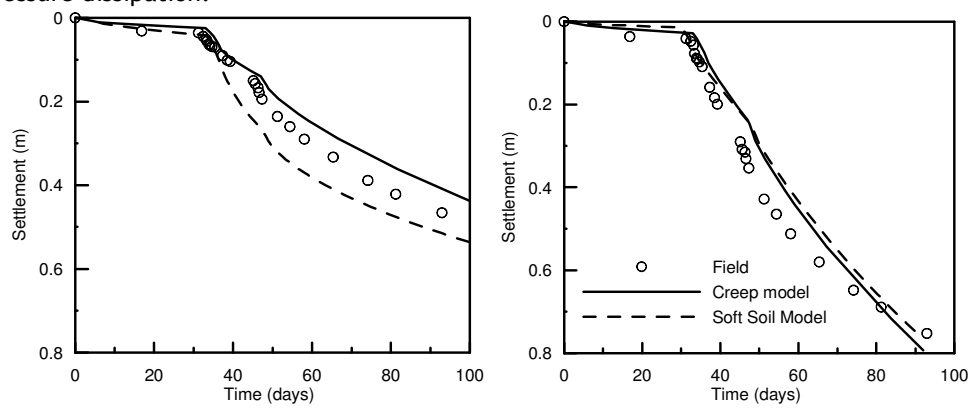


Figure 3: Finite element mesh for plane strain analysis

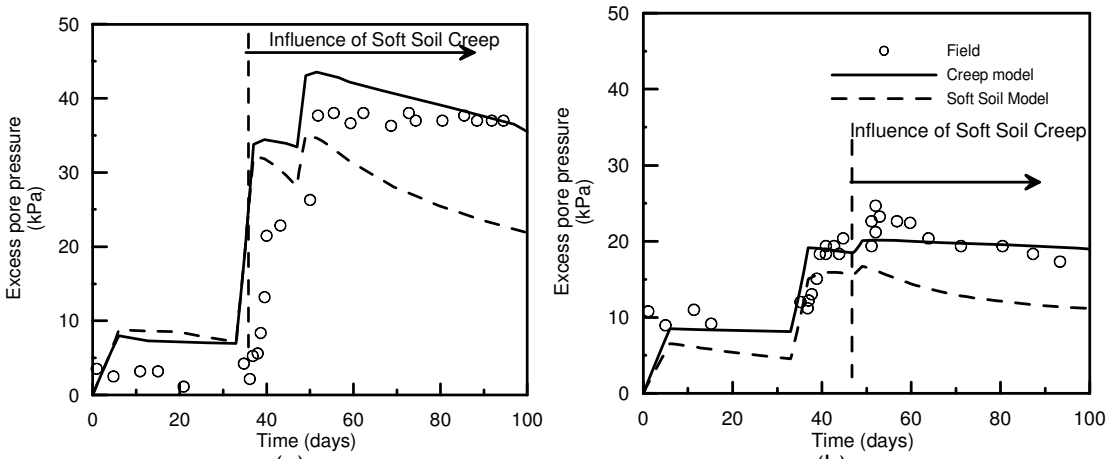
3.2 Results and Discussions

Figure 4 shows the comparison of the surface settlement for SS and SSC models with the field data. Numerical results from both models generally agree well with the field measurements. Figures 5 and 6 compare the excess pore pressures between field data and finite element predictions. The predictions obtained from the SSC model are much better than the SS model after about 50 days. The phenomenon of undissipated excess pore pressure during the ongoing settlement can be captured by the SSC model. This is because, at a given mean effective stress, the viscous nature of clay causes additional soil compression and associated excess pore pressure for a certain period of time. As explained earlier, the associated high shear strains will also cause a retardation of excess pore pressure dissipation.



(a) (b)

Figure 4: Surface settlements at the embankment centreline (a) Section B and (b) Section C

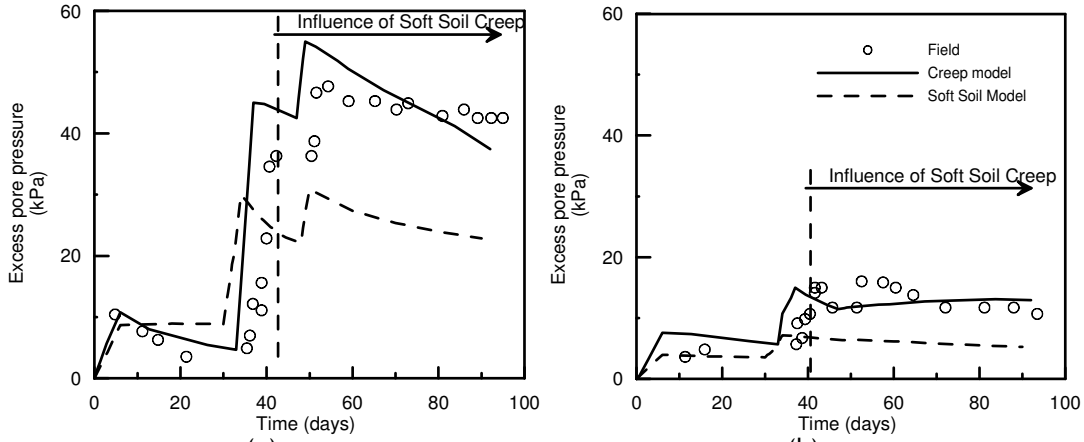


(a) (b)

Figure 5: Variation of excess pore water pressure for Section B (a) 3m deep below the surface and 1.0m away from centreline and (b) 3m deep below the surface and 15.0m away from centreline

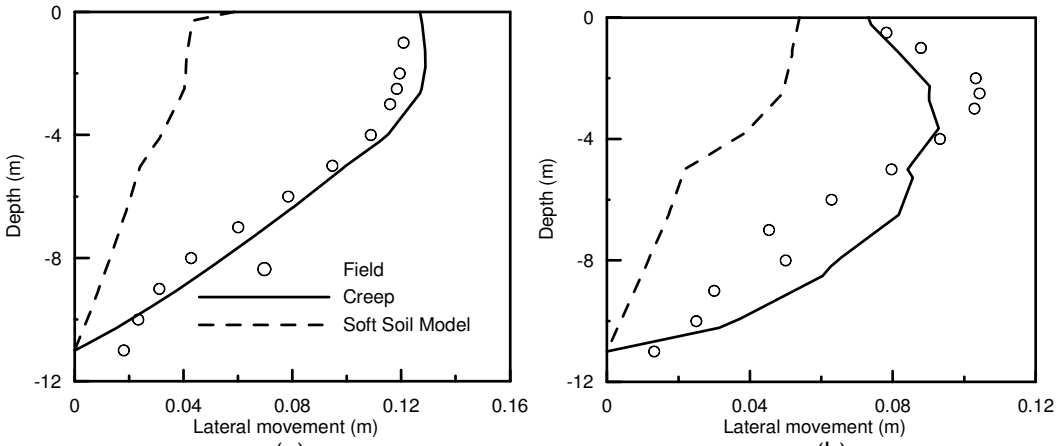
Figure 7 presents the comparisons of the lateral displacement at the embankment toe. The SSC model gives better predictions whereas the SS model under-predicts the lateral displacement. This is because, in view of the strain path shown in Fig. 8a, the shear strain calculated based on the SSC model is more than SS model due to creep, resulting in more lateral deformation. Figure 8b illustrates the benefits of PVDs in reducing the lateral displacement at the embankment toe. At a given volumetric strain (ε_v), PVD induces higher shear strain (ε_s) causing less lateral strain (ε_2). High shear strains also contribute to retarded rates of excess pore pressure dissipation. Hence, as observed here, this excess pore pressure does not dissipate rapidly in some regions beneath the embankment (Fig. 5). High shear strains may also cause substantive stress re-distributions affecting the pore pressure dissipation. Probably, drain clogging, well resistance, excessive smear or

piezometer tips malfunctioning as pointed out by many studies in the past are not the only reasons for the retarded excess pore pressure dissipation and excessive lateral displacement (Jamiolkowski et al. 1983; Indraratna and Redana, 2000). Therefore, the inclusion of creep in the FEM techniques for some soft clays is pertinent in the accurate prediction of time-dependent excess pore pressures and lateral displacement.



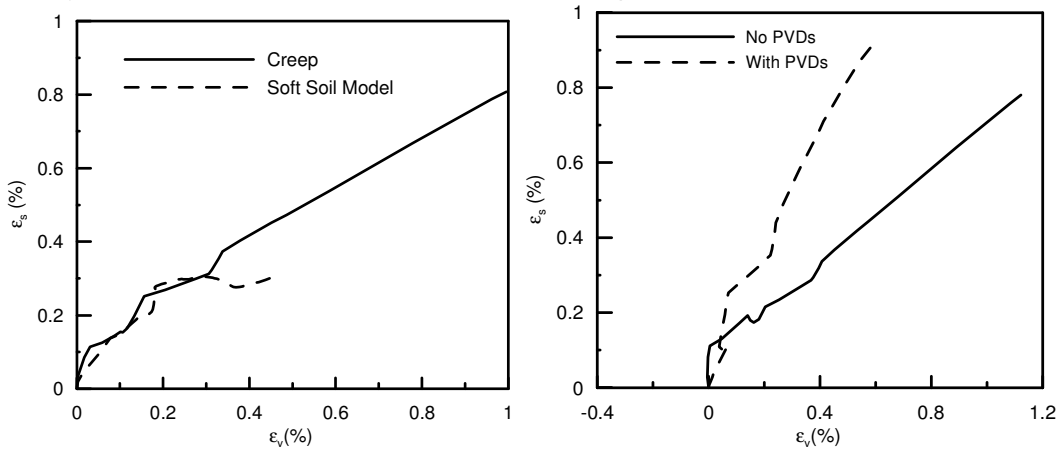
(a) (b)

Figure 6: Variation of excess pore water pressure for Section C (a) 3m deep below the surface and 1.0m away from centreline and (b) 3m deep below the surface and 15.0m away from centreline



(a) (b)

Figure 7: Predicted and measured lateral displacements (a) Section B and (b) Section C



(a) (b)

Figure 8: Strain paths at 2m deep beneath the embankment toe

4 CONCLUSIONS

In this paper, the settlements, excess pore pressures and lateral displacements of the test embankment with and without PVDs at the Sunshine Motorway, Australia were simulated using a finite element analyses with the Soft Soil creep model and Soft Soil model. Although, the predicted settlements obtained from both models agree well with the measured data, the Soft Soil Creep Model gives better accuracy in predicting the excess pore pressures and lateral displacements. It is found that the apparent delay of excess pore pressure dissipation can be attributed to the creep nature of the soft soil. While various past studies have explained the apparent 'retarded' pore pressure dissipation to drain clogging, piezometer tip malfunction, soil smearing and the measuring instrument, this study clearly implies that additional soil compression due to viscous (creep) nature will cause additional pore pressures, hence, the phenomenon of apparently no-dissipating excess pore water pressure.

ACKNOWLEDGEMENT

The writers gratefully acknowledge the continuing support of Queensland Department of Main Roads in providing much needed field data for various past and present studies. Various efforts of past and current research students supervised by the first author in soft clay improvement are gratefully appreciated.

REFERENCES

Bjerrum, L. (1967). *Engineering geology of Norwegian normally-consolidated marine clays as related to settlement of buildings*. Geotechnique, 17(2), 81-118.

Brinkgreve, R.B.J. and Vermeer P.A. (2006) *Plaxis Manual (*Version8). University of Stuttgart, Germany A.A.Balkema/Rotterdm/Brookfield.

Hird, C.C., Pyrah, I.C., Russell, D. and Cinicioglu, F. (1995). *Modelling the effect of vertical drains in two-dimensional finite element analyses of embankments on soft ground*. Can. Geotech. J., 32, 795-807.

Indraratna, B. and Redana, I. W. (1998). *Laboratory determination of smear zone due to vertical drain installation*. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 124(2), 180-184.

Indraratna, B. and Redana, I W. (2000). N*umerical modelling of vertical drains with smear and well resistance installed in soft clay*, Canadian Geotechnical Journal, 37, 132-145.

Indraratna, B., Sathananthan, I., Rujikiatkamjorn C. and Balasubramaniam, A. S. (2005). *Analytical and numerical modelling of soft soil stabilized by PVD incorporating vacuum preloading*. International Journal of Geomechanics, 5(2), 114-124.

Indraratna, B, Rujikiatkamjorn, C., Shahin, M., and Christie, D. (2006). *Soft Soil Stabilisation with Special Reference to Railway Embankments*. Proc. of 4th International Conference on Soft Soil Engineering, Vancouver, Canada, (Edited by D. Chan and K. T. Law), 35-56.

Jamiolkowski, M., Lancellotta, R., and Wolski, W. (1983). *Precompression and speeding up consolidation*. In Proceedings of 8th European Conference on Soil Mechanics and Foundations, Helsinki, Finland, 3, 1201-1206.

Queensland Department of Transport (1992) *Sunshine Motorway Stage 2 – Interim Report on the Performance of the Trial Embankment Area 2A* (Ch 28490-28640). Materials and Geotechnical Services Branch Report No. R1802, July 1992.

Vermeer, P.A. and Neher, H.P. (1999). *A soft soil model that account for creep*. Beyond 2000 in computational geotechnics, Balkema, 249-261.

Wijeyakulasuriya, V., Hobbs, G and Brandon, A. (1999). *Some experiences with performance monitoring of embankments on soft clays*. 8th ANZ Conference on Geomechanics, Hobart, Vol. 2, 783-788.

Yin, J.-H. and Zhu, J.G. (1999). Elastic visco-plastic consolidation modelling and interpretation of pore water pressure responses in clay underneath Tarsiut Island. Canadian Geotechnical Journal, 36(4), 708-717.