

SELECTION OF SUITABLE GROUND IMPROVEMENT TECHNIQUES FOR SOUTHEAST QUEENSLAND SOFT CLAY

Erwin Yan-Nam Oh

PhD Candidate, School of Engineering, Griffith University, Queensland, Australia

Abstract: Soft estuarine clays are found in many expressway and motorway projects in Southeast Queensland. The strengths of these clays are very low and as such embankments failures can be encountered during construction. Several ground improvement techniques are available to increase the soil strength, and these techniques include the use of surcharge with stone column or vertical drains. When the coefficient of consolidation is low, the sensitivity and organic contents are high, preloading techniques with vertical drains may not be effective due to smear effects. Thus, chemical stabilisation may be the appropriate alternative ground improvement technique. The cement stabilisation improves the strength of soft clay by effectively aggregating smaller particles with additional chemical bonds. A laboratory study has been conducted to examine the influence of cement additives on Southeast Queensland soft clay. Unconfined compression tests showed that, 5% cement additives cured for 7 days increased the unconfined compressive strength when compared to untreated samples. Further, cement additives were also found to increase the pre-consolidation pressure in the oedometer tests. Thus, the initial studies conducted have demonstrated its potential use in shallow and deep stabilisation for Southeast Queensland soft clay.

INTRODUCTION

Soft compressible clays are found in many expressway and motorway projects in Southeast region of Queensland. Such sub-soil conditions can have considerable implications on the design of embankments and structural foundations. This is due to both low shear strength, and a tendency to consolidate and deform with time. Often the simplest solution to such unfavourable soil conditions is to find an alternate alignment, although this can be costly and impractical. As an economic alternative to structural foundations, ground improvement techniques are becoming more prevalent. Ground improvement in Australia primarily encompasses the use of granular stone columns, surcharge with vertical drains, and chemical stabilisation.

In the case of the sensitive soft clays found in Southeast Queensland, substantial remoulding takes place during the stone column or vertical drain installation, resulting in smearing of the drain surface, thus rendering them ineffective. When the coefficient of consolidation is low, and also when the organic content is high, preloading techniques may not be the most appropriate technique. Therefore, the use of cement or lime stabilisation, which entails mixing the chemicals with the soil has various advantages. These methods improve the engineering properties of soft soils by effectively aggregating smaller particles into larger cementitious clusters, subsequently increasing its stiffness and volumetric stability while accelerating consolidation.

Southeast Queensland clays have widely varying engineering properties, depending largely on the deposit's depth below the ground surface and the proximity to the water table (as shown in Figure 1). Based on the field shear vane, the undrained shear strength of soft/very soft clays is around 10-15 kPa. Natural moisture contents commonly vary between 60 and 120%. The liquidity

indices are generally in the range of 1.5 - 2.5, displaying high sensitivity. Compressibilities as high as $C_v/(1 + e_0) = 0.4 - 0.5$ have been observed in the laboratory. At these high compressibilities, strain rate effects can be significant. Macro fabric features have been variable, and in the worst cases $C_v = 0.1 - 0.3 \text{ m}^2/\text{yr}$, and $C_v/C_h = 1.0$ have been typical based on laboratory testing. Organic contents up to 10% have been observed, with high creep rates ($C_{ae} > 1\%$). Given the sensitivity of soft clays, the compressibility parameters are likely to be underestimated in the normally consolidated range. Piezocone dissipation tests are also masked by the remoulding of the clay caused by insertion of the cone (Wijeyakulasuriya *et al.*, 1999 [1]).

Cement, lime and fly-ash are the commonly used stabilisers for chemical stabilisation which were successfully executed by many researchers (Saitoh *et al.*, 1985 [1]; Bergado, *et al.*, 1996 [3]; Fahoum, *et al.*, 1996 [4]; Porbaha, 1998 [5]; Bergado, *et al.*, 1999 [6]; Holm, 1999 [7]; Hoyos, *et al.*, 2004 [8]). In addition, shallow stabilisation with chemical admixtures has long been used to improve the performance of base course and subgrade materials in the construction of road pavements. It is considered a cost-effective method of improving long term performance and reducing whole-of-life costs of heavily trafficked pavements (Austroads, 1998 [9]). The increased bearing capacity of cement-modified subgrade allows a reduction in the thickness of the base course required to ensure prolonged serviceability.

In this paper, the research focuses on the cement addition technique. General purpose cement, also known as ordinary Portland cement (OPC), is widely available throughout Australia, making it a feasible ground improvement medium in most cases. Cement can be applied to soft clays via one of two methods. Shallow mixing, where cement is added to the upper 200-300 mm of the subgrade using a stabilising machine over a relatively

wide area, is widely utilised as a rehabilitation technique to improve the strength of granular pavement materials found in road bases. Deep mixing is the process of mixing cement with clay using drilling equipment to form small radii deep cylinders, which act somewhat similarly to traditional concrete and steel piles.

This paper will explore the effects of cement additions to Southeast Queensland soft clays, with particular attention to strength gains and lessening compressibility. A laboratory testing program comprising Unconfined Compression and Oedometer tests has been undertaken to investigate the increase in strength and the reduction in the compressibility characteristics, resulting from differing magnitudes of cement addition.

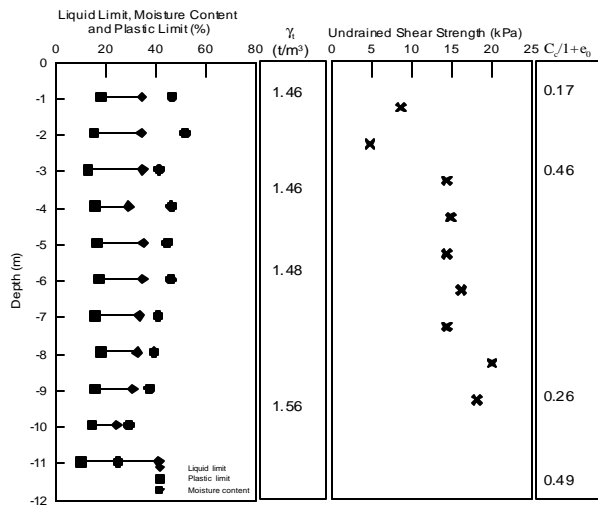


Figure 1(a) Geotechnical properties of clay in Gold Coast Highway (based on Wijeyakulasuriya *et al* (1999) [1]).

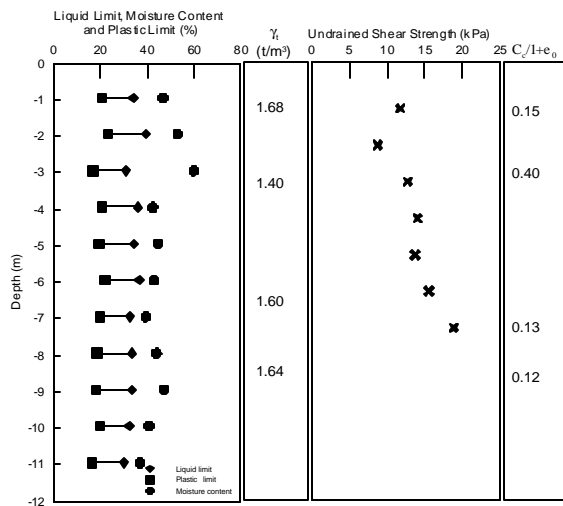


Figure 1(b) Geotechnical properties of clay in Sunshine motorway (based on Wijeyakulasuriya *et al* (1999) [1])

QUEENSLAND EXPERIENCES

Wijeyakulasuriya *et al* (1999) [1] presented the behaviour of three trial embankments founded on sensitive soft clays along the eastern coastal belt of Queensland. In Case Study A, the embankment at Mackay was built to

5m height by stage loading. The construction period was 6 months and the period of preload was 9 months. Case study B was at the Sunshine Motorway, to assess the feasibility of 2-staged construction within an overall construction period of 300 days. Case study C was at Coombabah Creek on the Gold Coast. The behaviour of these embankments is still being studied. In Case Study C, stone columns were used. In Case Study B, the section of the motorway traverses a swamp comprising very soft organic marine silty clay ranging in thickness from 4-10 m and underlain by sandy deposits. The height of the embankment was 2.8 m and was reinforced with high strength geo-synthetic at the embankment and foundation interface.

The embankment at the Sunshine Coast had a top width of 17 m on nominally 1V:2H batters. The berms were 1m high with a width of 5m on one side and 8m on the other side. The trial embankment comprised three 20 m sections, with the end sections installed with wick drains (Section A, 1m spacing and Section C, 2m spacing) and the middle section on undisturbed virgin ground as a control section (Section B). The settlements of the three sections shown in Figure 2 indicate that the wick drains have not accelerated settlements to any great extent. However the settlements in all sections were in excess of 1.5m. These measurements are now being further analysed.

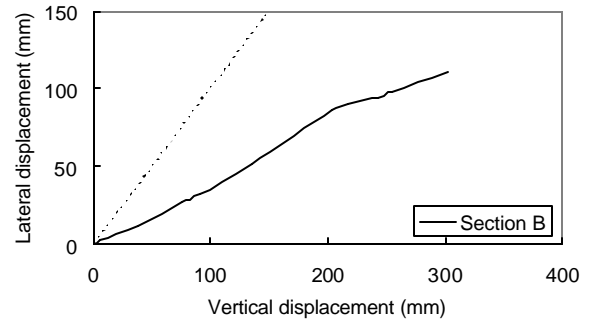


Figure 2(a) Variation in lateral displacement with settlement in Sunshine motorway trial embankment (based on Wijeyakulasuriya *et al* (1999) [1])

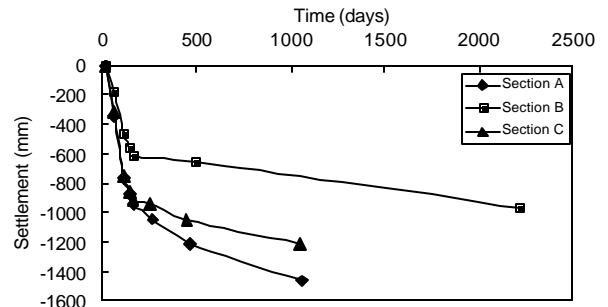


Figure 2(b) Time versus settlement curve for Sunshine motorway trial embankment (based on Wijeyakulasuriya *et al* (1999) [1])

The trial embankment at Coombabah traversed a swamp with soft clay up to 13 m. Here again the trial

embankment consisted of 3 sections. Section A had stone columns at 1m spacing and Section C had the stone column spacing as 3m. Section B was without any stone columns. The stone columns extended to 16 m. The height of the trial embankment was 2m with a top width of 12 m on 1V: 2 H batters. The stone columns were installed by the jetting process as used in vibro-flotation. The stone columns too were not found to be effective in reducing the settlements (as shown in Figure 3).

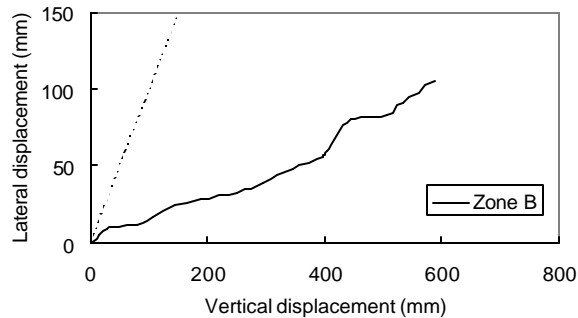


Figure 3(a) Variation in lateral displacement with settlement in Gold Coast Highway trial embankment (based on Wijeyakulasuriya *et al* (1999) [1])

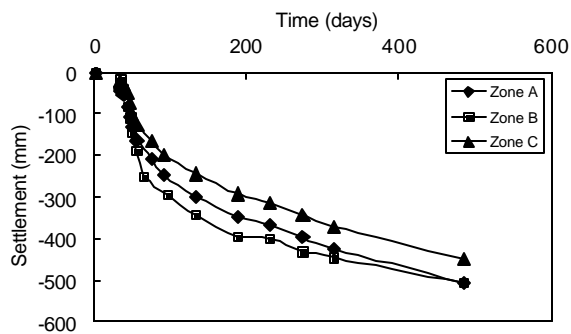


Figure 3(b) Time versus settlement curve for Gold Coast Highway trial embankment (based on Wijeyakulasuriya *et al* (1999) [1])

LABORATORY STUDIES

In this paper, the soil samples are taken from a site in Gold Coast Highway. This section of the highway traverses a swamp with up to 13.5 m of soft clay. The moisture content ranges approximately 110% at the surface and 60 % at a depth of 11m. The wet density (r_{wet}) of the clay was determined for several depths, and ranged from a low of 1.46 t/m^3 to a high of 1.56 t/m^3 . The dry density (r_{dry}) of the clay ranged from a low of 0.54 t/m^3 to a high of 0.96 t/m^3 . The density fo solid (r_s) of the clay ranged from a low of 2.61 t/m^3 to a high of 2.69 t/m^3 . The liquid limit is generally uniform with depth, at a value of 60% to 70%. The plastic limit is generally consistent with depth and ranged from 25% to 49 %. The classification of the soils is based on the Unified Soil Classification System. Using these grading (fine-grained soil, with 50% or more is $< 0.075 \text{ mm}$) and the

Atterberg limit given (liquid limit of 70%, and plasticity index of 35%), the soil can be classified as “inorganic clay of high plasticity (CH)”.

The physical properties of Southeast Queensland soft estuarine clay samples, both treated with cement and untreated, have been ascertained (as tabulated in Table 1). As expected, cement treatment increased total and dry densities, raised plastic and liquid limits, and reduced the water content and void ratio when compared to untreated clay. The addition of cement to this clay produced an immediate reduction in void ratio, as demonstrated below in Table 1. This is likely due to the interaction between cement particles and pore water to produce solidification, reducing water content and filling in the voids with the resulting hydrated cementitious material.

Table 1 Physical properties of cement treated clay

Cement Content (%)	Total Unit Weight (t/m^3)	Dry Unit Weight (t/m^3)	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Void Ratio, e
0	1.255	0.711	90.72	59.8	23.0	2.727
5	1.351	0.765	86.93	109.1	31.8	2.464
10	1.459	0.828	77.92	121.5	44.3	2.188
15	1.483	0.845	75.26	125.0	69.2	2.112

Untreated specimens of Southeast Queensland soft clay were tested in unconfined compression. It is evident from the results that the natural clay was very soft, attaining a peak unconfined compressive strength of about 27 kPa. Further, cement treated specimens of Southeast Queensland soft clays were tested. Samples of 5, 10, and 15% cement addition ratios were tested at 7, 14 and 28 days after mixing. The results of these unconfined compression tests have been presented to explore the two parameters under investigation. Plots of normal stress and axial strain for sample sets of differing cement content at curing times of 7, 14 and 28 days are presented overleaf in Figure 4.

For samples tested at 7, 14 and 28 day curing times, a sharp rise in stress was observed, attaining a maximum value at approximately 1.25% strain. The rate of stress rise for initial stages of each curing time plot seemed to grow with increasing cement content. It can then be concluded that the stress-strain behaviour of different cement addition ratios is consistently improved, independent of curing time. Maximum stress was attained at a much lower strain for cement treated samples than for untreated samples. The effect of additional cement is noticeable at these peak values, with higher admixture ratios yielding higher strength. This effect can be quantified by comparing the peak axial stresses, as demonstrated in Figure 5.

The addition of cement produces dramatic improvement in strength of Southeast Queensland soft clay. The effect of curing time is observed to be much less significant than the cement content parameter in terms of the rate of unconfined compressive strength gain.

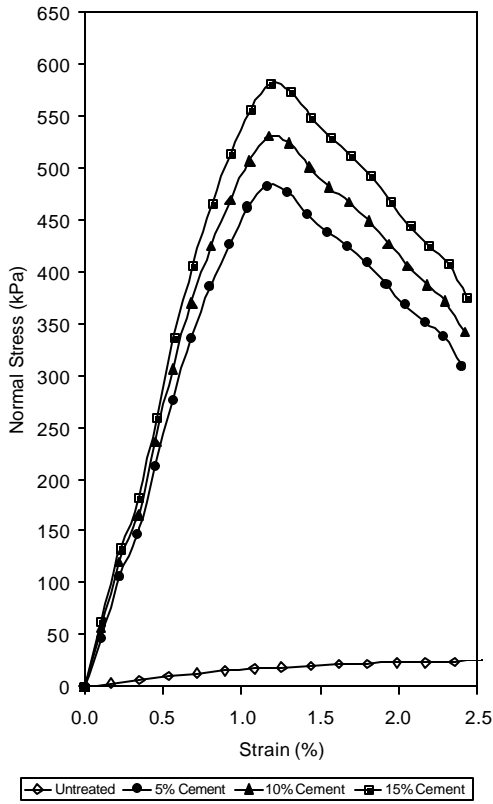


Figure 4(a) Comparison of stress-strain behaviour of treated and untreated clay (7 days curing period)

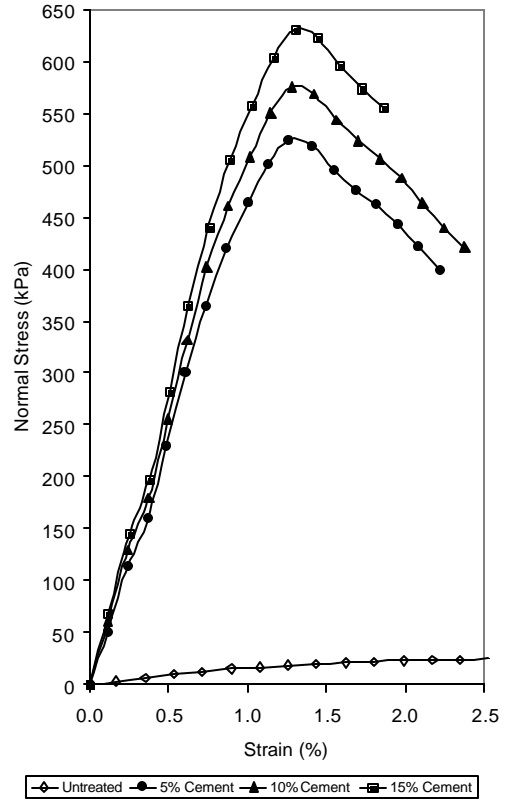


Figure 4(c) Comparison of stress-strain behaviour of treated and untreated clay (28 days curing period)

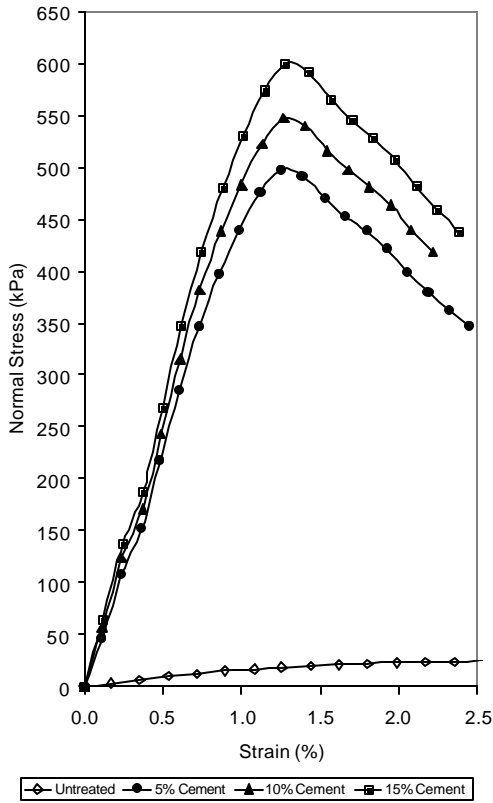


Figure 4(b) Comparison of stress-strain behaviour of treated and untreated clay (14 days curing period)

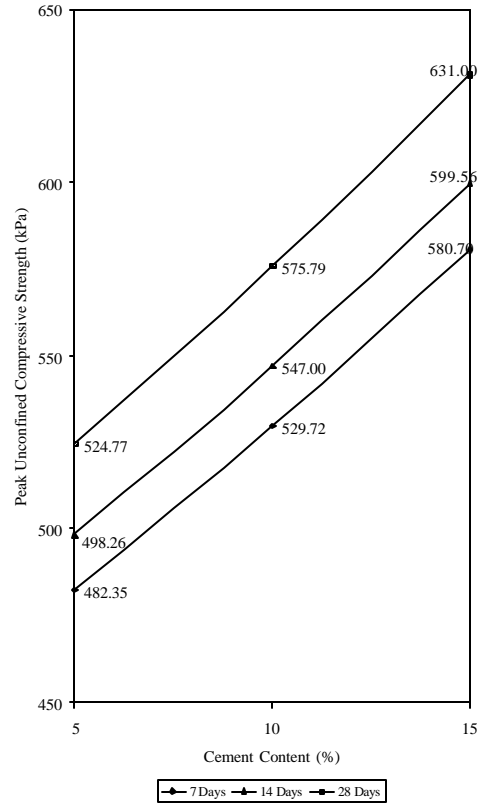


Figure 5 Relationship of Peak Unconfined Compressive Strength with different cement content.

Compressibility characteristics of untreated specimens of Southeast Queensland soft clay were tested using the oedometer consolidation test. The results of these tests are graphically presented in Figure 6. It is apparent from the results that, the natural clay was very compressible, attaining a peak compression index (C_c) of 1.79. Plots of void ratio and vertical stress for sample sets of differing cement content at curing times of 7, 14 and 28 days are presented in Figure 6. A dramatic difference in compressive behaviour is evident between the 5% cement sample and the higher ratios at all curing times explored. The slope of the $(e, \log s_v)$ plot for 5% cement is much greater than the same plot for 10 and 15% cement additions. This suggests that this sample was much more compressible than the higher cement content samples. The difference in slope became less extreme at higher curing durations, although still significant.

For the 10 and 15% cement samples, behaviour was very similar. A very low $(e, \log s_v)$ slope is observed for stresses up to 800kPa, indicating considerable compressibility improvement compared to untreated samples. It was observed that the samples treated with 10 and 15% cement displayed largely incompressible behaviour up to an applied load of 750 kPa. It was shown that curing time had very little influence on the rate at which it compressed. The addition of 5% cement did not improve the preconsolidation pressure of this clay.

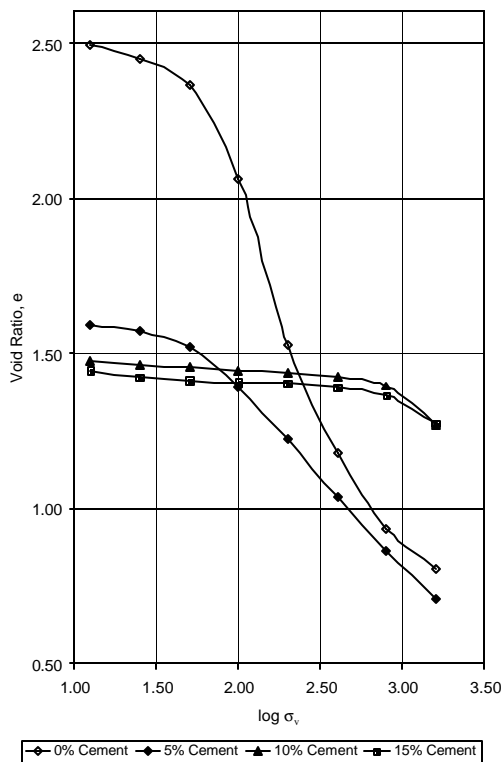


Figure 6(a) Void ratio (e) and $\log s_v$ relations of treated and untreated clay in oedometer test (7 days curing time)

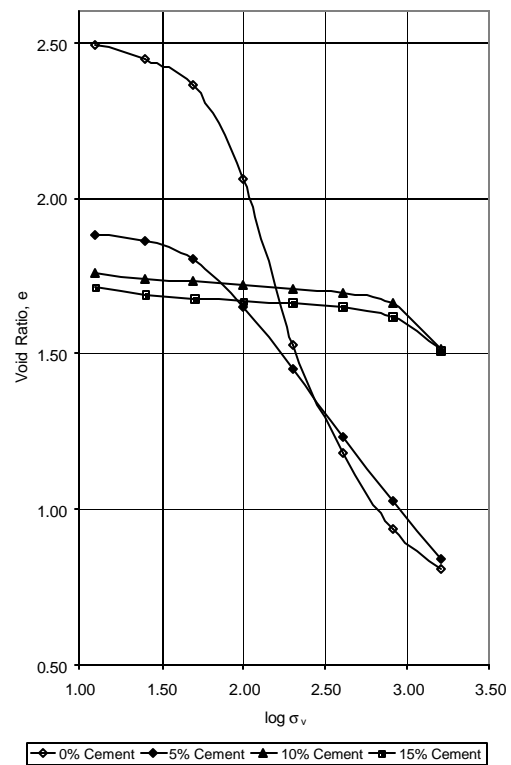


Figure 6(b) Void ratio (e) and $\log s_v$ relations of treated and untreated clay in oedometer test (14 days curing time)

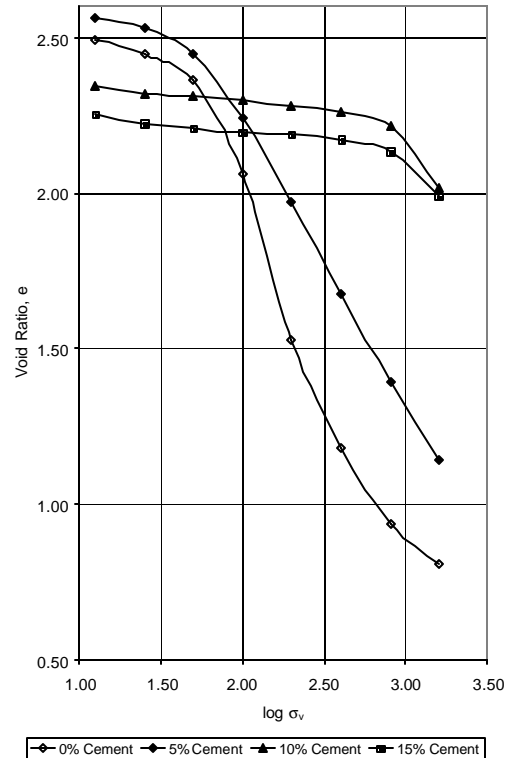


Figure 6(c) Void ratio (e) and $\log s_v$ relations of treated and untreated clay in oedometer test (28 days curing time)

CONCLUSIONS

Ground improvement techniques developed for roads, expressways and other infra-structure developments are now widely used in particular for embankments on soft clays. This paper summarizes some ground improvement techniques used in Southeast Queensland, and demonstrated the applicability of cement stabilisation.

Unconfined compression tests showed that 5% cement additions cured for 7 days produced dramatic increases in unconfined compressive strength when compared to untreated samples, from 27 to 482 kPa. Further cement addition and longer curing duration gave gradual strength benefits, with 15% cement samples cured for 28 days yielding an unconfined compressive strength of 631 kPa. Cement addition was found to increase the preconsolidation pressure and reduce the compression index of the local clay at ratios of 10 and 15%, while it was observed that 5% cement addition was ineffective in these terms. Preconsolidation pressures of 700 - 800 kPa were common for samples of 10 and 15% cement cured for 7 - 28 days. The average compression index of untreated clay over the 50 - 800 kPa stress range was shown to improve dramatically with 10% cement, from over 1.18 to less than 0.10.

Overall it was concluded that the addition of cement has favourable effects on the strength and compressibility characteristics of Southeast Queensland soft clays.

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