University of Wollongong
Research Online

Faculty of Engineering - Papers (Archive)

Faculty of Engineering and Information Sciences

2007

Cyclic behaviour of PVD-soft soil subgrade for improvement of railway tracks

A. Attya
University of Wollongong, anass@uow.edu.au

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

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

Publication Details

This conference paper was originally published as Attya, A, Indraratna, B and Rujikiatkamjorn, C, Cyclic behaviour of PVD-soft soil subgrade for improvement of railway tracks, in Proceedings of the 10th Australia New Zealand Conference on Geomechanics, Brisbane, Australia, 21-24 October 2007, 2, 36-41.

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

Cyclic behaviour of PVD-soft soil subgrade for improvement of railway tracks

Anass Attya[1], Buddhima Indraratna[2], Cholachat Rujikiatkamjorn[3]
[1] PhD Student, [2] Professor and Head of School of Civil, Mining and Environmental Engineering,
[3] Research Fellow
University of Wollongong, NSW, Australia

Keywords: cyclic, vertical drains, pore pressure, soft soils, railtrack

ABSTRACT

The behaviour of saturated soft clays subjected to cyclic loading is of considerable importance in the design of railway subgrades. Soft clays can be extensively found in many coastal regions of Australia up to significant depths, including the coastal belt and the central part of NSW. These soft clay deposits are characterised by very low bearing capacity and excessive settlement. The increase in generated excess pore pressures due to heavy freight trains significantly reduces the bearing capacity and causes serious damage to the rail infrastructure such as clay pumping underneath tracks and excessive subsidence. The use of prefabricated vertical drains (PVDs) is one of the popular methods for soft ground improvement. In this paper, the behaviour of soft clay subjected to cyclic loads is investigated using large-scale triaxial tests. Cyclic triaxial tests on remoulded soft clay samples with vertical drains have been carried out using a large-scale triaxial apparatus designed and built at the University of Wollongong. The improvement gained by drained compression using PVDs is presented and discussed in terms of the pore pressure ratio. An attempt is also made to model such behaviour numerically in CRISP finite element code.

1 INTRODUCTION

In the recent decades, the development of high speed train lines has grown widely all over the world. As a consequence, crossing areas of soft formation soils has become inevitable in order to achieve straight lines and short travel times. Train loads mainly induce cyclic loads on the railtrack substructure especially at high speeds (Indraratna et al. 2006, Li & Selig 1996). The prediction of the behaviour of soils under cyclic loading is a problem of considerable importance in geotechnical engineering. The behaviour of soft clays subjected to cyclic loading is highly significant in both railways and roadway design (Carter et al. 1982). Also, the rapid increase in population and associated urbanisation has necessitated the utilisation of the poorest of soft soils. In Australia, soft clays exist extensively in the coastal regions of Australia where most of the Australian railway network traverses (Indraratna et al. 2006). These soft formations are usually characterised by low bearing capacity and high compressibility properties, affecting the performance of major transportation infrastructure.

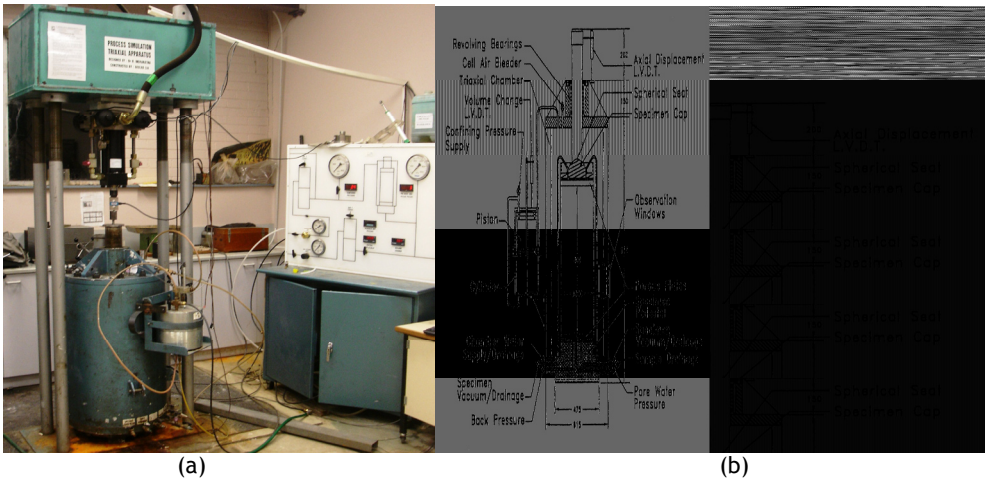
It is well known that failure in soft clays under cyclic loads occurs at strengths well below the undrained shear strength obtained from the standard static tests (Larew & Leonards 1962, Sangrey et al. 1969). The rapidly generated excess pore water pressures due to cyclic loads play a key role in causing failure of the clay subgrade as it dramatically decreases the effective stress under undrained cyclic loading. Hence, a ground improvement technique is deemed necessary to control the excess pore pressure as well as the initial and final settlements (Kaynia et al. 2005). The use of prefabricated vertical drains (PVDs) with preloading has been widely used to stabilise soft soil deposits prior to construction (Indraratna et al. 1994, Indraratna et al. 2003), inducing most of the expected ultimate settlement under the given loading by promoting rapid radial consolidation (Richart, 1957). This results in a gain in the shear strength of the soft formation soil.

The purpose of the current study is to investigate the effect of cyclic load application to soft clay improved by PVDs, and to discuss the potential advantages of PVDs under cyclic loading situations such as in railway environments.

2 EXPERIMENTAL INVESTIGATIONS

2.1 Testing equipment

Experimental investigation of PVDs in soft clay demands large-scale laboratory testing (Indraratna & Redana 1998). In the current study, the large-scale cylindrical dynamic triaxial equipment designed and built at the University of Wollongong (Indraratna et al. 1998) was used (Figure 1a). The apparatus is capable of accommodating 300 mm diameter and 600 mm height samples and utilises a hydraulic type dynamic actuator to apply load cycles to soil specimens. Figure 1(b) shows a schematic illustration of the different components of the equipment: the triaxial chamber, the axial loading unit, the air pressure and the water control unit, the pore pressure measurement system and the volumetric change measurement device.



(a) (b)

Figure 1: (a) Large-scale cylindrical dynamic triaxial equipment, (b) schematic diagram of the large-scale triaxial cell

The equipment was modified by the authors to measure the excess pore water pressure at different locations inside the soil sample. Miniature type pore pressure transducers were fitted through the base of the triaxial rig and then through the specimen pedestal to the soil sample as shown in Figures 2(a) and 2(b). A proper seal was provided to the fitting holes to avoid any leakage.

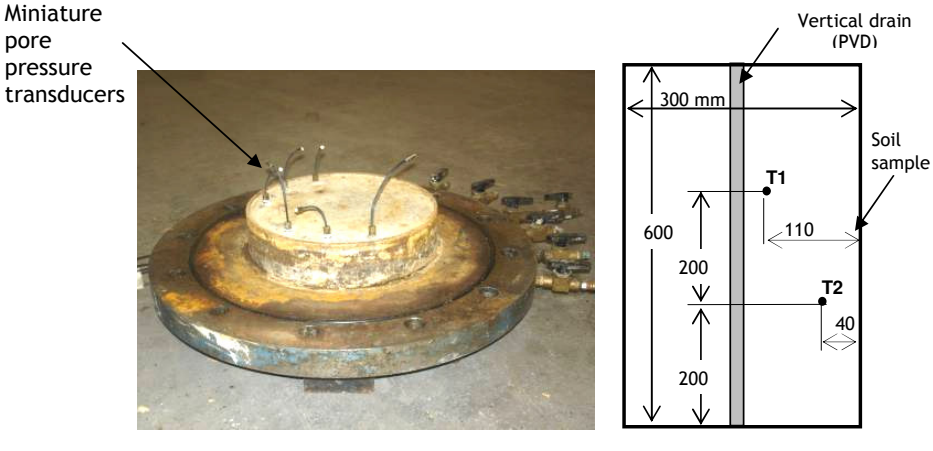


Figure 2: (a) Triaxial base and miniature pore pressure transducers, (b) Location of the pore pressure transducers at different positions from the PVD inside the soil sample

2.2 Testing procedure

Reconstituted alluvial clay from North-eastern NSW, Australia was used to make large samples as it is neither feasible nor possible to obtain one big undisturbed sample for the purpose of large-scale testing (Indraratna & Redana 1998). The clay particles (<2 μm) formed about 40%, while particles smaller than silt size (<6μm) constituted approximately 70% of the soil specimen. The liquid limit w_L was found to be 69% and plasticity index I_P = 40%. The soil was classified according to the Plasticity Chart (Casagrande 1932) as a clay of high plasticity (CH). The compression index (c_c) and the swelling index (c_s) were 0.85 and 0.15 respectively. The preparation procedure of the reconstituted sample is detailed below (Attya & Indraratna 2006):

1. The clay was wet-screened through a # 40 sieve (0.425 mm opening size) to remove larger particles and any coarse organic materials.
2. The clay was then re-mixed with water using a rotary mechanical mixer to a water content approaching the liquid limit.
3. The rubber membrane was clamped into the base of the triaxial equipment and a geosynthetic filter layer was placed at the bottom to prevent clogging of the drainage line.
4. Subsequently, the clay slurry was placed and lightly compacted in four layers (150 mm each) inside the membrane to a unit weight of about 15.5 kN/m^3.
5. During the placement of the clay in the membrane, four pore pressure transducers were positioned at selected locations (Figure 2).
6. A vertical band drain was inserted into the clay specimen. A geosynthetic layer was placed at the top of the sample also, after inserting the PVD and prior to placing the top loading cap, in order to protect the top drainage holes from clogging.

The soil sample was consolidated under k_o condition to model the approximate field condition by inducing the appropriate insitu stresses. Upon finishing the consolidation stage, the cyclic loading was applied to simulate the train load cycles. The test was conducted at cyclic stress ratio (CSR) of 0.6 and a loading frequency of 5 Hz with radial drainage allowed via the PVD and the top porous plate. The cyclic stress ratio is defined as the ratio between the cyclic deviator stress q_{cyclic} to the static deviator stress at failure $q_{failure}$ (Brown et al. 1975, Zhou & Gong 2001). The insitu stress conditions and the cyclic stress state are shown in Figure 3. After the cyclic load was removed, drainage was permitted to dissipate the developed cyclic excess pore pressure. The excess pore pressures at the locations indicated in Figure (b) were measured.

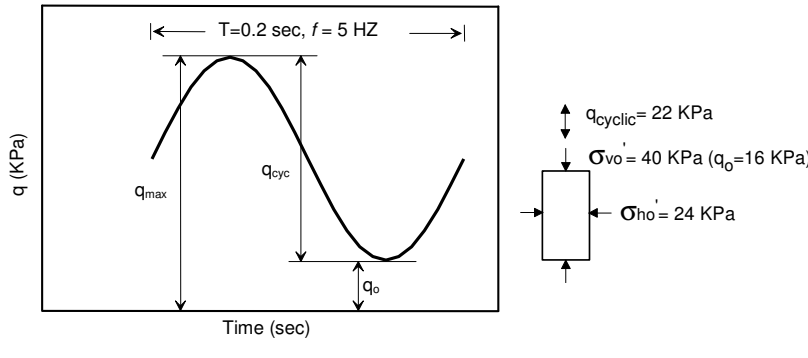
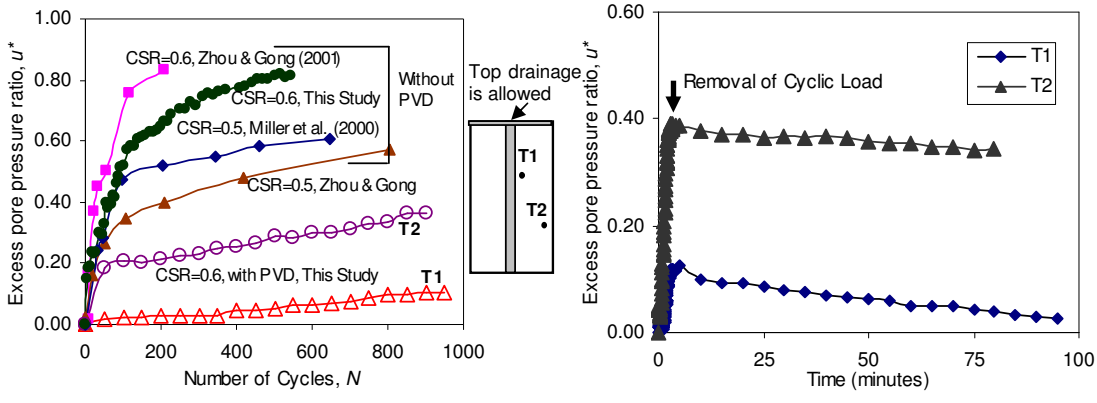


Figure 3: Cyclic stress state and insitu stress state

2.3 Test results

The cyclic shearing behaviour of saturated samples is mainly dependent on the buildup of pore water pressures and the associated reduction in effective stresses occurring under cyclic loading conditions. Excess pore ware pressure ratio (u^*) is usually used to depict that behaviour (Miller et al. 2000, Zhou & Gong 2001), where excess pore water pressure ratio is defined as the excess pore water pressure normalised to the effective initial confining pressure. Figure 4(a) shows the

development of excess pore water pressures with and without PVD for this study compared to available data from the literature on undrained cyclic behaviour in the absence of PVDs (Miller et al. 2000, Zhou & Gong 2001). The dissipation of excess pore pressures after removal of the cyclic load is illustrated in Figure 4(b). It is obvious from Figure 4 that the role of PVD is vital in controlling the rapid buildup of pore water pressures and to provide improvement of soft soils even under cyclic loading conditions. In addition, it reduces the risk of any potential shear failure as shown in Figure 4(a) for CSR of 0.6 without PVD. The use of PVDs also significantly assists in the dissipation of cyclically developed pore water pressures after the removal of cyclic loads, making the soil more resistant to the next loading stage in case of repeated cyclic loadings as applicable in railway environments. The length of the drainage path plays a very important role, and as expected, a faster dissipation rate was observed for T1 having the shorter drainage path length, while a slower rate was associated T2.



(a) (b)

Figure 4: (a) Excess pore water pressures development under cyclic loading with and without PVDs, (b) Post-cyclic loading dissipation of excess pore water pressures via PVDs.

3 NUMERICAL ANALYSIS

An axisymmetric finite element analysis was employed to model the improved behaviour of soils by PVDs under cyclic loading conditions. A single drain condition, as in the laboratory, was investigated using the finite element code CRISP V5.2 (2006). The discretised finite element mesh is shown in Figure 5, where six-node linear strain triangular elements with three excess pore pressure nodes were considered in this mesh.

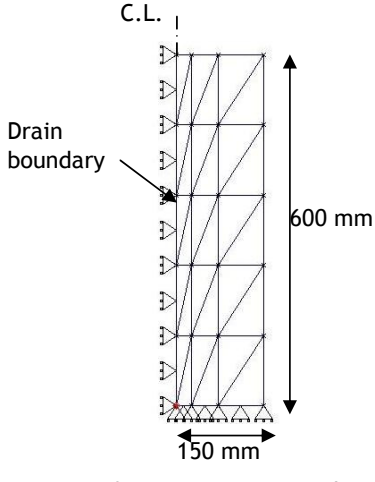


Figure 5: Finite element discretisation for axisymmetric analysis of soil unit cell in the large-scale cylindrical triaxial.

The modified Cam-clay (MCC) model (Roscoe & Burland 1968) was used in the analysis, the Cam-clay parameters for the soil were selected as measured in the laboratory and are as follows: slope of isotropic compression line in v : ln p' (λ) is 0.367, slope of unload-reload lines in v : ln p' (κ) is 0.065, slope of critical state line in q : p' (M) is 1.12, reference voids ratio on the critical state line at unit consolidation pressure (e_{CS}) is 2.85. The excess pore water pressures were set to zero along the drain boundary to simulate pore pressure dissipation at the PVD boundary. The loading and boundary conditions were applied to simulate the laboratory conditions as closely as possible. The finite element predictions together with the measured experimental data are shown in Figure 6, and the numerical predictions illustrate the elastic recoverable as well as the plastic components of the excess pore pressures. As expected, the excess pore pressures for T1 with the shorter drainage path (Figure 6a) were less than those for T2 (Figure 6b). However, when the cyclic stresses are first applied (where time is almost zero), the modelled soil follows the MCC undrained stress path in which the undrained increase in pore pressure is rapid and very high. This indicates that Cam-clay predictions under cyclic loads are quicker and higher for distances far from the PVD, one way to overcome that may be to introduce a cyclic dissipation parameter under repeated loading. It is also hard to experimentally capture the fluctuations in pore pressures at the at the frequency of the applied load without having a significant amount of noise in the measured data, and that is why only the residual excess pore pressures were measured as shown. The accelerating effect of the PVDs on the dissipation of excess pore pressure is shown in Figure 7 indicating the significance of the drainage length.

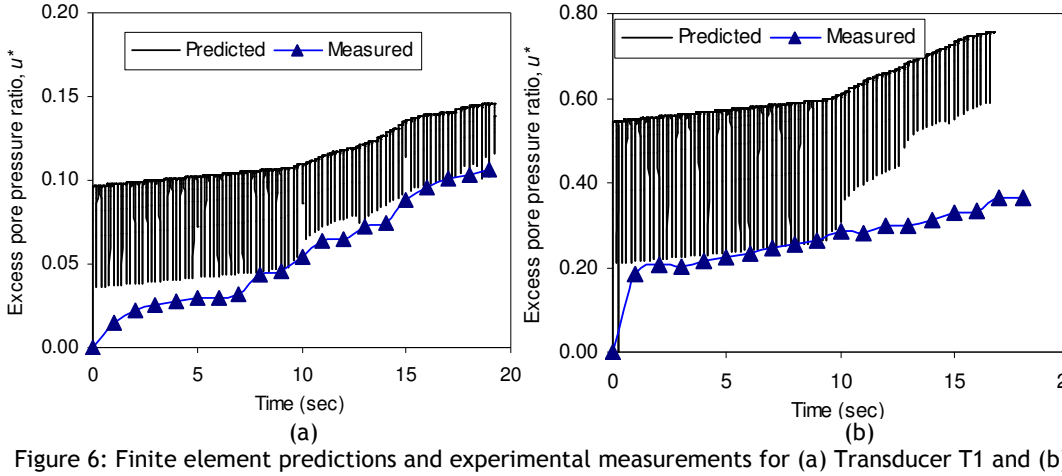


Figure 6: Finite element predictions and experimental measurements for (a) Transducer T1 and (b) Transducer T2

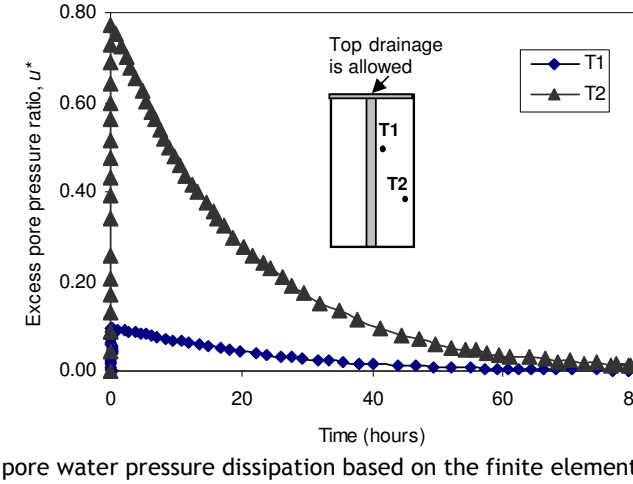


Figure 7: Excess pore water pressure dissipation based on the finite element results for different positions from the PVD

4 CONCLUSIONS

An experimental study using large-scale triaxial equipment together with finite element numerical modelling was conducted to investigate the influence of prefabricated vertical drains (PVDs) on the cyclic behaviour of soft clay, simulating typical cyclic loads encountered in railway environments. The excess pore water pressure ratio and the post-cyclic loading dissipation rate were considered in the assessment of the performance of PVDs. During the application of cyclic loading, the PVDs reduced the rate of generation of excess pore water pressure, when compared to situations without PVD. Under the same cyclic stress ratio, the magnitude of the excess pore pressure generated was significantly less when PVDs were used. As expected, irrespective of the magnitude of the cyclic stress ratio and the number of cycles, the development of excess pore pressure was the least for the part of the soil specimen nearest to the central PVD, as indicated by the transducer (T1) located closest to the PVD. The findings presented here clearly suggest that railway tracks will benefit considerably by having PVDs installed in the soft subgrade, by reducing the risk of undrained failure and soil slurrying under high excess cyclic pore pressures.

REFERENCES

Attya, A., and Indraratna, B. (2006). *Large-scale cyclic triaxial testing of soft clay*. Proceedings of the 2006 Symposium on Soft Ground Engineering, Australian Geomechanics Society, Sydney, Australia, 167-172.

Brown, S. F., Lashine, A. K. F., and Hyde, A. F. L. (1975). *Repeated load triaxial testing of a silty clay*. Geotechnique, 25(1), 95-114.

Carter, J. P., Booker, J. R., and Wroth, C. P. (1982). *A critical state soil model for cyclic loading*. Soil Mechanics-Transient and Cyclic Loading, G. N. Pande and O. C. Zienkiewicz, eds., John Wiley & Sons Ltd, 219-252.

Casagrande, A. (1932). *Research on Atterberg limits of soils*. Public Roads, 13(8), 121-136.

CRISP. (2006). *CRISP V. 5.2 Manuals*, The CRISP Consortium Ltd, UK.

Indraratna, B., Balasubramaniam, A. S., and Ratnayake, P. (1994). *Performance of embankment stabilized with vertical drains on soft clay*. Journal of Geotechnical Engineering, ASCE, 120(2), 257-273.

Indraratna, B., Bamunawita, C., Redana, I. W., and McIntosh, G. (2003). *Modelling of prefabricated vertical drains in soft clay and evaluation of their effectiveness in practice*. Ground Improvement, 13, 127-137.

Indraratna, B., Ionescu, I., and Christie, H. D. (1998). *Shear behavior of railway ballast based on large-scale triaxial tests*. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 124(5), 439-449.

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., Rujikiatkamjorn, C., Wijeyakulasuriya, V., Shahin, M., and Christie, D. (2006). *Soft soil stabilisation with special reference to road and railway embankments. Fourth International Conference on Soft Soil Engineering (4th ICSSE)*, Vancouver, British Columbia, Canada.

Kaynia, A. M., Lacasse, S., and Madshus, C. (2005). *Geodynamics issues in high speed railway lines on soft soils*. proceedings of the Fifth International Geotechnical Conference, Cairo University, Egypt, 91-113.

Larew, H. G., and Leonards, G. A. (1962). *A strength criterion for repeated loads*. Proceedings of the Highway Research Board, No. 41, 529-556.

Li, D., and Selig, E. T. (1996). *Cumulative plastic deformation for fine-grained subgrade soils*. Journal of Geotechnical Engineering, ASCE, 122(12), 1006-1013.

Miller, G. A., Teh, S. Y., Li, D., and Zaman, M. M. (2000). *Cyclic shear strength of soft railroad subgrade*. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 126(2), 139-147.

Roscoe, K. H., and Burland, J. B. (1968). *On the generalized stress-strain behaviour of wet clay*. Geotechnique, 535-609.

Sangrey, D. A., Henkel, D. J., and Esrig, M. I. (1969). *The effective stress response of a saturated clay soil to repeated loading*. Canadian Geotechnical Journal, 6(3), 241-252.

Zhou, J., and Gong, X. (2001). *Strain degradation of saturated clay under cyclic loading*. Canadian Geotechnical Journal, 38, 208-212.